Modelling Small-Scale Sanitation in the Nile Delta:

A Material Flow Analysis with Nutrient Reuse Perspective

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Executive summary

This report is a result of the *Egyptian-Swiss Research on Innovations in Sustainable Sanitation* (ESRISS - www.sandec.ch/esriss), a parallel research component of the World-Bank funded *Integrated Sanitation and Sewerage Infrastructure Project* (ISSIP); this component is administered by the *Swiss Federal Institute of Aquatic Science and Technology* (Eawag) in partnership with the *Egyptian Holding Company for Water and Wastewater* (HCWW) and financed by the *Swiss State Secretariat for Economic Affair*s (Seco).

This report is primarily addressed to all stakeholders of the sanitation sector, decision-makers, governmental agencies, consultants and academics, who deal with rural sanitation and small-scale sanitation in general. It completes the two first reports of the ESRISS Project, "*Small-Scale Sanitation in Egypt: Challenges and Ways Forward*" (2012) and "*Small-Scale Sanitation in the Nile Delta: Baseline Data and Current Practices*" (2013), as well as the 10 Points Research for Policy Brief (2013). It is the theoretical basis for the practical "*Model-Based Tool to Quantify and Characterise Wastewater in Small Settlements in the Nile Delta" (2014)*. All documents can be downloaded on ESRISS webpage (www.sandec.ch/esriss).

Objectives

Lack of baseline data and design parameters characterising rural wastewater in the Nile Delta is seen as a major gap in the development of sound sanitation strategies for settlements under 5,000 inhabitants. Such data is usually made up of the characteristics and quantities of the wastewater to treat, be it in the form of sewage or septage. However, Nile delta ezbas and villages are very heterogeneous, which prevents the definition of generic values applicable to all settlements; instead, developing a baseline data in this context means understanding current sanitation practices, the factors influencing the quantities and characteristics, and the extent of this influence. For this reason, the ESRISS project decided to undertake a thorough analysis of the sanitation-related flows (blackwater, greywater, animal manure) within Nile Delta settlements, with the following objectives:

1. Identify, quantify and characterise the sanitation-related flows
2. Understand the main factors influencing wastewater quantities and characteristics
3. Develop a model which will help designers and consultants to quickly estimate the quantity and characteristics of the raw wastewater to be treated, on a site-specific basis
4. Compare sanitation system scenarios
5. Estimate the nutrient flows (nitrogen and phosphorus) in the perspective of an optimal wastewater reuse.

Points 1 and 2 are developed in the ESRISS Report "*Small-Scale Sanitation in the Nile Delta: Baseline Data and Current Practices*". This report focuses on the development of the model (Point 3), with a focus on the wastewater quantities and the nutrient flows. In the end, different scenarios for nutrient reuse are compared (Points 4 and 5).

Methodology

The analysis of the sanitation-related flows in Nile Delta settlements presented in this report is based on a method called *Material flow analysis* (MFA). Through a systematic analysis of the different flows (e.g. blackwater, greywater, liquid manure) with the mass balance principle, MFA results in a model which describes what happens within defined boundaries, taking into account what comes in, what goes out and what happens in between. The mass balance allows to cross-check the available data and to provide an informed estimate of the value of the missing data. Finally, the model provides a visual representation of the flows within a village; it allows to estimate the quantities and characteristics of the wastewater to be treated and a comparison between different sanitation scenarios, which makes it a useful tool for decision making. The methodology is described in detail in Montangero (2007).

The following activities were carried out to achieve the objectives of the study:

- Literature review (national and international data on rural wastewater characteristics and sanitation-related flows)
- Selection of villages suitable for conducting the baseline study
- Description of the villages and sanitation situation through field observations, transect walks, household surveys and semi-structured interviews with the sanitation key stakeholders.
- Sampling campaigns
- Material flow analysis
- Comparison of scenarios

Eight villages were selected in Beheira Governorate to provide the data necessary to establish and calibrate the model. Specific methodologies were developed to assess each flow in the MFA model. The quantification of flows was carried out primarily based on the surveys and field observation, whereas the characterisation was carried out through detailed sampling campaigns.

Once the model was complete, it was possible to define which parameters are constant among villages and which vary on a site-specific basis. This means that inflow quantities and characteristics to a future treatment plant in any village can be determined by measuring only a limited amount of site-specific parameters. These features were used for the development of simplified model to be used by practitioners (cf. the "*Model-Based Tool to Quantify and Characterise Wastewater in Small Settlements in the Nile Delta*").

Through the systematic material flow analysis, the different nutrient flows are quantified. Nutrients can be tracked, allowing the development of appropriate end-use strategies.

Results

The MFA model can be used for different purposes:

1. To estimate the concentrations and volumes of the different sanitation flows, including the sewage to be treated, in present and future situations.
2. To compare sanitation system scenarios
3. To develop scenarios to optimise nutrient recovery

- **A systematic assessment of sanitation-related flows**

  This study provides a very systematic assessment of the sanitation-related flows and parameters in Nile Delta villages under 5,000 inhabitants. The *system boundary* is the settlement itself and does not include wastewater treatment nor agriculture, but the quantities and characteristics of the flows leading to them. For each flow and parameter, clearly referenced values are provided (primary data, literature or estimations). The model was calibrated based on first-hand data from eight villages. It now needs to be applied and validated for further villages. The model is in the form of an Excel sheet (available on www.sandec.ch/esriss). It can be adapted to reflect the reality of villages in other regions (e.g. Upper Egypt) or countries.

  The amount of phosphorus and nitrogen present in the wastewater produced in a village can be estimated through the model, with a clear distribution between sewage, septage, blackwater, greywater and animal manure. It provides quantitative evidence of the amount of nutrients which potentially could be reused in agriculture and the potential benefits of separating certain streams at the source. The quantity of nutrients that can be recovered in a village depends mainly on the number of inhabitants, the liquid manure quantity, its management, and the amount of greywater discharged into the sanitation system. Number of inhabitants is the most significant parameter because most of the nutrients come from human excreta. Although the liquid animal manure has a really high concentration of nitrogen, it is however to be found in much lower volumes than domestic wastewater. Depending on the number of cattle and the proportion of liquid manure discharged into the sanitation system it can have a big impact on the nutrient concentration in wastewater. Its influence on the phosphorus load is much lower. As for the greywater, it has a comparatively small nutrient concentrations, but because of its high volume it can have a non-negligible impact when discharged into the sanitation system. The flows at village-level are represented in the form of Sankey diagrams, which allow to visualise them with arrows which have a width proportional to their importance.

- **Assessment of sanitation system scenarios**

  Two main scenarios can be distinguished in the Nile Delta: (i) villages relying on onsite systems (bayaras) ; (ii) villages with one or several sewer network(s).

  Several questions regarding sanitation planning could be answered through the model:

  a. What are the flow volume and nutrient loads in sewage, respectively septage?

  b. What influence does liquid manure have on loads and concentrations of nutrients and organic matter in sewage?

  c. Which flow volume and nutrient loads can be isolated through the centralised management of liquid animal manure? What impact does it have on the nutrients loads in sewage, respectively septage?

  d. What are, in terms of reuse potentials and volumes to be treated, the benefits of storing blackwater and animal manure in onsite sanitation systems (bayara or biogas digesters) and separating greywater, either through soak pits or simplified sewer systems?

  In order to answer these questions, five sanitation system scenarios were developed and compared. First, the two common scenarios of villages with sewers and villages with bayaras are investigated. Then, the potential benefits of the centralised management of liquid animal manure in sewered and unsewered villages, as well as the potential benefits of the diversion of greywater through simplified sewer networks, are discussed. It highlights the pros and cons in terms of volumes to transport, volumes to treat and volumes for reuse. The study compares theoretical villages counting 1,000 inhabitants and with typical characteristics as per the baseline data collected within the ESRISS Project (cf. *Baseline Data Report*).

  The comparison between the two first scenarios reflects what happens when a sewer network is built in a village equipped with bayaras. It shows significant differences. 67% more wastewater is expected in the sewered than in the unsewered scenario due to the following reasons: whereas with bayaras most greywater is discharged directly into the environment, people prefer the convenience of also discharging greywater into the sewer network, when it exists, and do not limit their water consumption anymore. The same thing happens with liquid animal manure, thereby increasing the load of nutrients in the sanitation system.

  The implementation of a centralised liquid manure management can be justified by two reasons: (a) attempt to decrease the loads in the wastewater to be treated, thus reducing the size and the costs of the treatment units; (b) direct reuse of liquid animal manure, either by bringing it directly to the fields or by storing it in a centralised liquid manure storage unit. The liquid manure has a very high concentration of nitrogen and high COD loads. Depending on the number of cattle, the implementation of a liquid management unit leads to a reduction of 5% to 40% of the nitrogen and COD concentration and loads in sewage. In average, it permits a reduction of about 20% of both constituents. However, such a unit has no significant impact on the volume of sewage to be treated and the phosphorus load in sewage. In terms of nutrient recovery, the construction of a manure management unit allows to recover from 0.4 to 6 tons of nitrogen per year with an average of 2.2 tons, in a flow that is highly concentrated (2988 TN mg/L).

Greywater is the total volume of water generated from washing food, clothes and dishware, as well as from bathing, but not from toilets. Greywater is hardly contaminated with pathogens and has low organic concentrations. Separating greywater from the blackwater (i.e. the mixture of urine, faeces and flushwater along with anal cleansing water and/or dry cleansing materials) thus offers a number of advantages:

(i) Greywater can be discharged without risk into the drains; as it represents more than 60% of the total amount of wastewater generated (up to 80%), it is a huge amount that does not need to be treated, thus drastically reducing the size and the cost of treatment infrastructure;

(ii) Because it is hardly contaminated and has low organic concentrations, it can be conveyed through cost-effective shallow or even small-bore sewer systems; in some cases, the otherwise often dysfunctional “informal” sewer systems built by the villagers could be used for that; alternatively, in case of deep groundwater table and permeable soil, greywater can be infiltrated into the ground through soak pits;

(iii) In villages relying on bayaras, diverting the greywater will dramatically reduce the filling rate of the bayaras and thus the amount of money spent for emptying, which is a major incentive; the study shows that this measure permits to reduce of approximately 57% the flow volume ending up in the on-site sanitation systems;

(iv) Diversion of the greywater means that only blackwater and liquid animal manure still end up in the bayara, thus forming a very concentrated septage/faecal sludge. This high concentration makes treatment (with anaerobic systems) more cost-effective. In case there are enough animals and space, a biogas digester can be built instead of the bayara and biogas can be produced for domestic use, as happens already in Fayoum. The digester slurry can be used as a very high value fertiliser.

The diversion of greywater leads to the collection in the onsite systems of the highest nitrogen loads of all scenarios, in a form that is 5 times more concentrated than in septage and sewage (TN 844 mg/L and TP 55 mg/L).

- **Tools for the assessment of the initial situation**

Tools for the assessment of the initial situation in villages were developed, including semi-structured interview guidelines, household survey guideline and a protocol for sample analyses with a portable lab. Together, they form a tool package for the preliminary assessment of small settlements, in order to get the site-specific data necessary to feed the model.

Recommendations

It is clear that in a nutrient-reuse perspective, source separation should be the favoured option. The study shows that separating the blackwater and liquid manure from the greywater leads to a very nutrient-rich (both in nitrogen and phosphorus) and concentrated product in the onsite systems. These can be either treated offsite or digested onsite in a biogas reactor. In some cases, only a few adjustments to the existing situation are needed.

The most effective recommendations to recover nutrients for agricultural use are the following:

(1) **Creation of a liquid manure storage unit**: because liquid animal manure has a high nitrogen concentration and is currently almost always collected separately, it makes it an ideal source for nutrient recovery. The implementation of a manure storage unit could allow to recover up to 50% of the nitrogen in a village.

(2) **Separate blackwater and greywater**: Most nutrients are present in the blackwater. Disposal of the blackwater in the bayara and discharge of the greywater to drains through simplified or small-bore sewer networks would allow to substantially reduce the volumes to be emptied from the bayara and to get a much more concentrated septage, which is easier to treat and reuse. In some cases, the blackwater could be diverted into a biogas digester and mixed with animal manure to produce biogas and a very nutrient-rich slurry that is safe for reuse in agriculture (cf. Fayoum case study in ESRISS *Factsheet Report*).

(3) **Anaerobic treatment systems:** If source separation is not possible, nutrient management is shifted to the offsite treatment stage. It is very difficult and expensive to recover nutrients from wastewater. However, what can be done, is to remove the undesirable components of wastewater while conserving the nutrients in the perspective of a direct reuse of the effluent for irrigation. For this purpose, it is recommended to use anaerobic treatment systems such as anaerobic baffled reactors and anaerobic filters. Effluent from anaerobic treatment have a comparatively high nutrient content, as compared with aerobic systems.

(4) **Use of the sludge stored in the bayara**: a lot of nutrients accumulate in the sludge settled in the bayaras and are not removed during emptying. Proper emptying followed by septage/faecal sludge treatment would allow the production of safe dried sludge, which, besides being rich in nutrients, is also rich in organic matter, useful for soil structure.

(5) **Reuse of sludge from wastewater treatment plants (WWTP)**: building treatment units, either for sewage or for septage, is an important step towards safe reuse. The sludge, once properly dehydrated and stored, can be spread on the fields, and the treated effluent can be used for irrigation.

Nutrient reuse does not stop with the flows leaving the village boundary. It is actually where it really starts. The nutrients still have a way to go before reaching the fields and, in-between, many losses are to be expected. Optimising nutrient reuse also means selecting appropriate treatment options and field application methods, which conserve the nutrients and make them bioavailable to the plants. This part, however, is out of the scope of this report and is well described in the literature.

The study showed that nutrient reuse is something very important for Egyptian farmers (see *Baseline Data and Current Practices* Report), at a time when the price of chemical fertilisers is rising. However, so far, the farmers only use the solid part of animal manure and, sometimes, dry sludge from existing WWTPs. There is a big margin for improvement, which a well-designed nutrient management at village-level can highly support.

Each scenario necessitates an integrated planning approach, to ensure that all stakeholders agree and that the system is sustainable on the long run. Each of them implies a certain number of preconditions in order to be successfully implemented. Table 1 synthesises the measures to be taken and the potential impacts of each scenario.

The centralised management of liquid animal manure implies the implementation of a proper management scheme, where the liquid manure is collected by a private stakeholder in a mobile tank, brought to a central storage unit, to be later redistributed to the interested farmers and transported to the fields, by the farmers themselves or by the private stakeholder; villagers themselves cannot be expected to transport liquid manure on more than a few dozen meters. Financial arrangements must be developed so that this activity is attractive for the private stakeholder. It is unlikely that households will pay a fee for liquid animal manure collection. However, the stored urine could be sold. In order to be financially feasible, this activity probably needs to be coupled with other environmental services, such as solid waste management or sewer maintenance.

The separation of blackwater and greywater will not be feasible everywhere. It requests pre-existing onsite systems and buildings where blackwater and greywater can easily be separated. It may be difficult in existing buildings where both streams are mixed already inside the house. The feasibility and cost of retrofitting such a system must be checked. The optimal situation for this scenario is a village of low density, with space available next to the buildings and a higher number of cows per households (at least 3 cows per building if biogas is to be produced). The digested and stabilised slurry can be used directly on the field without further treatment, in the same way as solid animal manure. This is not the case for septage, which needs a dedicated treatment plant.

The implementation of anaerobic treatment systems with direct effluent reuse for irrigation may imply amendments at the legal framework. The exact feasibility scope of such a scenario must be checked in the Egyptian context. The Law 48/1982, which requests implicitly the addition of an aerobic polishing step, must be amended if necessary, as well as the Code of Practice for Reuse. Besides, an obstacle for the direct enduse of the treated effluent in the Nile delta is the lack of space for effluent storage and dedicated agricultural land. A WWTP produces effluent 24/7, whereas farmers need irrigation water at specific times. Thus, storage is necessary, which implies extra costs and space. In some cases, nutrients can be reused indirectly for fish farming in ponds: the nutrients are consumed by algae which are then consumed by the fish. This is already practiced in some parts of the Nile Delta and does not request extra space if fish ponds are already present.

Finally, if proper treatment of sludge at WWTP level seems a pretty easy measure to achieve, proper collection, transport and treatment of sludge/septage from the bayaras present much more of a challenge. It implies an institutional reform, where clear roles and responsibilities would be defined for septage management, with corresponding financial arrangements between private and public stakeholders and the design of proper septage/faecal sludge treatment plants. For both sewage sludge and faecal sludge, it is important not to mix it with industrial wastewater, in order not to contaminate it with heavy metals and other trace contaminants. This advocates for the decentralised treatment of sludge, where the wastewater remains exclusively domestic and where the treated effluent and sludge can be reused directly in the surrounding agricultural land.

In all cases, the implementation of such scenarios necessitate a strong political will, institutional support and awareness to sustain the efforts and change of mindset that are requested.

Table 1: Synthesis of the measures to be taken and the potential impacts of the reuse-oriented scenarios

SCENARIOS	MEASURES	POTENTIAL IMPACTS
1. Creation of a liquid manure storage unit	• Involvement of the community for the development of a centralised liquid manure management scheme • Build on the current practice of liquid manure separation	• Recovery of an average of 2.2 tons of nitrogen per 1,000 inhabitants per year, ready to be reused in agriculture.
2. Separate blackwater and greywater	• Check feasibility at house level • Adapt the piping system and cesspit • Check feasibility for biogas production and enduse interest	• Substantial reduction of the volumes to be emptied from the bayaras and, thus, of the volumes to be treated. • A much more concentrated septage, which is easier to treat and reuse • Biogas production is possible
3. Anaerobic treatment systems	• Select anaerobic systems • Check effluent reuse options	• Most nutrients are conserved in the effluent, which can be used for irrigation or fish farming.
4. Use of the sludge stored in the bayara	• Improve septage management and build septage treatment plants	• A high amount of treated sludge is available for agriculture
5. Reuse of sludge from WWTPs	• Improve sludge treatment in the WWTPs • Systematise the sale of sludge	• Increase of good quality dry sludge available for agriculture

Acronyms

BOD	Biological Oxygen Demand
BWADC	Beheira Water and Drainage Company
CDA	Community Development Association
COD	Chemical Oxygen Demand
EAWAG	Swiss Federal Institute of Aquatic Science & Technology
EGP = LE	Egyptian Pound = “Livre Egyptienne” (1 EGP = 0.13 CHF - *rate on 29.08.2013*)
ESRISS	Egyptian-Swiss Research on Innovations in Sustainable Sanitation
FAO	Food and Agricultural Organization of the United Nations
HCWW	Holding Company for Water and Wastewater
ISSIP	Integrated Sanitation & Sewerage Infrastructure Project
LE = EGP	Egyptian Pound
MFA	Material Flow Analysis
MOHP	Ministry of Health and Population
MWRI	Ministry of Water Resources & Irrigation
MWSU	Ministry of Water and Sanitation Utilities
NOPWASD	National Organisation for Potable Water and Sanitary Drainage
NRC	National Research Centre (Markaz El Behoos, in Dokki)
PE	Population-Equivalent
PIU	Project Implementation Unit (ISSIP)
PMC	Project Monitoring Component
PM/TA	Project Monitoring / Technical Assistance
PPP	Public-Private Partnership
QMRA	Quantitative Microbial Risk Assessment
SANDEC	Department for Sanitation in Developing Countries (Eawag)
SD	Standard Deviation
SECO	Swiss State Secretariat for Economic Affairs
TN	Total nitrogen
TP	Total phosphorus
TSS	Total suspended solids
WB	World Bank
WUA	Water User’s Association
WWTP	Wastewater Treatment Plant

Glossary

Bayara :	Local name used for the on-site sanitation facilities, as well as “*tranches*”. It can be translated as “vault” or “cesspit”.
Septage :	The liquid waste emptied from on-site systems (*bayaras/trenches*); also called “faecal sludge”
Ezba :	Name used for small villages, usually < 1,500 inhabitants, in the Nile Delta
Omda :	Community leader, assigned by the government, responsible for a small group of villages, within an “*Omodeya*” (see also (Reymond et al., 2013))
Sheikh el Balad :	Informal community leader at village-level
Informal sewer network :	Sewer network usually constructed by the inhabitants themselves. The lack of proper design very often leads to problems like clogging and flooding
Canal :	Water body, directly derived from the Nile, serving as a source of water for irrigation
Drain :	Usually referring to agricultural drains; drains in the Nile Delta are used as disposal point for any kind of waste.

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It is the third published of a series of reports. It completes the two previous ESRISS Project reports: "Small-Scale Sanitation in Egypt: Challenges and Ways Forward", which was synthesised in a Research for Policy Brief, entitled "Small-Scale Sanitation in Egypt: 10 Points to Move Forward", and "Small-Scale Sanitation in Egypt: Baseline Data and Current Practices". All documents can be downloaded on ESRISS webpage.

1 Introduction: target of the model

Lack of baseline data and design parameters characterising rural wastewater in the Nile delta is seen as a major gap in the development of sound sanitation strategies for settlements under 5,000 inhabitants (Reymond et al., 2012). Such data is usually made up of the characteristics and quantities of the wastewater to be treated, be it in the form of sewage or septage. However, Nile delta ezbas and villages are very heterogeneous, which prevents the definition of values applicable to all settlements; instead, developing a baseline data in this context means understanding current sanitation practices, the factors influencing the quantities and characteristics, and the extent of this influence. The available information has been compiled in the ESRISS Project Report *"Small-Scale Sanitation in Egypt: Baseline Data and Current Practices"* (Reymond et al., 2013).

Small-scale sanitation in Egypt faces numerous challenges (Reymond et al., 2012). One of them is the heterogeneity of the settlements, as the villages can present very diverse characteristics regarding their size, density, level of income, groundwater table, the number of animals, the presence of industrial activity and, of course, the existing sanitation situation. There is a need for a case-by-case approach (El-Gohary, 2012).

The analysis of the sanitation-related flows presented in this report is based on a method called *Material flow analysis* (MFA). MFA was chosen as a suitable tool to compute and cross-check the quantities of different flows, visualize them, compare different scenarios and simulate the impact of sanitation systems in nutrient loads and nutrient saving/recovery (Montangero and Belevi, 2008). Through a systematic analysis of the different flows with the mass balance principle, MFA results in a model which describes what happens within defined boundaries, taking into account what comes in, what comes out and what happens in between. The mass balance allows to cross-check the available data and to estimate the missing data. Finally, the model provides a visual representation of the flows within the *system boundary*, here the village, and allows comparison between different sanitation scenarios, which makes it a useful tool for decision making. The methodology is described in detail in (Montangero, 2007).

The ESRISS Project decided to undertake a thorough analysis of the sanitation-related flows (blackwater, greywater, animal manure) within Nile delta settlements, with the following objectives:

1. Identify, quantify and characterise the sanitation-related flows
2. Understand the factors influencing wastewater quantities and characteristics
3. Develop a model which will help designers and consultants to estimate quickly the quantity and characteristics of the raw wastewater to be treated, on a site-specific basis
4. Compare sanitation system scenarios
5. Estimate the nutrient flows (nitrogen and phosphorus) in the perspective of an optimal wastewater reuse.

Points 1 and 2 are developed in the ESRISS Report "*Small-Scale Sanitation in the Nile Delta: Baseline Data and Current Practices*". This report focuses on the development of the model (Point 3), with a focus on the wastewater quantities and the nutrient flows. In the end, different scenarios for nutrient reuse are compared (Points 4 and 5).

Eight villages were selected in Beheira Governorate to provide the data necessary to establish the model. The field work was carried out in partnership with HCWW and the respective Affiliated Companies, with support from the ISSIP PMC. Specific methodologies were developed to assess each flow in the MFA model. Quantification of flows was carried out primarily through the surveys and field observation, whereas the characterisation was mainly done through sampling campaigns.

Such a study makes it possible to define which parameters are constant among villages and which vary on a site-specific basis. This means that in the future, thanks to the model, inflow quantities and characteristics to a future treatment plant in any village can be determined by measuring only a limited amount of site-specific parameters. As for the nutrient flows, they are quantified through the systematic material flow analysis; nutrients can be tracked and the most appropriate strategies for enduse in agriculture, if desired, can be elaborated.

These features have been used for the development of a simplified model to be used by practitioners (see the *Model-Based Tool to Quantify and Characterise Wastewater in Small Nile Delta Settlements* – an Excel-based tool with user manual and data collection tools). The ultimate ambition is to provide a replicable methodology for quick and accurate assessment of small communities in Nile Delta, leading to a site-specific estimation of wastewater quantities and characteristics to be treated. The potential for time and money savings is very significant, as it allows practitioners to define realistic design parameters in less than three days and to design the infrastructure as close to the needs, avoiding the wide-spread under- or over-dimensioning practices.

This report is primarily addressed to all stakeholders of the sanitation sector, decision-makers, governmental agencies, consultants and academics, who deal with rural sanitation and small-scale sanitation in general. It completes the first reports of the ESRISS Project, "*Small-Scale Sanitation in Egypt: Challenges and Ways Forward*", the "*10 Points Research for Policy Brief*", and "*Small-Scale Sanitation in Egypt: Baseline Data and Current Practices*". All documents can be downloaded on ESRISS webpage (www.sandec.ch/esriss).

2 Methodology

The following activities were carried out to achieve the objectives of the study:

- Literature review (national and international data on rural wastewater characteristics and sanitation-related flows)
- Selection of villages suitable for conducting the baseline study
- Description of the villages and sanitation situation through field observations, transect walks, household surveys and semi-structured interviews with the sanitation key stakeholders.
- Sampling campaigns
- Elaboration of the model, material flow analysis
- Comparison of scenarios

The methodology for the village selection, semi-structured interviews, field observation and sampling campaigns is described in detail in the ESRISS Report "*Small-Scale Sanitation in Egypt: Baseline Data and Current Practices*" (Reymond et al., 2013). In what follows, we focus on the MFA methodology, model construction and household survey.

The results of the literature review per se and village descriptions are also to be found in the Baseline Data Report. We do not repeat it here.

2.1 Material flow analysis – model development

The Material Flow Analysis (MFA) method consists of three basic steps (Montangero, 2007):

1. System analysis
2. Quantification of flows
3. Graphical representation and interpretation of the results.

The basic methodology, as described for example in (Brunner and Rechberger, 2004) has been adapted and successfully applied in developing countries, despite data scarcity and high uncertainties (Montangero and Belevi, 2008), (Do-Thu Nga et al., 2011), (Huang et al., 2007), (Yiougo et al., 2011).

The mathematical description of material flows in a system allows to simulate the impact of changes in the system. It can be used to evaluate the impact of potential environmental sanitation systems on resource consumption and environmental pollution. In our case, it can be used to anticipate the quantities and characteristics of wastewater in different scenarios, or find the best solution in a perspective of nutrient reuse.

The material flow analysis methodology is explained in detail in Montangero (2007): *Material Flow Analysis: A Tool to Assess Material Flows for Environmental Sanitation Planning in Developing Countries*. It is a report on its own and we can only summarise the basic principles here. For those interested to use Material Flow Analysis, please refer to Montangero (2007)[1].

2.1.1 System analysis

First of all, the boundary of the system must be defined. In our case, it is a Nile delta settlement under 5,000 inhabitants; the agricultural field around, the drains or a potential treatment plant are located outside the system boundary defined here. The system analysis includes the selection of processes, goods, substances and system boundaries, as well as the identification of system variables:

- **Processes** describe the transformation, transport or storage of goods and substances (e.g. “bayara”, “sewer”).
- **Goods** are materials or material mixtures such as wastewater or liquid animal manure.
- **Indicator substances** are chemical elements and their compounds such as nitrogen and phosphorus.
- **System variables** are the relevant flows, Fi,j-s (flow of substance i from process j to process s) and stocks, dMi(j)/dt (stock change rate of substance i within process j during time t), as featured in Figure 1.

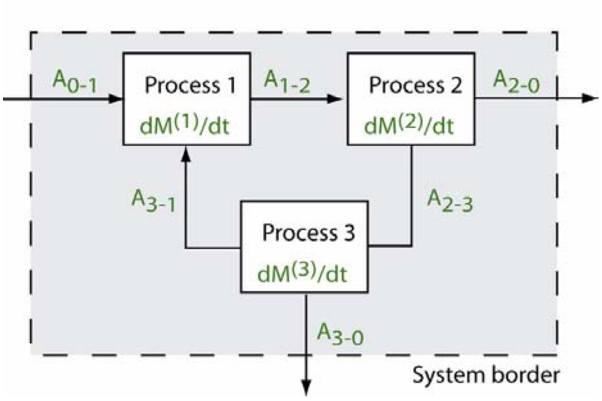

Figure 1: Example of a system analysis illustrating system variables (green) (Montangero, 2007); note: in Montangero’s study, flows are represented by “A” letter.

2.1.2 Development of equations

In a MFA model, the different flows of the system are translated into equations: *balance equations* and *model equations*. Balance equations are based on the law of mass conservation. That means that all the quantity of goods coming in a process will be equal to the ones going out and stocked within it. It is described by the following formula:

$$(dM_i^{(j)}/dt) = \sum F_{i,r\text{-}j} - \sum F_{i,j\text{-}s} \qquad (1)$$

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[1] To be downloaded on www.sandec.ch/esriss

where $\sum F_{i,r\text{-}j}$ accounts for the total of substance i entering process j and $\sum F_{i,j\text{-}s}$ for the total of the same substance leaving the process (e.g. the amount of nitrogen entering and exiting a bayara). For each of the processes, one balance equation is formulated.

For example, in our case, considering nitrogen (N) in the sewer network $[m^3/y]$:

N in greywater* *+ N in blackwater** *+ N in liquid manure** *+ N in Non-domestic building** *+ N in groundwater infiltration – N in sewage – N gas loss = 0*

* *Amount of N discharged in the sewer network*

Model equations are determined based on scientific and expert knowledge. They represent the characteristic features of the system and express how the different parameters define the variables of the system (Montangero and Belevi, 2008). They are as follows:

$F_{i,r\text{-}j} = f(p_1,p_2 \ldots p_n)$ (2)

where $p_1,p_2 \ldots p_n$ represent the model parameters.

For example, the amount of N in blackwater ($F11_N$) discharged into the sewer system [kg/year] is described as:

$$F11_N = r_{sew} * N_{inhab} * a_{N,bw} * 365 * 0.001$$

r_{sew}	*Percentage of households connected to the sewer system [%]*
N_{inhab}	*Village Population [cap]*
$a_{N,bw}$	*N content in blackwater [g/cap.d]*

The model equations for our case are provided in Table 4, and the model parameters in Table 5 and Table 6 . When developing model equations by limited data availability, it is important to minimize as much as possible the number of parameters. Moreover, equations containing parameters difficult to assess should be reformulated so as to eliminate these parameters.

Transfer coefficients, commonly used when modelling material flows, describe the partitioning of a substance in a process and provide the fraction of the total input of a substance transferred to a specific output good. Transfer coefficient values are substance and process specific. The transfer coefficient for a substance i (e.g. nitrogen) through a process j (e.g. liquid manure collection) to an output good g (e.g. sewer system) is defined by the following equation:

$$k_{i,g}^{(j)} = A_{i,g}^{(j)} / \sum_r A_{i,r-j},$$

where $k_{i,g}^{(j)}$ stands for the transfer coefficient of substance i in output good g for process j, $A_{i,g}^{(j)}$ is the flow of substance i in good g generated in process j, and $\Sigma_r A_{i,r-j}$ the total input flow of substance i into process j.

For example, the transfer coefficient $k_{man,sew}$ is the fraction of the total liquid manure produced discharged in the sewer system:

Manure discharged in the sewer system = $k_{man,sew}$ ** Liquid manure produced*

2.1.3 Assessing parameter values

Once balance and model equations are formulated, parameter values must be assessed in order to quantify the variables (material flows and stock change rates).

It is important to start by a rough parameter assessment, particularly where data collection means are limited. Parameter values should thus initially be assessed by reviewing local reports, statistical data, scientific publications and databases, and by eliciting expert judgement (Montangero and Belevi, 2007). Variables are initially calculated on the basis of the first parameter approximation values. Plausibility of parameter values (e.g., the range of values in which the parameters should most probably fall) and model outcomes is subsequently assessed. If not all the plausibility criteria are met, the most sensitive parameters are reassessed more accurately. A more differentiated literature review and/or field measurements or surveys can be carried out to obtain a more accurate assessment of the sensitive parameters. Plausibility criteria can be based on crosschecking. For example, a flow value calculated using the model could be compared with the results of field measurements or literature data considered as reliable. Another possibility to establish plausibility criteria is to use an overdetermined set of equations, i.e. having more equations than necessary.

2.1.4 Model calibration

Since limited data availability and reliability has been identified as one barrier to a wider application of MFA in policy-making, considerations regarding uncertainty are of utmost importance (Elmitwalli et al., 2003). In order to get an overview as realistic as possible, each flow is considered individually using different approaches in order to cross-check data. Parameter values were obtained through multiple channels: some were found in Egyptian and international literature, others were obtained through sampling and analysis, or deduced from calculations derived from the surveys and questionnaires and direct field observations. APPENDIX 2 describes the different approaches used for the estimation of the most important flows.

The first set of model equations and values for the model parameters was established based on information derived from literature and similar studies. These were later revised and updated based on the results from the field work (observations, survey results and measurements). The model was then applied to the five villages. The amount and concentration of nutrients computed by the model were then compared to the observations and measurements obtained during the sampling campaigns, allowing to assess the validity of the model.

For example, the nitrogen amount in excreta was first chosen in the literature within a plausible range (also from literature). However, it appeared that it was a sensitive parameter and that the model was not able to predict correctly the nitrogen amount in sewage. New sampling campaigns were organised in order to adjust sensitive parameters, including nitrogen in excreta.

All calculations of the mass flows were done using Excel software.

2.1.5 Model visualisation – Sankey diagrams

In order to be able to visualize the result (flows, processes and stock), Sankey diagram were created with the STAN[2] software, which is an intuitive programme but with advance settings. The Sankey diagram represents processes with boxes and flows with arrows having a width proportional to their value.

2.1.6 Sensitivity analysis

Sensitivity analysis provides insight into the most significant parameters. It is a method to assess the impact of the variability of parameters on the final result. In other words it allows observing which parameters have a big influence on the amount and concentration of septage and sewage. This helps design effective measures and select parameters requiring a more precise assessment in order to reduce variable uncertainty. This is a very important step where only limited data collection resources are available, as it reduces the number of parameters requiring further quantification.

Sensitivity was estimated by studying the effect of a 10% increase of each parameter on the key flows (septage or sewage) while all other parameters were left unaltered. The difference between the variable value and the value obtained by changing one parameter was then determined. The procedure was repeated for all parameters influencing the given variable.

The most sensitive parameters *(change of 0.1% or more in the key flows)* were taken into consideration when conducting additional field work with an adapted questionnaire focused on them. The parameters which could be considered as constant in all villages were defined (cf. *A Model-Based Tool to Quantify and Characterise Wastewater in Small Nile Delta Settlements – User Manual)*

2.2 Data collection

In order to have a strong and consistent model, there is a need to have a local and global understanding of the sanitation practices. Data collection was carried out through different means:

- Literature review
- Visit of 44 villages in order to understand the general situation
- Semi-structured interviews with sanitation stakeholders and household surveys in eight villages in Beheira Governorate in order to get a good understanding of the local situation
- Sampling campaign in these eight villages
- Transect walks and field observation

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[2] To be downloaded for free at: www.stan2web.net

The information used in the MFA is mainly coming from the household surveys and the sampling campaigns. Therefore those two methods are described below; the other methods are described in the Baseline Data Report (Reymond et al., 2013).

2.2.1 Household surveys

In a first stage, the *omda* or *sheikh al balad* was asked to identify and propose a set of households for the surveys to be held. These households should present different main occupations, levels of income and social status. Later, when villagers were more familiar with the procedure and the members of the study team, selection of households was random, making sure that the buildings were located in different parts of the village.

The MFA version of the questionnaire (APPENDIX 1) is made of five sections, covering the different topics of relevance, namely:

A. Household characteristics: size of household, main occupation, type of toilet and sanitation system
B. Drinking water supply: quality of water supply, quantity of water consumed, alternative sources of water used, monthly bills and level of satisfaction with the Water and Wastewater Company
C. Greywater: sources and amount of water for washing; collection of grey-water and disposal; products used for cleaning/washing/personal hygiene
D. Blackwater: (i) Sewers (type of sewers, problems, maintenance, expenses); (ii) On-site sanitation (design and dimensions of bayara, frequency and ways of emptying, disposal of sludge, problems and expenses)
E. Animal Manure: species and number of animals, quantities and handling of solid and liquid manure generated, reuse practices

Though the questionnaire is quite lengthy and highly structured, there is space for any information the interviewee wish to bring up, which they were encouraged to.

Before preparing a survey, it is important to know exactly which data is needed and what it will be used for. The following points are important to be kept in mind (adapted from Tayler-Powell (1998)):

- Purpose of data to be collected, expected use (e.g. frequency, percentage)
- Information available elsewhere?
- Try to view the questions through the respondent’s eyes; wording is important; understand and utilize the social language, the specific vocabulary and be aware of context-sensitiveness[3]

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[3] For example, a question like “Do you discharge sludge directly on agricultural fields?” may threaten a truck operator, which is usually aware of the non-conformity – or even illegality - of such practice; he may then answer “no”, even if he does. Thus, the question should rather be formulated as: “Some farmers are known to ask for sludge on their fields. Did they ever contacted you, and how?”

- Keep only necessary questions, so as not to overburden the surveyed persons, except a few contact questions at the beginning to put the interviewee at ease
- The response or information obtained is only as good as the question!

2.2.2 Sampling campaign

During the sampling campaigns of May 2013 and 2014, the following parameters were evaluated: BOD_5, COD, TS, TSS, NH_4-N, TN, TP, pH, DO and Conductivity. BOD_5, TS and TSS were measured at the Central Wastewater Laboratory of BWADC in Damanhur, while the others were evaluated by the ESRISS team with the portable lab equipment (see the *ESRISS Baseline Data Report*).

The procedure followed for the sampling of each one of the flows is described below. All the samples and composite samples were kept in a coolbox, in order to avoid modification of the characteristics.

- **Raw wastewater:**

Raw wastewater was collected directly from the outlet of an informal sewer network or from a manhole as close to the outlet as possible. In order to eliminate the effect of individual events, only composite samples were produced. Those were produced differently depending on the analysis to be done:

- Full day sampling with 1:30 hour composite sample. Each sample was composed of 6 subsamples of 220 mL taken every 15 min (i.e., one sample = 1:30 hour). This method was used in Fisha al Safra and Kawm an Nuss during 16 and 24 hours respectively. They allow to compute the average daily concentration and get an idea of the variability of the daily flow and concentrations.
- Morning sampling with 1:30-hour composite samples. Three sample were taken, each composed of 6 subsamples of 220 mL taken every 15min (one sample = 1:30 hour). This was replicated three times during a same week in two different villages (Fisha al Safra and Kawm abo Khalifa).
- Morning sampling with a 5 hour composite sample. Each sample consisted of the the sum of 50 mL subsamples taken every 15 min from 8 am to 1 pm. This was the first method used; it was applied in two villages (Fisha al Safra and Minshet Nassar). It helps to see the differences between villages while reducing the number of analyses.

This schedule were selected instead of simple hourly grab samples, as the sewage was observed to present great variations in flow rate and quality. Ideally, the volume of the subsamples should be proportional to the flow rate; however, flow rates could almost never be measured. Collecting equal sample volumes in regular time intervals was thus selected as the most appropriate method, given the conditions.

In order to use the sampling results for the model validation, the flows and concentrations measured at the outlets have to be expressed in m3/day or in daily average mg/L respectively. For the two last sampling methods (morning sampling only), the concentrations were adjusted with factors computed based on the full day samplings, the factors being the average concentration during the morning divided by the average daily concentration.

The two last methods allow to observe the variability of the concentrations measured several times in the same sewer outlet, which was found to be lower than 30%, as shown in Table 2.

Table 2 Variability of concentration measured in sewage

	TN	TP	COD	TSS
Average standard deviation between sewage samples from the same outlet	25%	16%	20%	29%

During the second sampling campaign (2014) a simple flow-measurement device was built in order to measure the sewage flow at the outlet (see Figure 2 and Figure 3). It works with a weir and a pressure logger measuring the water head upstream of the weir. The flow could be measured during more than one week in in Fisha and Kawm an Nuss. These measurements gave a precise idea of the daily peak flowsand the peaks appearing during the sewage unclogging event. The flow of the second full day sampling campaign was measured by this method. The one from the first sampling campaign was estimated every 15 min by measuring the time needed for an 18-litre bucket to fill up.

Figure 2: “KaCo” weir for flow measurement constructed by Eawag team; the datalogger is a Levelogger Gold model 3001, manufactured by the Solinst Company

Figure 3: Raw wastewater sampling at the outlet of the flow measurement weir (in Fisha el Safra)

- **Septage:**

Septage samples were taken from the vacuum trucks at the disposal points (see Figure 4). 500 ml of septage was collected at the beginning of the discharge, 500 ml when it was half empty and 500 ml shortly before the end, to make sure that the septage analysed was as close as possible to what would actually reach a treatment unit (Klingel, 2001).

The samples were subsequently mixed in a 1.5 L plastic bottle. In order to be able to explain the difference in the results, truck drivers were also asked to provide information on the nature of the bayara characteristics: frequency of emptying, size of bayara, number of trip, and numbers of people connected to the bayara.

It is to be noted that it is very difficult to get representative samples out of the pits/bayara themselves, because the content is highly heterogeneous and structured into different layers with different concentrations (e.g., scum, settling zone, sludge).

Figure 4: Septage sampling from a vacuum truck

- **Liquid animal manure:**

Liquid animal manure was grabbed in the collection hole in the stables (see Figure 5). The content of the holes was gently stirred and a sample was taken with a plastic jar. The samples were transferred into plastic bottles. The sampling took place between 7:30 and 8:30 am, before the daily emptying of the collection holes.

Figure 5: Liquid animal manure collection hole

2.3 Literature review

A thorough literature review was carried out in order to identify the existing documents dealing with the sanitation situation and practices in rural Egypt and featuring data on rural wastewater characteristics (see Baseline Data Report); the review led to the identification of the gaps in knowledge. As information about flow characteristics was not sufficient, an international literature review was also done, in order to get order of magnitudes in other studies in the same field.

Existing documents in Egypt should always be taken with caution and the reliability of data assessed. Data quality (especially statistics) is often questionable, and, in very dynamic contexts, may be quickly outdated. It should be kept in mind that many reports, especially from consultants, are never published officially and cannot be found on Internet. Individual meetings with the various organizations and agencies have been carried out. Part of the literature review was conducted in the library of Chemonics Egypt, where there is documentation on the numerous projects Chemonics has been involved in as well as other studies collected during the last 20 years.

2.4 Villages selected for model development

Beheira Governorate was selected among the three Governorates of ISSIP (Beheira, Garbeya, Kafr El Sheikh), as the Affiliated Company in Damanhur (Beheira Water and Drainage Company – BWADC) offered the best working conditions. Villages suitable for further study were selected based on the following criteria:

I. Population between 500 and 5’000 inhabitants (ideally between 1’000-3’000)
II. Domestic wastewater only (no presence of industry)
III. Acceptance and support from the local authorities (*Omdas* or *Sheikhs al Balad*)

Care was taken that the diversity of Egyptian villages was well represented in the selection, e.g. bayara-based villages vs. villages served with an informal sewer network, compact village vs. long villages along canals, high- vs. low-density villages.

The selection process as well as the assessment of the current sanitation situation are to be found in the Baseline Data Report (Reymond et al., 2013).

During the first campaign, the three following villages were selected (the field notes with satellite images are provided in Appendix 2 of the Baseline Data Report):

- **El Ashara (markaz Abu Hommus)**: village with density below average and on-site sanitation systems (bayara); supportive *sheikh (Sheikh Mohsen Saad),* who is respected in the village
- **El Hamamee (markaz Abu Hommus)**: very dense village inhabited mainly by poor workers, informal sewer network facing important problems

- **Kabeel (markaz Damanhur)**: village with a denser part built on a hill and a newer part being developed around it, both informal sewers (with problems) and on-site systems are used, friendly *omda* (*Omda Abd el Wahab Hagag*).

During the second campaign, the three following villages were selected out of the list provided by ISSIP PMTA (Hydroplan, 2013); more information and satellite images can be found in the field report provided in Appendix 3 of the Baseline Data Report:

- **Minshet Nassar (markaz *Damanhur*)**: village with an average density and an informal sewer network; 2 sewer lines where sampling is possible. Supportive Sheikh *(Mosaad Nassar)*
- **El Haderi (markaz Abu Hommus)**: village with low density and only on-site sanitation system, high number of cattle. No sheikh but supportive influent villager (*Nabil El Tanikhi*)
- **Kawm an Nuss (markaz Kafr el Dawar)**: really dense village, built on a hill, informal sewers (with problems) serving most of the village and discharging in a drain 2 km out of the village. Some isolated buildings still rely on bayaras.

During the third campaign, the two following villages were selected; more information and satellite images can be found in the Baseline Data Report and in the field report (upon request):

- **Kawm Abo Khalifa (markaz Damanhur)**: dense village, built on a small height, having two main sewer lines discharging into the drain close by. 80% of the village is served by the network, the rest is using bayaras.
- **Fisha el Safra (markaz Damanhur)**: 95% of the village is served by several sewer lines discharging into the nearby drain.

The location of the eight villages is featured on the satellite image below (Figure 6). They are all within ISSIP area (Mahmudeya Command Area). A KMZ file, which allows visualising the villages on Google Earth, is available upon request.

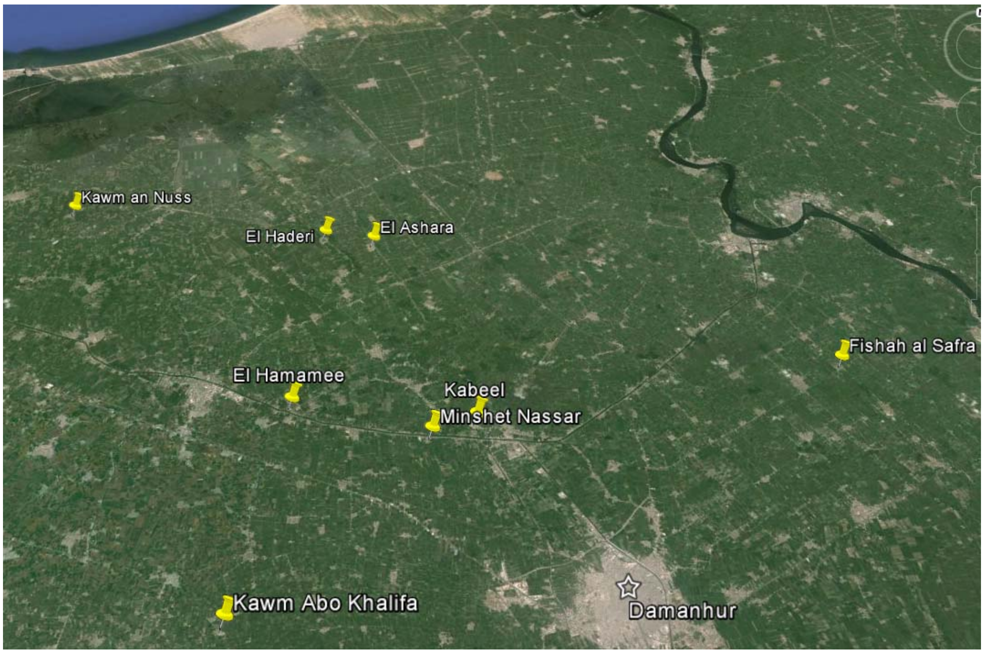

Figure 6: Satellite image of the eight studied villages

The main information on the eight selected villages is given in Table 3, with the more detailed table provided in Appendix 4 of the Baseline Data Report.

Table 3: Main characteristics of the selected villages

	Population[4]	Sanitation system	Density	Building repartition	Quality of water supply (interruptions/pressure)
Ashara	2252	Bayara	Low	Low density	Bad
Hadery	1854		Low	Low density	Low pressure
Kabeel	1762	Sewer + Bayara	High & Low	Nucleus	Low pressure
K. Nuss	3000		Very high	Nucleus	Bad
K. a. Khalifa	4070		High	Nucleus	Low pressure
Fisha	2630		Middle	Linear-Nucleus	Bad
Hamamee	730	Sewer	Very high	Nucleus	Good
M. Nassar	1917		Middle	Linear-Nucleus	Good

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[4] Value from census or estimation from the ESRISS team

3 Model

The model aims to represent Nile delta settlements under 5,000 inhabitants. The system boundary is the border of the settlement; the agricultural fields, the drains or a potential treatment plant are outside the system. They are exit points for the flows inside the system.

Quantification of flows was carried out primarily through the surveys and field observation, whereas the characterisation was mainly done through sampling campaigns. Eight villages were selected in Beheira Governorate to provide the data necessary to establish the model and to calibrate it.

The model focuses on the quantities of the different sanitation-related flows and nutrient management. The model currently allows to represent the flow, nitrogen and phosphorus for all processes, whereas the COD and TSS fluxes are computed for the sewered scenarios only.

3.1 Description of the model

3.1.1 Processes and flows

The model represents the sanitation system of a small community in the Nile Delta (< 5,000 inhabitants) and, in its final form, entails 9 processes and 27 flows as illustrated in Figure 7. Processes within the system boundary are:

1. **The household wastewater collection:** the household wastewater is divided into two fluxes: blackwater and greywater. Both can be discharged in the bayara or in a sewer network. The greywater can also be discharged in the drain/canal or in the street.
2. **The non-domestic wastewater collection:** receiving all the wastewater from non-domestic buildings (mosques, schools…) and discharging it in both sanitation systems and/or in a drain.
3. **The liquid manure collection:** it receives the total amount of liquid manure from the stables; the discharge can take place into a sewer network, a bayara or into all the four processes outside the system boundary.
4. **The onsite sanitation storage system** (cesspits, bayara, "trenches"): it receives wastewater from households, non-domestic buildings, some liquid manure and groundwater infiltration. The effluent can go into all the processes outside of the system boundary, to the atmosphere through gas loss, to agriculture through sludge deposition in the field, to groundwater through exfiltration and to a drain/canal.
5. **The sewer networks:** like the onsite storage system, it receives the wastewater from the households, the non-domestic buildings, some liquid animal manure and the groundwater infiltration. The effluent can go into all the processes outside of the system boundary.

The onsite sanitation process is the only one which has a storage capacity (i.e., the flows entering the system are not always equal to the flows going out) Indeed, the settled sludge tends to accumulate in the bottom of the bayara as a stock of organic matter and nutrients, which is taken into account in the mass balance equations.

Processes outside the system are: (i) the agriculture; (ii) the surface water (Canal/drains); (iii) the soil/groundwater; (iv) the atmosphere.

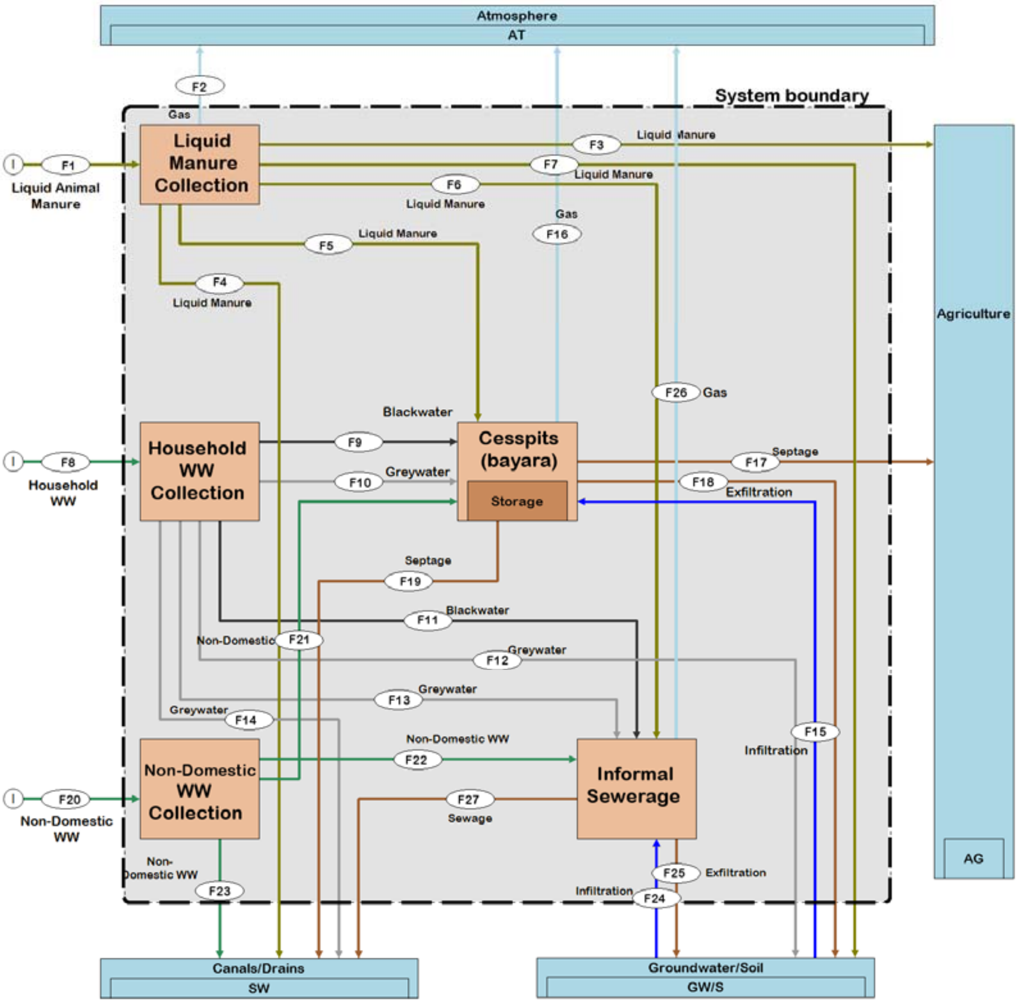

Figure 7: Model of the sanitation system in Nile Delta *ezbas*

3.1.2 Equations and parameters

Table 4 gives the model equations allowing to compute the wastewater and nitrogen flows in a village. The equations for the other chemical characteristics (TP, COD and TSS) are similar to the nitrogen ones. Table 5 gives the equation parameters specific to each village, e.g., the number of inhabitants and cattle, the proportion of people connected to each sanitation system. Table 6 gives the equation parameters which are constant in all villages, e.g., the percentage of time spent in field by cattle, the discharge point of septage or the amount of nitrogen in excreta. The full list of equations and parameters can be found in APPENDIX 3 and APPENDIX 4 respectively.

Table 4: System equations for flow and nitrogen

Flux	FLOW [m^3/y]	Flux	NITROGEN [kg/y]
F1	$N_{\text{anim,cap}}*0.1*N_{\text{inhab}}*q_{\text{manure}}*(1-r_{\text{field}})*365*0.001$	**$F1_N$**	$F2_N+F3_N+F4_N+F5_N+F6_N+F7_N$
F2	$k_{\text{man-atm}}*F1$	**$F2_N$**	$k_{\text{man-atm,N}}*(F3_N+F4_N+F5_N+F6_N+F7_N)$
F3	$k_{\text{man-agr}}*F1$	**$F3_N$**	$f_{\text{N,man, liq}}*F3_{\text{flow}}*0.001$
F4	$k_{\text{man-can}}*F1$	**$F4_N$**	$f_{\text{N,man, liq}}*F4_{\text{flow}}*0.001$
F5	$k_{\text{man-bay}}*F1$	**$F5_N$**	$f_{\text{N,man, liq}}*F5_{\text{flow}}*0.001$
F6	$k_{\text{man-sew}}*F1$	**$F6_N$**	$f_{\text{N,man, liq}}*F6_{\text{flow}}*0.001$
F7	$k_{\text{man-str}}*F1$	**$F7_N$**	$f_{\text{N,man, liq}}*F7_{\text{flow}}*0.001$
F8	F9+F10+F11+F12+F13+F14	**$F8_N$**	$F9_N+F10_N+F11_N+F12_N+F13_N+F14_N$
F9	$r_{\text{bay}}*N_{\text{inhab}}*(a_{\text{excreta}}+ q_{\text{analclean}} +q_{\text{flush}})*365*0.001$	**$F9_N$**	$r_{\text{bay}}*N_{\text{inhab}}*a_{\text{N,bw}}*365*0.001$
F10	$N_{\text{inhab}}*(r_{\text{bay}}*q_{\text{gw,bath}}+ k_{\text{gw-bay}}*q_{\text{gw,excl\_bath}})*365*0.001$	**$F10_N$**	$N_{\text{inhab}}*(r_{\text{bay}}*a_{\text{N,gw,bath}}+ k_{\text{gw-bay}}*a_{\text{N,gw}})*365*0.001$
F11	$r_{\text{sew}}*N_{\text{inhab}}*(a_{\text{excreta}}+ q_{\text{analclean}} +q_{\text{flush}})*365*0.001$	**$F11_N$**	$r_{\text{sew}}*N_{\text{inhab}}*a_{\text{N,bw}}*365*0.001$
F12	$N_{\text{inhab}}*k_{\text{gw-str}}*q_{\text{gw,excl\_bath}}*365*0.001$	**$F12_N$**	$N_{\text{inhab}}*k_{\text{gw-str}}*a_{\text{N,gw}}*365*0.001$
F13	$N_{\text{inhab}}*(r_{\text{sew}}*q_{\text{gw,bath}}+ k_{\text{gw-sew}}*q_{\text{gw,excl\_bath}})*365*0.001$	**$F13_N$**	$N_{\text{inhab}}*(r_{\text{sew}}*a_{\text{N,gw,bath}}+ k_{\text{gw-sew}}*a_{\text{N,gw}})*365*0.001$
F14	$N_{\text{inhab}} *k_{\text{gw-can}}*q_{\text{gw}}*365*0.001$	**$F14_N$**	$N_{\text{inhab}}*k_{\text{gw-can}}*a_{\text{N,gw}}*365*0.001$
F15	$r_{\text{inf-bay}}*(F5+F9+F10+F21)$	**$F15_N$**	$f_{\text{N,groundwater}}*F15_{\text{flow}}$
F16	$k_{\text{bay-atm}}*(F5+F9+F10+F15+F21)$	**$F16_N$**	$k_{\text{bay-atm,N}}*(F5_N+F9_N+F10_N+F15_N+F21_N)$
F17	$k_{\text{bay-agr}}*(F5+F9+F10+F15+F21)$	**$F17_N$**	$k_{\text{bay-agr}}*(F5_N+F9_N+F10_N+F15_N+F21_N)$
F18	$k_{\text{bay-ground}}*(F5+F9+F10+F15+F21)$	**$F18_N$**	$k_{\text{bay-ground}}*(F5_N+F9_N+F10_N+F15_N+F21_N)$
F18*[5]	0	**$F18_N$*[5]**	$k_{\text{bay-sludge,N}}*(F5_N+F9_N+F10_N+F15_N+F21_N)$
F19	(F5+F9+F10+F15+F21)-(F16+F17+F18)	**$F19_N$**	$(F5_N+F9_N+F10_N+F15_N+F21_N)-(F16_N+F17_N+F18_N+F18_N*)$
F20	$Q_{\text{ww,non-dom}}$	**$F20_N$**	$F20_{\text{flow}}*f_{\text{N,non-dom}}*0.001$
F21	$r_{\text{bay,non-dom}}*F20$	**$F21_N$**	$r_{\text{bay,non-dom}}*F20_N$
F22	$r_{\text{sew,non-dom}}*F20$	**$F22_N$**	$r_{\text{sew,non-dom}}*F20_N$
F23	$r_{\text{can,non-dom}}*F20$	**$F23_N$**	$r_{\text{can,non-dom}}*F20_N$
F24	$r_{\text{inf,sew}}*(F6+F11+F13+F22)$	**$F24_N$**	$F24_{\text{flow}}*f_{\text{N,groundwater}}*0.001$
F25	$r_{\text{sew-ground}}*(F6+F11+F13+F22)$	**$F25_N$**	$k_s*(F6_N+F11_N+F13_N+F22_N+F24_N)$
F26	$k_{\text{sew-atm}}*(F6+F11+F13+F22)$	**$F26_N$**	$k_{\text{sew-atm,N}}*(F6_N+F11_N+F13_N+F22_N+F24_N)$
F27	F6+F11+F13+F22+F24-(F25+F26)	**$F27_N$**	$F6_N+F11_N+F13_N+F22_N+F24_N-(F25_N+F26_N)$

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[5] Storage in Bayara

Table 5: Village-specific parameters

Parameters		Description	Unit	Typical Value[6]	Source
Village	**N_{inhab}**	Village Population	cap	**1450**	Surveys
	$q_{water,tap}$	Daily tap water consumption per cap.	L/cap.d	**110**	Surveys
	$q_{water,sup}$	Daily water importation	L/cap.d	**10.0**	Surveys & Assumptions
	r_{bay}	Percentage of households served by bayara	%	**0%**	Surveys
	r_{sew}	Percentage of households connected to sewerage	%	**100%**	Surveys
	$r_{pourflush}$	Ratio of inhabitants equipped with pour flush toilets	%	**77%**	Surveys
	$r_{WCflush}$	Ratio of inhabitants equipped with WC toilets	%	**23%**	Surveys
Infiltration/exfiltration	**$r_{inf,sew}$**	Ratio between groundwater infiltration into sewerage and total wastewater flow	%	**20%**	(Montangero and Belevi, 2008) & Assumptions
	$r_{sew\text{-}ground}$	Fraction of sewage infiltrating into the soil	%	**0%**	Assumption
	$k_{bay\text{-}ground}$	Fraction of septage infiltrating into the soil	%	**0%**	Surveys & Assumptions
	$r_{inf\text{-}bay}$	Ratio between groundwater infiltration into bayara and total septage	%	**0%**	Surveys & Assumptions
Greywater	**$k_{gw\text{-}bay}$**	Fraction of greywater (excl. bathr.) discharged in bayara	%	**0%**	Surveys
	$k_{gw\text{-}str}$	Fraction of greywater (excl. bathr.) discharged on streets	%	**2%**	Surveys
	$k_{gw\text{-}sew}$	Fraction of greywater (excl. bathr.) discharged in sewerage	%	**89%**	Surveys
	$k_{gw\text{-}can}$	Fraction of greywater (excl. bathr.) discharged in canal/drain	%	**7%**	Surveys
	$q_{gw,tot}$	Daily per capita production of greywater (total)	L/cap.d	**46**	Computation
	$q_{gw,bath}$	Daily production of greywater from bathroom	L/cap.d	**14**	Computation
	$q_{gw,excl\_bath}$	Daily per capita production of greywater (excl. bathrooms)	L/cap.d	**32**	Computation
Non-dom. buildings	**$Q_{ww,non\text{-}dom}$**	Water consumption of non-domestic users	m^3/y	**196.0**	Surveys & Assumptions
	$r_{bay,non\text{-}dom}$	Ratio of connection of non-domestic ww sources to bayara	%	**70%**	Surveys
	$r_{sew,non\text{-}dom}$	Ratio of connection of non-domestic ww sources to sewers	%	**0%**	Surveys
	$r_{canal,non\text{-}dom}$	Ratio of connection of non-domestic ww sources to drain/canal	%	**30%**	Surveys
Cattle	**$N_{anim,cap}$**	Number of animals (cattle) per 10 inhabitants	animal/10cap	**1.4**	Surveys
	$k_{man\text{-}agr}$	Fraction of liquid manure discharged on fields	%	**33%**	Surveys
	$k_{man\text{-}can}$	Fraction of liquid manure discharged in canal/drain	%	**25%**	Surveys
	$k_{man\text{-}bay}$	Fraction of liquid manure discharged in bayara	%	**0%**	Surveys
	$k_{man\text{-}sew}$	Fraction of liquid manure discharged in sewers	%	**42%**	Surveys
	$k_{man\text{-}str}$	Fraction of liquid manure discharged on the streets	%	**0%**	Surveys

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[6] Here Minshet Nassar

Table 6: Constant parameters

Parameters		Description	Unit	Value	Source
Divers	$r_{gw,bath/gw}$	Ratio of greywater from bathroom to total greywater	%	**30%**	Surveys & Assumptions[7]
	q_{drink}	Daily per capita consumption of water for drinking	L/cap.d	**2**	Assumption
Bayara & Sewer netw.	$k_{bay\text{-}atm}$	Ratio of gas losses from bayara to total input	%	**0%**	Assumption
	$k_{bay\text{-}agr}$	Fraction of septage emptied from bayara applied on fields	%	**0%**	Surveys
	$k_{bay\text{-}can}$	Fraction of septage discharged in drain/canal	%	**100%**	Surveys
	$k_{sew\text{-}atm}$	Ratio of gas losses from informal sewer to total input	%	**0%**	Assumption
Blackwater	$a_{excreta}$	Daily per capita production of excreta (wet)	L/cap.d	**1.5**	(Heinss et al., 1998)
	$q_{analclean}$	Daily consumption of water for anal cleansing	L/cap.d	**0.35**	(Faechem et al., 1993)
	q_{flush}	Daily consumption of water for flushing	L/cap.d	**11.5**	Computation
	$q_{pourflush}$	Daily consumption of water for flushing toilet (pour flush)	L/cap.d	**11.5**	Surveys & Assumptions
	$q_{WCflush}$	Daily consumption of water for flushing the toilet (WC)	L/cap.d	**40**	Assumptions
Cattle	r_{field}	Percentage of time spend by cattle in field	%	**20%**	Surveys
	q_{manure}	Production of liquid manure per animal	L/day	**16.22**	Surveys
	$k_{man\text{-}atm}$	Ratio of evaporation from manure to total imput	%	**0**	Assumption
Nitrogen composition	$f_{N,man,liq}$	Content of N in liquid manure	mg/L	**2988**	Sampling campaign
	$k_{man\text{-}atm,N}$	Fraction of N lost from manure storage to atmosphere	%	**30%**	(Hansen, 2006)
	$k_{bay\text{-}sludge,N}$	Fraction of N settled in bayara (storage)	mg/L	**20%**	Assumption
	$a_{N,bw}$	N content in blackwater	g/cap.d	**12**	Assumptions[8]
	$a_{N,gw,tot}$	N content in greywater	g/cap.d	**2.00**	(Suleiman et al., 2010)
	$a_{N,gw,bath}$	N in greywater generated from the bathroom	g/cap.d	**0.3**	(Suleiman et al., 2010, Montangero, 2006)
	$a_{N,gw}$	N content in greywater (excl. bathrooms)	g/cap.d	**1.70**	(Suleiman et al., 2010, Montangero, 2006)
	$k_{bay\text{-}atm,N}$	Fraction of N lost from bayara to the atmosphere (TC)	%	**0**	(Montangero and Belevi, 2007, Jacks et al., 1999)
	$f_{N,non\text{-}dom}$	N content in non-domestic ww	mg/L	**70**	(Metcalf&Eddy, 2003)
	$f_{N,groundwater}$	N content in groundwater infiltrating in sewers	mg/L	**0**	Assumption
	$k_{sew\text{-}atm,N}$	Fraction of N lost from informal sewer to atmosphere	%	**0%**	Assumption

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[7] Based on Morel and Diener (2006), Faruqui and Al-Jayyousi (2002), Siegrist et al. (1976), Henze (1997), Huang et al. (2007), Metcalf&Eddy (2003)

[8] Based on Jönsson et al. (2004), Friedler et al. (2013)

3.1.3 Model assumptions

All values in such a model could not be scientifically deducted with the available resources. Thus, assumptions were to be made for some parameters. The main assumptions of this model are the following:

1. The stormwater contribution to the overall flow of wastewater, nitrogen and phosphorus is assumed to be negligible
2. No stock (storage function) in processes, except in bayaras.
3. Flush water: 5 flushes per capita per day are assumed. It means that for pour flushing toilets the daily per capita consumption of flush water is 11.5 L/cap.d (5 flush/cap.d * 2.3 L/flush as found out from the surveys) while for WC toilets it is 40 L/cap.d.
4. Only the households that have more WC toilets than squatting ("baladi") ones will actually use the WC (the survey shows that people usually prefer the squatting toilets)
5. Greywater generated from bathrooms (showering, washing hands, ablution) all ends up in the sanitation system (either bayaras or sewers). The fraction of the total greywater it represents was assumed to be 30% (footnote nb. 7 p. 34). Greywater from laundry and dishwashing was partitioned to the different possible discharging points (sanitation system, street, surface water), according to the results from the survey.
6. Gas N losses from stables include losses from handling and storage of the liquid manure and are assumed to represent 30% of the total input. Gas N losses from the bayaras and from the sewer system, as well as P losses, are assumed to be negligible.
7. Evaporation is assumed to be negligible for the flows.
8. Non-domestic wastewater has the characteristics (nitrogen, phosphorus, COD and TSS) of a strong wastewater. The water consumption of mosques, schools and health-centres are assumed to be constant (do not depend on the number of users) and are not village specific.
9. Infiltration in informal sewer network was assumed to be 20% of the total flow.
10. Animals other than cattle (i.e. goats, sheep, horses, poultry) are not taken into account in the calculation of the production of manure: their populations and the volume of their excretions are much lower; these animals are also kept most of the time outside of the stable.
11. In all the villages (except Haderi) the bayaras are well sealed, so that no infiltration nor exfiltration takes place. In Haderi, the groundwater infiltration was assumed to be 20%. The bayaras in Haderi are not sealed and the comparison between the water consumption and the frequency of emptying shows the presence of another source of water.
12. The contribution of groundwater to the nutrient and phosphates flows was assumed to be negligible (concentration of N and P in groundwater equals 0)

13. Based on the quality of the drinking water supply system and the sanitation system, the water consumption was estimated for Ashara, Kabeel and Hammamy. The results of the survey were not sufficient to have precise data.
14. For Kabeel, the connection rates to bayaras and sewers as driven from the household surveys were corrected to match better with observations (36% connected to bayaras and 64% to sewers were corrected to 20% and 80% respectively)
15. In bayaras the differences between the input and output quantities of N and P (evaluated with samples) are due to the settling of nutrients along with the sludge. The proportion of settled nutrients which are stored in the bayaras (sludge which is not removed during pit emptying) vary in function of the frequency of emptying, the size of the bayara and if the bayara is completely emptied or not. An empirical value of 20% for both N and P has been used.

3.2 Quantification of the different flows

All the flows were quantified in terms of volume, TN and the TP. The COD and TSS flows were computed in case of sewers, but not in case of bayaras.

The equations were first developed based on the literature. The field observations, the surveys and the sampling campaign results (liquid animal manure) allows to estimate the first values of parameters. The sensitive parameters were then "adjusted" within their plausibility criteria in order that the computed flows of the model fits with the concentrations measured in sewage and septage in those three villages. It is thus an iterative method.

The list of equations and parameters can be found in Table 4 - Table 6. The methods used to quantify the most important flows are described below.

3.2.1 Household wastewater quantities

The survey did not allow to quantify precisely the amount of grey- and blackwater. Instead, the quantities had to be estimated through the following methods:

- **Blackwater:**
  - The amount of blackwater was estimated based on the volume of excreta ($a_{excreta}$), the quantity of water for cleaning ($q_{analclean}$) and the amount of water for flushing (q_{flush}, depending on the proportion of pour flush and WC toilets)

    $q_{bw}=a_{excreta}+q_{analclean}+q_{flush}$

- **Greywater:**
  - The total amount of greywater was estimated based on water consumption:

    $q_{gw,tot} = q_{water} - q_{drink} - q_{flush} - q_{analclean}$

    where $q_{flush} = r_{WC,flush} * q_{WC,flush} + r_{pourflush} * q_{pourflush}$, i.e. the percentage of people using WC and squatting toilets multiplied by the respective flushwater quantity.

    $q_{gw,tot}$ and q_{flush} are the daily per capita flows of greywater and flushwater in L/cap.d; the other parameters are defined in Table 5. The specific water consumption for each village (q_{water}) was calculated based on two or more water readings taken during the surveys (in 9 to 20 buildings per village).
  - The amount of greywater generated from the bathrooms was assumed to be 30%[9] of the total greywater flow. This amount flows directly into the sanitation system: $q_{gw,bath} = r_{gw,bath/gw,tot} * q_{gw,tot} = 0.3 * q_{gw,tot}$
  - The remaining fraction of greywater ($q_{gw,excl\_bath}$) was partitioned according to the percentages of households discharging greywater in sanitation systems, drains, canals, sewers and on the street respectively, as per the household survey results.

3.2.2 Household wastewater nutrient content

The amount of nutrients in black- and greywater are among the most sensitive parameters (cf. section 0). However no precise value could be found in the literature, due to its variability. Its estimation was based first on literature and then adjusted during the calibration process in order to fit with the sampling results (cf. section 3.4).

Some studies (Montangero and Belevi, 2008, Mihelcic et al., 2011) used the following formula based on the capita protein intake in order to get estimation for the respective countries under study (Jönsson et al., 2004):

$a_{N,excr}$=0.13*total food protein

$a_{P,excr}$=0.011*(total food protein + vegetal food protein)

The total and the vegetal food protein intake can be found on the FAO website. This method, however, seemed to overestimate the amount of P. Firstly, because these equations estimate a really high amount of phosphorus in Egypt compared to other neighbour countries (Figure 8); secondly, because the comparison of the N:P ratio found with this method (6.6) do not fit with the ones obtained during the sampling campaign of septage (12.3, cf. Baseline Data Report) and sewage (19.5, cf. Baseline Data Report).

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[9] Based on Morel and Diener (2006), Faruqui and Al-Jayyousi (2002), Siegrist et al. (1976), Henze (1997), Huang et al. (2007), Metcalf&Eddy (2003)

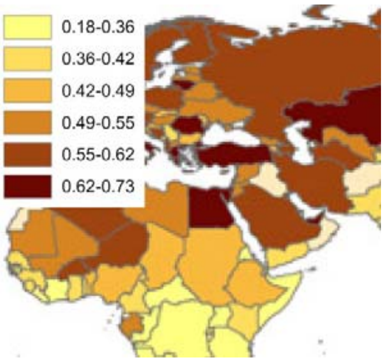


Figure 8: Phosphorus excreted per capita annually in 2009 [kg] (Mihelcic et al., 2011, Kvarnström et al., 2006)

During the calibration process a lower amount of phosphorus was chosen. This value still matches with the range of P in excreta mentioned (Friedler et al., 2013), as shown in Table 7.

Table 7: Nutrients in excreta in literature and the chosen values

		(Jönsson et al., 2004)	(Friedler et al., 2013)	Chosen
$a_{N,excr}$	g/cap.day	12.0	12.5 (4.3-20.2)	**12**
$a_{P,excr}$	g/cap.day	1.8	1.53 (1.1-2.8)	**1.2**
a_N:a_P	-	6.6	8.2	**10**

The amount of nitrogen in greywater is taken from a study in Jordan (Suleiman et al., 2010). The repartition of these nutrients between greywater generated from bathroom and other greywater sources is based on the greywater composition found in literature (Montangero and Belevi, 2007).

3.2.3 Wastewater from non-domestic buildings

The quantity of wastewater from the non-domestic buildings (schools, health centres and mosques) was derived from observation. Two water meter readings allowed to estimate the average water consumption of a mosque and a health centre. The schools' water consumption is derived from the frequency of emptying of bayara, i.e. from the amount of wastewater produced. Table 8 gives the results used in the model; they are indicative and are each only based on one single sample, but they allow to have a rough estimation for the size of villages under investigation.

Table 8: Average water consumption of non-domestic buildings

	Water consumption [m^3/year]
Mosque	930
Health centre	230
School	390

3.2.4 Infiltration/exfiltration in the bayaras and sewer networks

Infiltration/exfiltration may happen at two levels: (a) in the bayaras and (b) in the sewer networks.

In villages with well-sealed bayara, the influence of groundwater was assumed to be zero (no infiltration/exfiltration). In villages with unsealed bayara, the infiltration/exfiltration varies depending on the groundwater level, the depth of the bayara and the average septage level in the bayara. Among the four visited villages having onsite sanitation, only one has unsealed bayara (Q23 from the household surveys), with an average depth of 2.3 m (Q24), a groundwater table at 1.1 m and bayaras that are most of the time completely emptied. In this specific case an empirical value of 30% of infiltration (i.e. from the groundwater into the bayara) and 0% of exfiltration was chosen.

In informal sewer systems, the infiltration of groundwater can have a significant impact on the sewage concentrations. It mainly depends on the depth, the length, the age of the network and the groundwater table. Montangero and Belevi (2008) give an average infiltration rate of 20%. In Kawm an Nuss where the network is old and is connected to the drain by a 1.6 km pipe passing through the water table, the volume of the infiltrated groundwater was estimated to amount to 30% of the total sewage volume. This estimation fits with the infiltration estimated by the measurement of the flow from 2 to 5 am (which amounts to 36%, cf. *Baseline Data Report*) and allows to fit the model with the average measured flow and the concentrations.

The depth of the ground water level can be considerably high in certain villages (up to a few dozen centimetres below surface), leading to a significant groundwater infiltration into the sewer network if it is not watertight (which is common), thus resulting in the dilution of wastewater with groundwater. In case of a really high depth of the groundwater table, some exfiltration of sewage into the soil could occur; however, this process has been considered non-existent in the model.

The estimation of the infiltration (groundwater to sewer) phenomenon is difficult. We propose an estimation based on the difference between the groundwater level and the depth of the sewer network outlet as shown in Table 9. The infiltration rate should not be higher than 30% of the flow.

Table 9 Estimation of the infiltration into the sewer network

Proportion of the sewer network below groundwater	Infiltration (% of total sewage)
25%	10%
50%	20%
75%	30%

In an ideal case, where the outlet of a functioning sewer network can be observed, the amount of groundwater infiltration can be deducted from the residual flow in the middle of the night (from 2 to 5 am).

3.2.5 Sludge storage and biodegradation in the bayaras

The MFA and the sampling campaign both show significant changes in loads and concentrations of nutrient and organic matter within the pits/bayaras; it reflects the facts that (i) part of the sludge that settles in the bayara is not removed during the emptying process and thus stored (cf. also §5.3 of the *Baseline Data Report*), and (ii) biological degradation occurs. In order to take this into account, a “storage process” was added to the model, within the process “Cesspits (bayara)” . The extent of storage depends on the retention time of the wastewater in the pit, the size of the bayara and the frequency of emptying. The number of samples is still too small to characterise it precisely but the calibration process allows to draw an estimation between 0 and 40% of the incoming nutrients. In the selected village, sludge is mostly not removed during the emptying and tends to accumulate in the bayara, therefore a value of 30% was chosen.

It was assumed that if the chemical form of nutrients may change in the pits during biological degradation, the quantities are not affected and losses in gas form can be neglected.

3.2.6 Liquid animal manure

The amount of liquid manure entering the system ($q_{manure.stable}$) was estimated as the average amount of manure emptied every day from the collection hole. It depends on the number of animals per capita (N_{anim}), the number of inhabitants (N_{inhab}), the daily liquid manure production per cow (q_{manure}) and the proportion of time spent in the field (r_{field}). It was modelled through the following model equation:

$$q_{manure.stable}=N_{anim.cap}*N_{inhab}*q_{manure}*(1-r_{field})$$

The number of cows per inhabitants, the daily manure production per cow and the time spent on the field come from the household survey results where there is one specific question for each parameter (Section E of the household questionnaire in APPENDIX 1). All answers were also confirmed by field observation.

The results from the surveys gave a daily liquid manure production of 16 litres/cow/day. As there are almost no variable parameters (in our case only one emptying per day), it was possible to verify several times the volume of the bucket used for emptying. This value is higher than the one in the literature which gives an amount of 9 litres/cow/day (Mansour, 1998, ASAE, 2003).

The proportion of liquid manure discharged in the different points (canal/drain, sanitation system, street or field) was estimated according to Q37 of the household survey questionnaire.

The chemical characteristics of liquid animal manure are derived from the analysis of 12 samples. The average characteristics are shown in Table 10 (full results in Appendix 18 from the *Baseline Data Report*). The liquid animal manure is characterised by really high levels of nitrogen, oxygen demand and total solids. Depending on the number of cattle and the proportion of manure discharged into the sanitation system, the loads due to manure can be considerable.

Table 10: Summary of animal liquid manure characteristics (in brackets = standard deviation)

	Nitrogen [mg/L]	Phosphorus [mg/L]	COD [mg/L]	BOD [mg/L]	TN:TP ratio	Nb. of samples
Liquid animal manure	**2'988** (1'256)	**27** (13)	**16'041** (3'691)	**9'173** (3'527)	**120**	10-12

3.3 Sensitivity analysis

The sensitivity analysis provides insight into the most significant parameters. It is a method to assess the impact of the variability of parameters on the final result (see §2.1.6). Sensitivity was estimated by studying the effect of a 10% increase of each parameter on the key flows (septage or sewage) while all other parameters were left unaltered.

The analysis shows that:

- Not surprisingly, the number of inhabitants is the most sensitive parameter for both flow and nutrients quantity, with a quasi linear behaviour. However it does not have any impact on the concentration of nutrients and oxygen demand computed by the model. Thus, an error on the estimation of the number of habitants only have an impact on the quantity of wastewater, not on its characteristics.
- To a lesser extent, greywater management, its discharge point(s) and its concentration are sensitive parameters for the nutrients and the flow volumes.
- The household water consumption and the groundwater infiltration are sensitive parameters for the flow volumes. However, because they both contain insignificant nutrient concentrations, they have no impact on the nutrient flows, only on the concentration.
- The proportion of households connected to the sewer network or to a bayara has an important impact.
- The daily amount of N and P excreted by human beings has a significant impact; to a lesser extent, the amount of nutrient in greywater does too.
- The number of cattle per household, the concentration of nitrogen in liquid manure, and the quantity of the latter discharged in the sanitation system are significant for the nitrogen model.
- The storage of nutrients in the bayara within the settled sludge is also a sensitive parameter.

Figure 9 to 7 show the percentage of absolute change caused by a 10% change in each of the displayed parameters in the amount of flow, nitrogen and phosphorus in septage and untreated wastewater discharged in surface water. The explanation of the latter can be found in Table 5 and Table 6.

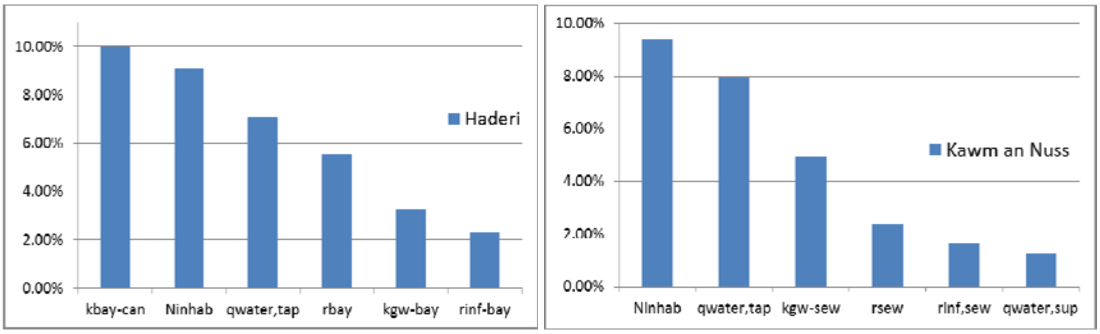


Figure 9: Percentage of absolute change in the amount of septage (left) and untreated wastewater (right) discharged in surface water caused by a 10% change in each parameter

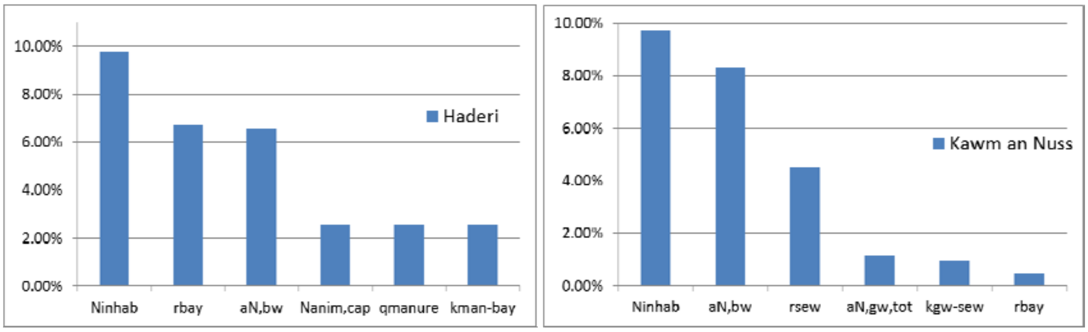


Figure 10: Percentage of absolute change in the amount of nitrogen in septage (left) and in untreated wastewater (right) discharged in surface water caused by a 10% change in each parameter

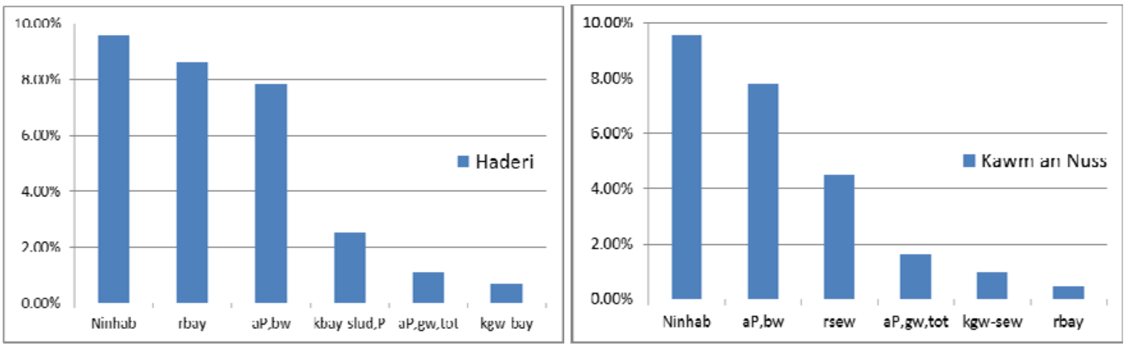


Figure 11: Percentage of absolute change in the amount of phosphorus in septage (left) and in untreated wastewater (right) discharged in surface water caused by a 10% change in each parameter

3.4 Illustration with Sankey diagrams

The Sankey diagram makes the visualisation of the different flows easier, as the width of the arrows is proportional to the size of the respective flows. In order to ease comparison, the flows have been computed for 100 inhabitants.

Figure 12 to Figure 14 depicts the application of the model to two representative villages. The first one, Haderi, is served only by onsite sanitation systems and has a particularly high number of cattle per household (5 cows per 10 inhabitants). The second, Kawm an Nuss, is served mostly by an informal sewer network, while only a few buildings are still connected to onsite sanitation (5%). The nutrient loads for 100 inhabitants are given in Table 11 and Table 12.

Households are by far the main contributors of wastewater and nutrients. Greywater has a big impact on the flows, but due to its low nutrient concentration, it almost has no impact on the quantity transferred. Blackwater produces the largest amount of both nitrogen and phosphorus.

Liquid animal manure can have a big impact on the nitrogen load, as shown in Haderi. However, the level of phosphorus is low.

Non domestic-buildings have an insignificant impact on the load of flows and nutrients. However, they may contribute to the peak flow before the prayer or during breaks at school.

Table 11: Summary of loads and concentrations of nitrogen in the main flows, for 100 inhabitants

Flow, sources/destination	**HADERI** (population: 1854)		**K. NUSS** (population: 3000)	
	Loadkg/y/100 cap	Conc. mg/L	Load kg/y/100 cap	Conc. mg/L
Liquid animal manure - Total Import	**929**	~3'300	**202**	~3'300
Discharged in canal/drain	447		83	
Discharged in sanitation system	179		10	
Discharged in other places: atmosphere, street, field	304		109	
Household Wastewater - Total Import	**511**	-	**511**	-
Blackwater (to sanitation system)	438	667	438	643
Greywater (to sanitation system)	46	38	62	23
Greywater (discharged on the streets & canal/drain)	27	51	11	30
Non-Domestic Wastewater - Total Import	**0.1**	70	**0.0**	70
To sanitation system	0.1		0.0	
Storage in bayara	**135**	-	**5**	-
Septage	**541**	196	**19**	150
Sewage	**0**	0	**500**	125

Table 12: Summary of concentration and quantity of phosphorus in the main flows for 100 inhabitants

Flow, sources/destination	HADERI (population: 1854)		K. NUSS (population: 3000)	
	Load kg/y.100cap	Conc. mg/L	Load kg/y.100cap	Conc. mg/L
Liquid animal manure - Total Import	**6.9**	29.0	**1.5**	29.0
Discharged in canal/drain	**4.3**		**0.8**	
Discharged in sanitation system	**1.7**		**0.1**	
Discharged in other places: atmosphere, street, field	**0.9**		**0.6**	
Household Wastewater - Total Import	**62.1**		**62.1**	
Blackwater (to sanitation system)	**43.8**	66.7	**43.8**	64.3
Greywater (to sanitation system)	**13.5**	11.1	**16.3**	6.5
Greywater (discharged on the streets & canal/drain)	**4.8**	9.0	**2.0**	5.3
Non-Domestic Wastewater - Total Import	**0.0**	12.0	**0.0**	12.0
To sanitation system	**0.0**		**0.0**	
Storage in bayara	**12.3**		**0.6**	
Septage	**49.1**	17.7	**2.3**	17.6
Sewage	**0.0**	0.0	**59.7**	14.9

Figure 12: Wastewater flow for 100 inhabitant [m^3/y] in Haderi, a village with onsite sanitation (left) and Kawm an Nuss, a village with an informal sewer network (right)

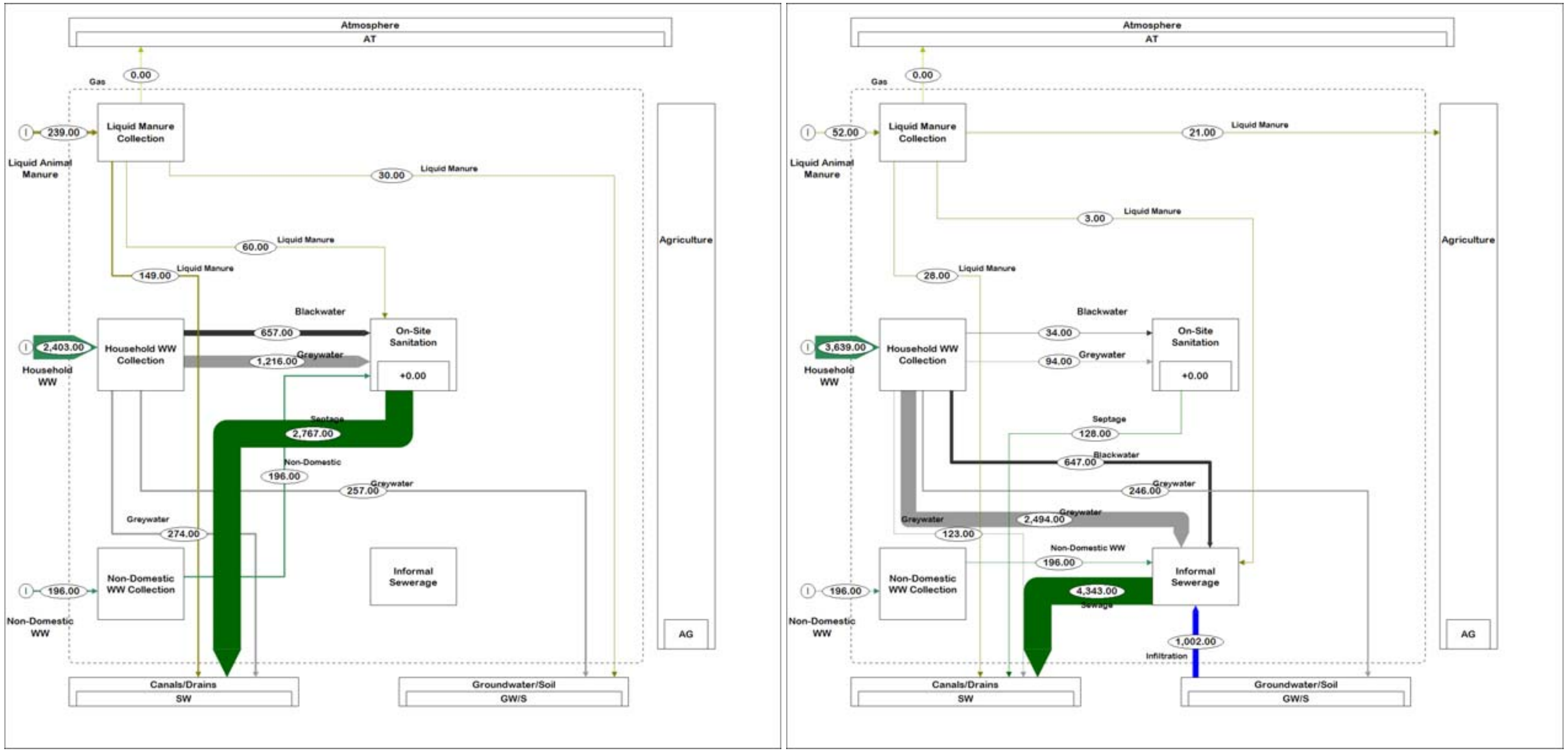


Figure 13: Nitrogen flow for 100 inhabitants [kg/y] in Haderi, a village with onsite sanitation (left) and Kawm an Nuss, a village with an informal sewer network (right)

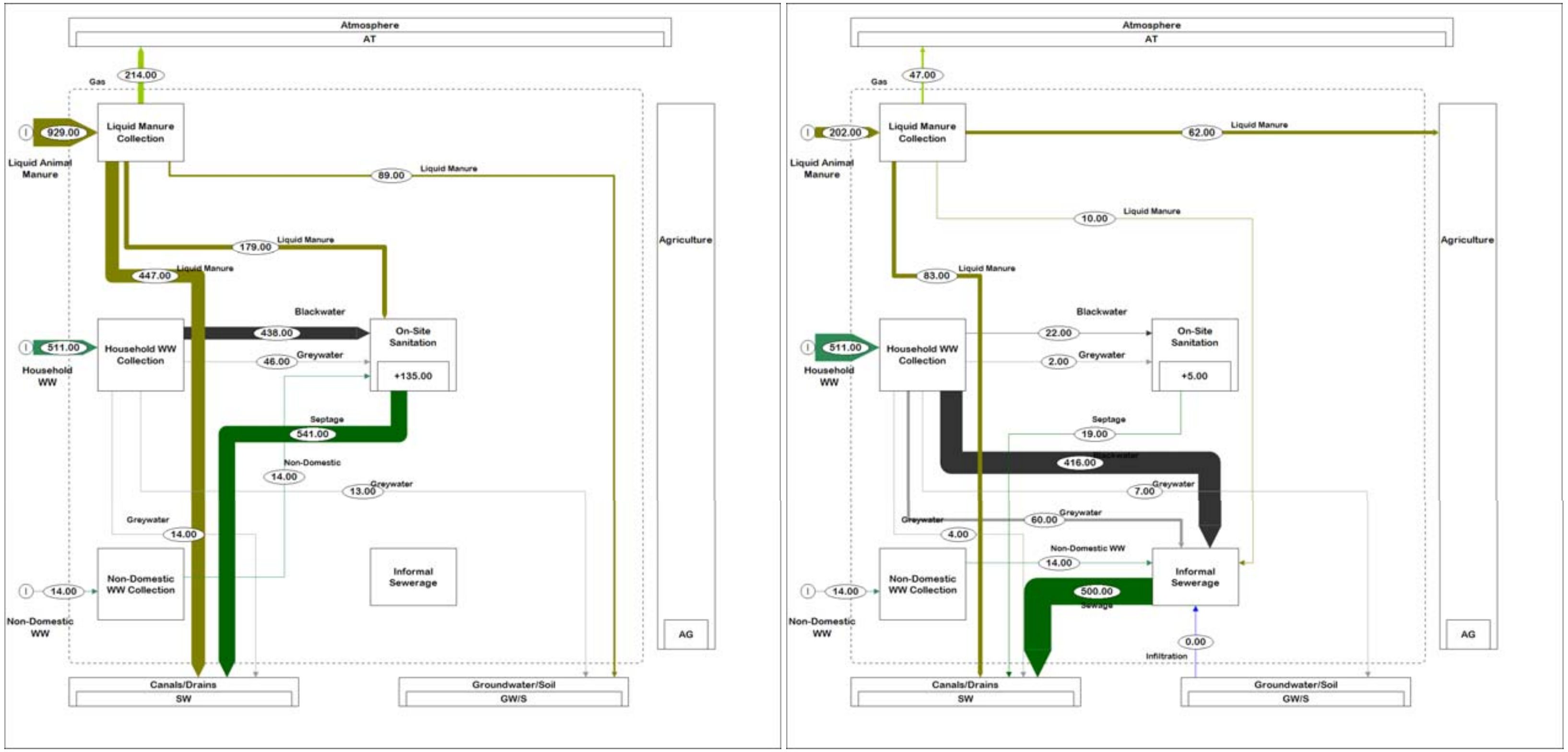
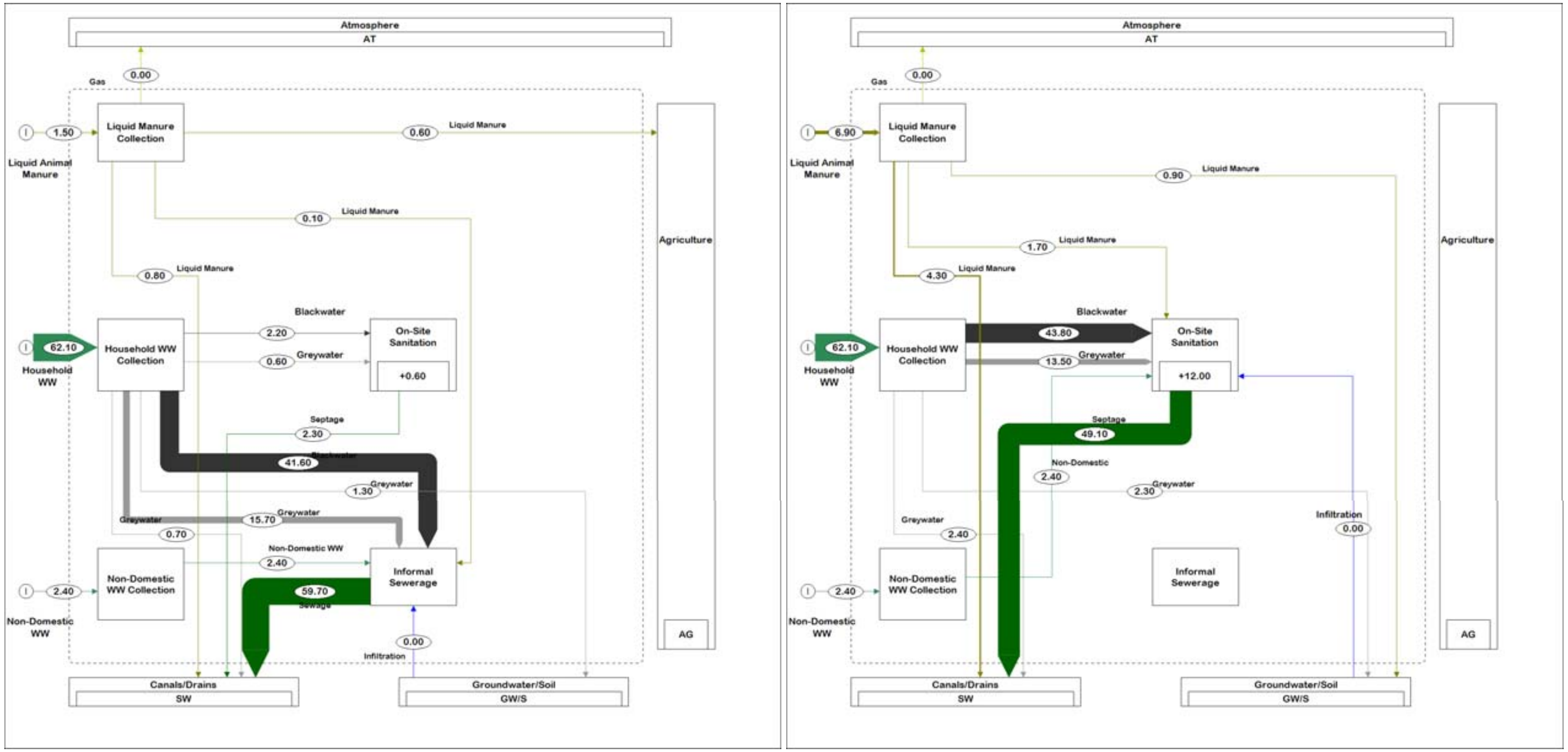


Figure 14: Phosphorus flow for 100 inhabitants [kg/y] in a village with onsite sanitation (left) and a village with an informal sewer network (right)



3.5 Validity of the model

In order to estimate its validity, the model was applied to five villages in Beheira Governorate: Haderi, Minshet Nassar, Kawm an Nuss, Fisha al Safra and Kawm abo Khalifa. Haderi is based on bayaras whereas the other villages are mainly based on sewer networks (see *Baseline Data Report* for more information). The flows and nutrient concentrations of septage/sewage estimated through the model were compared to the one measured during the sampling campaign. The COD and TSS concentrations found were compared to sewage characteristics but were not computed for the village with bayara. It shows that sewage concentration can be predicted in a +/- 30% range, which matches with the variation of sewage characteristics measured in sewage. As for septage, the model shows good correlation with the results of the sample analyses, but based on only one comparison.

3.5.1 Estimation of sewage characteristics for villages relying on sewers

The validation was done in four villages for sewage chemical characteristics and in two villages for the flow volume. The concentration estimated by the MFA represents a daily average. Therefore, in villages were the sampling took place only during the morning (from 8 am to 1 pm), the concentrations were adjusted with a factor in order to represent the daily average (see §2.2.2).

Figure 15 and Table 13 present the difference between the measurements and the model predictions. The variability of concentrations in sewage was found as 30% (see §2.2.2); whenever the difference between the model and the results in the table were higher than this value, it is put in red.

Table 13: Comparison between sewage characteristics estimated by the model and the measurements

		M.Nassar	K.Nuss	K.a. Khalifa	Fisha
FLOW [m^3/y]	**MFA**	199	310	320	288
	Sampling	-	257	-	276
	Diff.	**-**	**21%**	**-**	**4%**
TN [mg/L]	**MFA**	118	129	289	189
	Sampling	112	111	272	216
	Diff.	**5%**	**16%**	**6%**	**-13%**
TP [mg/L]	**MFA**	12	15	21	15
	Sampling	8	10	17	12
	Diff.	**56%**	**55%**	**22%**	**27%**
COD [mg/L]	**MFA**	746	816	1'743	1'127
	Sampling	823	605	1'499	1'366
	Diff.	**-9%**	**35%**	**16%**	**-17%**
TSS [mg/L]	**MFA**	321	358	720	474
	Sampling	172	0	467	405
	Diff.	**86%**	**-**	**54%**	**17%**

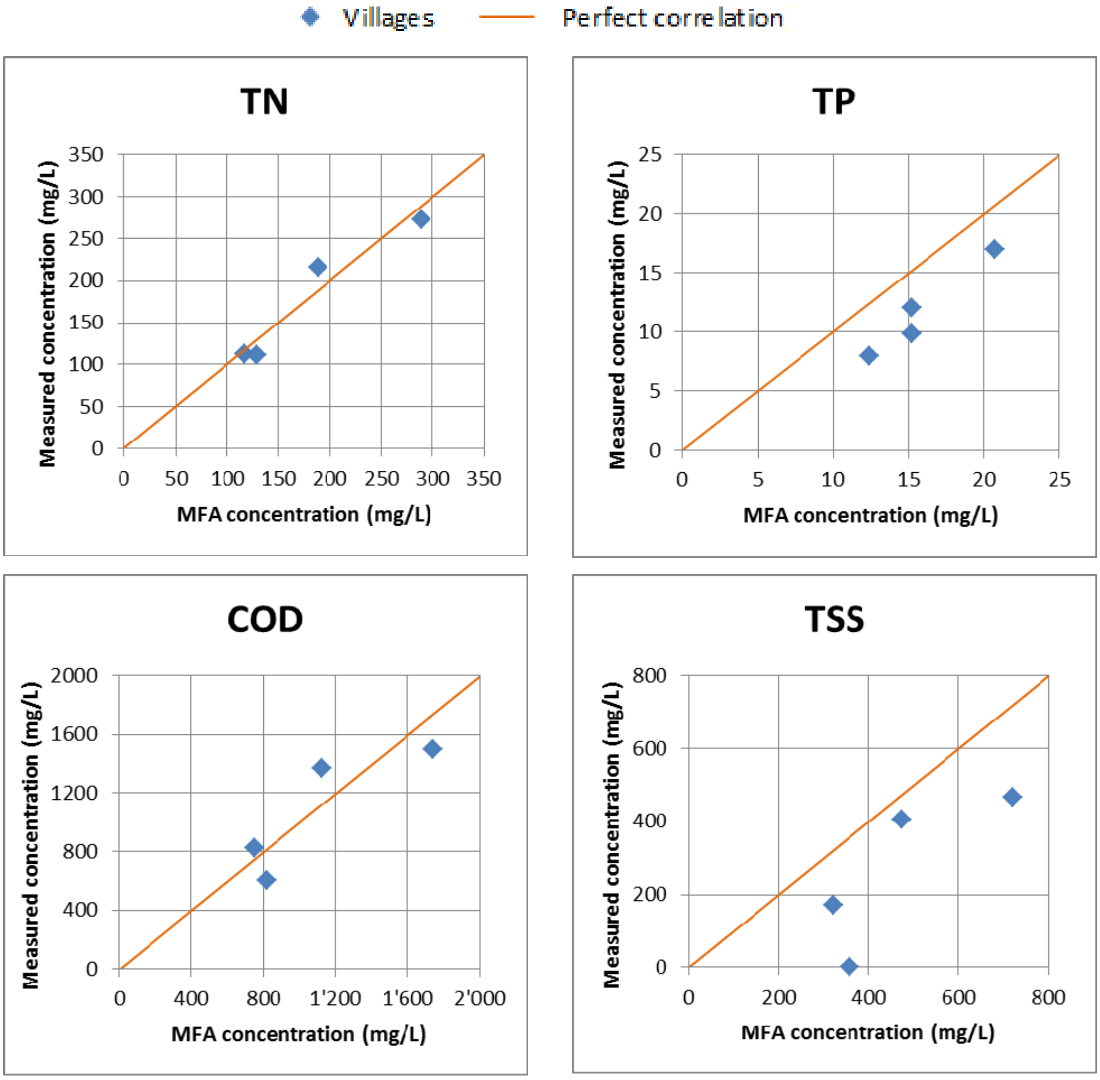


Figure 15: Comparison between sewage characteristics estimated by the model and the measurements

Figure 15 shows that the results of the model are well correlated with the measurements. Higher concentrations computed by the model correspond to higher concentrations in the sampling campaigns. But this correlation varies among parameters:

- The flow is well correlated (difference lower than 20%), but is only based on investigation in two villages.
- The nitrogen and the COD are also well predicted by the model. The differences with the measurements are lower than the variability of the sampling results (30%), which is quite good.

- The phosphorus and TSS are not as well predicted by the model. The model computed systematically higher concentration than the one measured during the sampling campaign (20-85% higher).

The difference between the TP and TSS predicted by the model and the measurements appears not to be caused by a bias in the parameters. The calibration process permitted to rechecked all parameters and it was not possible to fit the model with the sampling results while staying in the plausible range of the parameters. This difference might be caused by an underestimation of the clogging and settling effects in the sewer networks on sewage concentrations. Due to the fact that the villages use shallow networks, with low slope, cloggings often occur. The sludge accumulates in the network and is only washed out during short unclogging events. Sewage during unclogging features a high strength as shown in Table 14.

Table 14 Concentration of wastewater during unclogging events

	COD	TSS	TN	TP
Concentration during unclogging events (2 samples)	1601	870	196	15.0

The difference between the measurements and the estimations of the model do not mean that the model is wrongly built, it only shows that the sampling campaign do not permit to get the real average concentrations, because it did not take the clogging events in account.

In order to use the MFA model for prediction of concentrations, a factor should be used for TP and TSS (cf. *Manual* of the Excel-based model).

3.5.2 Estimation of septage characteristics for villages relying on bayaras

The calibration process allows to fit the model with the measured septage characteristics, as shown in Table 15. The differences (-3 to 9%) with the measured concentrations are low.

Table 15: Comparison between concentrations of nutrients in septage from the model and the measurements (Haderi).

	Haderi	
	N [mg/L]	P [mg/L]
Modelled flow	202	16.6
Measurement	209	15.2
Difference	**-3%**	**9%**

However, the model is still not finalised and need more data to be confirmed. This for several reasons:

- Regarding septage production, the model provides an estimation of 70 L/d/cap, whereas the volume computed based on the frequency of emptying amounts to 110 L/cap/day. This difference could be caused by the estimation of infiltration rate (which is already high: 30%) and approximate answer of villagers.

- The model was calibrated on one village only. More cases are needed to confirm the unknown parameters.
- Only three samples could be taken in the selected village. While the sampling campaign shows a high variability among septage samples, these variations could not be explained clearly; they most probably depend on the way of emptying, the residence time in the bayaras and the interaction with groundwater.
- Some of the processes within the bayara are really complex to model as the biological activity and the settlement of the organic matter depend on many parameters.

Therefore, the MFA model cannot be used to predict the septage concentrations yet. Typical septage concentrations are given in Table 16 (see also the *Baseline Data Report*).

Table 16: Summary of septage characteristics (in brackets = standard deviation)

	Nitrogen [mg/L]	**Phosphorus** [mg/L]	**COD** [mg/L]	**BOD** [mg/L]	**TN:TP** ratio	**Nb. of samples**
Haderi	**415** (343)	**41** (43.7)	**5'703** (5'556)	**2'017** (1'864)	**12.3**	12

4 Application of the model

The model can be used for different purposes:

1. Estimate the concentrations and volumes of the different sanitation flows (cf. Figure 7), including the sewage/septage to be treated, in present and future situations.
2. Compare sanitation system scenarios
3. Develop scenarios to optimise nutrient recovery

In what follows, five sanitation system scenarios are compared with a nutrient reuse perspective. First, the two common scenarios of villages with sewers and villages with bayaras are investigated. Then, the potential benefits of the centralised management of liquid animal manure through a liquid manure storage unit and the potential benefits of the diversion of greywater through simplified sewer networks are discussed. It highlights the pros and cons in terms of volumes to transport, volumes to treat and volumes to reuse.

In order to ease its application by practitioners, the model was later simplified and combined with results from the baseline data study to produce a tool to help designers and consultants to estimate quickly (max. 3 days) the quantity and characteristics of the raw wastewater to be treated, on a site-specific basis, i.e., the design parameters (BOD, COD, TS, TSS, TN, TP). The tool package is available at www.sandec.ch/esriss (*Excel-based Model; User Manual; Step-by-Step Procedure; Interview Guidelines and Household Survey Questionnaire for Field Data Collection*).

4.1 Estimation of nutrient loads and concentrations

4.1.1 Nitrogen and phosphorus in the different sanitation flows

Table 17 synthesises the average concentrations of nitrogen and phosphorus observed in the main flows of the model. The concentrations in sewage, septage and liquid manure are the one measured during the sampling campaigns (cf. §2.2.2 and *Baseline Data Report*). The other values were extrapolated through the MFA model applied to the five villages.

The liquid animal manure has a very high concentration in nitrogen, but its phosphorus concentration is in proportion quite low; the TN:TP ratio is close to 100. The blackwater, which is the sum of the faeces, urine, flush water and the anal-cleaning water, also has a high nutrient concentrations with a ratio of TN:TP ratio of around 10. It is always discharged in the sanitation system and mixed with greywater. Septage has a much higher concentration than sewage, due to several factors (see Section 5.3 in the *Baseline Data Report*).

Table 17: Average concentrations in the different flows (range between brackets)

Flow, sources/destination	Nitrogen mg/L	Phosphorus mg/L
Sewage	180 (100-250)	10 (6-15)
Septage	410 (200-1’300)	41 (10-70)
Household Wastewater		
Blackwater (to sanitation system)	**650**	65
Greywater (to sanitation system)	20-40	3-6
Greywater (discharged on the streets & canal/drain)	30-50	3-5
Non-Domestic Wastewater	110	6
Liquid animal manure	3’000 (1’000-4’000)	27 (10-50)

4.1.2 Factors influencing the loads of nitrogen and phosphorus in sewage and septage

The quantity of nutrients that can be recovered in a village depends mainly on the number of inhabitants, the liquid manure quantity and its management, and the amount of greywater discharged into the sanitation system (cf. §2.1.6):

- The amount of people is the most significant parameter because most of the nutrients come from human excreta.
- The liquid animal manure has a really high concentration of nitrogen, but is however to be found in much lower volumes than domestic wastewater. Depending on the number of cattle and the proportion of liquid manure discharged in the sanitation system it can have a big impact on the nutrient concentration in wastewater. Its influence on the phosphorus load is much lower.
- The greywater have a comparatively small nutrient concentrations, but because of its high volume it can have a non-negligible impact when discharged into the sanitation system.

4.2 Comparison of different scenarios

Two main situations can be distinguished in the Nile Delta: (i) villages relying on onsite systems (bayaras) ; (ii) villages with one or several sewer network(s). Thus, in what follows, the two following baseline cases are defined:

- **Case 1:** village relying on bayaras only
- **Case 2:** village relying on a single functioning sewer network

For the sake of comparison, the villages all count 1,000 inhabitants and have average characteristics as per the baseline data collected within the ESRISS Project (cf. *Baseline Data Report*).

The main questions to be answered through the model are:

e. What are the flow volume and nutrient loads in sewage, respectively septage?

f. What influence does liquid manure have on loads and concentrations of nutrients and organic matter in sewage?

g. Which flow volume and nutrient loads can be isolated through the centralised management of liquid animal manure? What impact does it have on the nutrients loads in sewage, respectively septage?

h. What are, in terms of reuse potentials and volumes to be treated, the benefits of storing blackwater and animal manure in onsite sanitation systems (bayara or biogas digesters) and separating greywater, either through soak pits or simplified sewer systems?

i. Which amounts of nutrients are stored in the bayaras (without being pumped out)?

These questions imply the definition of five scenarios:

- **Scenario 1:** onsite systems (bayaras) only – existing situation (*Case 1 above)*
- **Scenario 2:** single functioning sewer network – existing situation (*Case 2 above)*
- **Scenario 3:** onsite systems (bayaras) only, with centralised liquid manure management
- **Scenario 4:** single functioning sewer network, with centralised liquid manure management
- **Scenario 5:** onsite systems (bayaras, biogas digesters) for blackwater and animal manure, with greywater diversion through a simplified sewer system or soak pits.

The scenarios are further described below and compared side-by-side in order to answer the key-questions for nutrient reuse optimisation.

4.2.1 Sewer network vs. onsite systems (bayaras)

Scenario 1 and Scenario 2 are compared in terms of flow volume and nitrogen & phosphorus loads in septage, respectively sewage. This comparison reflects what happens when a sewer network is built in a village equipped with bayaras (for more information on that case, cf. the *User Manual* of the simplified Excel-based model).

Scenarios 1 and 2 can be described as follows:

- **Scenario 1:**

Scenario 1 represents the current situation found in many villages in the Nile Delta, and is based on one of the studied village – Haderi. The village has 1000 inhabitants and is served by onsite sanitation only; blackwater and greywater from bathrooms end up in the bayaras, as well as a significant portion of the rest of the greywater (60%) and some liquid manure (20% of total). Emptying of the facilities is done by trucks. The water consumption is low (60 L/cap.day) due to the poor quality of water supply and savings in order to reduce the bayara emptying frequency. There is 0.19 cow per capita, which is the average situation in the villages investigated.

- **Scenario 2 :**

In Scenario 2, a formal sewer network serves the whole village, replacing the bayaras. The construction of a well-functioning sewer network is expected to have a significant impact on the sanitation practices and behaviour of the inhabitants. First of all, the water consumption increases, as the problems of overflowing bayaras and costly emptying do not exist anymore; thus people can be expected to be less conservative with the water they consume. However the low quality of the water supply (frequent interruptions and low pressure) in this scenario may be a limiting factor for the increase of the water consumption. Thus, the water consumption is assumed to rise from 60 to 90 L/cap.day (water consumption in Kawm an Nuss). The two schools and the three mosques also get connected to the new network.

The fraction of greywater ending up in the sanitation system also rises when there is a sewer network. It is assumed that 85% of the households will discharge greywater in the sewer network as shown by the average in other villages with sewer network. A remaining 10% of greywater is still discharged directly into surface water and 5% onto the street.

In this scenario, there is also 0.19 cow per capita, but the percentage of liquid animal manure discharged into the sewer network is higher than into the bayaras: 35% of it is still transported into the field, 10% is discharged into the drain (40% in Scenario 1), while 50% mainly ends up in the network (20% in bayara in Scenario 1), with some inhabitants discharging in the street (about 5%), as shown in Table 19.

Table 18 and Figure 16 compare the amount of septage, respectively sewage, produced and the amounts of N and P in the two scenarios.

Table 18: Volume of septage and sewage and loads and concentrations of N and P in Scenarios 1 and 2 (1000 inhabitants)

	Flow		Nitrogen				Phosphorus			
	Septage	Sewage	Septage	Sewage	Septage	Sewage	Septage	Sewage	Septage	Sewage
	m3/y	m3/y	kg/y	kg/y	mg/L	mg/L	kg/y	kg/y	mg/L	mg/L
Scenario 1	19'411	-	4'314	-	222	-	464	-	23.9	-
Scenario 2	-	32'431	-	6'375	-	197	-	619	-	19.1
Difference (+% in Sc2)		**67.1%**	**-**	**47.8%**		**-11.5%**	**-**	**33.4%**		**-20.2%**

Figure 16: Volume of septage and sewage and loads and concentrations of N and P in Scenarios 1 and 2 (1000 inhabitants)

As illustrated in Table 18 and Figure 16, there are significant differences between the two scenarios. 67% more wastewater is expected in Scenario 2 than in Scenario 1 due to the following reasons: whereas with bayaras most greywater is discharged directly into the environment, when there is a proper sewer network, people prefer the convenience of discharging greywater into it and do not limit their water consumption anymore. The same thing happens with the amounts of liquid manure discharged in the sewer system, thereby increasing the load of nutrients. The increase in greywater and liquid manure discharged in the sanitation system generates an increase of 48% more nitrogen and 33% more phosphorus in Scenario 2.

As for the concentrations, two parameters have a significant influence: the water consumption and the discharge location of the liquid manure. In Scenario 2 more water is used, which contributes to dilute the wastewater and reduce the nutrient concentrations. In the studied case, the construction of a sewer network decreases the concentration of nitrogen and phosphorus measured in sewage (of 11% and 20% respectively) despite the increase of the loads; however, in a village with a high number of cattle, the concentration found in sewage could, theoretically, be higher than in septage (cf. §4.2.2).

4.2.2 Impacts of the implementation of a centralised liquid manure management scheme

The implementation of a centralised liquid manure management can be justified by two reasons: (a) attempt to decrease the loads in the wastewater to be treated, thus reducing the size and the costs of the treatment units; (b) direct reuse of liquid animal manure, either by bringing it directly to the fields or by storing it in a centralised liquid manure storage unit. The liquid manure has a very high concentration of nitrogen, as shown in §4.1.1; it also has high COD loads (cf. Table 10). A centralised liquid manure management unit thus allows to isolate the nitrogen present in liquid manure for potential reuse and remove part of the COD loads from the wastewater.

Scenario 3 and **Scenario 4** are Scenarios 1 and 2 respectively (cf. §4.2.1), with the addition of a centralised liquid manure management. Considering that this centralised management takes the form of a liquid manure storage unit, it is assumed that this unit is well received by the community and located in a convenient place, so that inhabitants are willing to transfer the liquid manure into it.

In the case of Scenario 3 compared to Scenario 1, the percentage of manure disposed in the bayara falls from 20% to 0% and most of the liquid manure is assumed to end up in the storage unit (85%). A remaining 10% of the households is assumed to keep discharging liquid manure directly into the drain and 5% in the street.

In the case of Scenario 4 compared to Scenario 2, the percentage of manure disposed in the sewer network falls from 50% to 0% and most of the liquid manure is assumed to end up in the storage unit (85%), such as above. A remaining 10% of the households is assumed to keep discharging liquid manure directly into the drain and 5% in the street.

Table 19 features the three cases.

Table 19: Disposal location of liquid manure with and without centralised management in a village based on onsite systems

Disposal location of liquid manure	Sanitation system	Canal/Drain	Street	Field	Storage unit
Scenario 1	20%	40%	5%	35%	0%
Scenario 2	50%	10%	5%	35%	0%
Centralised liquid manure management(Scenarios 3 and 4)	0%	10%	5%	0%	85%

Figure 17 and Table 20 compare Scenarios 1 and 3 and show the impact of the implementation of a centralised liquid manure management on the volume and nutrient loads of septage; the volume and loads collected through the centralised management of liquid manure are shown in the third bar in Figure 17. It shows that the unit leads to a reduction of the nitrogen load and concentration in septage of only about 10%, whereas it has almost no impact on the flow and phosphorus concentration of septage. Indeed, the quantity of liquid manure produced is insignificant in comparison to the quantity of domestic wastewater and the phosphorus concentration of liquid manure is relatively low.

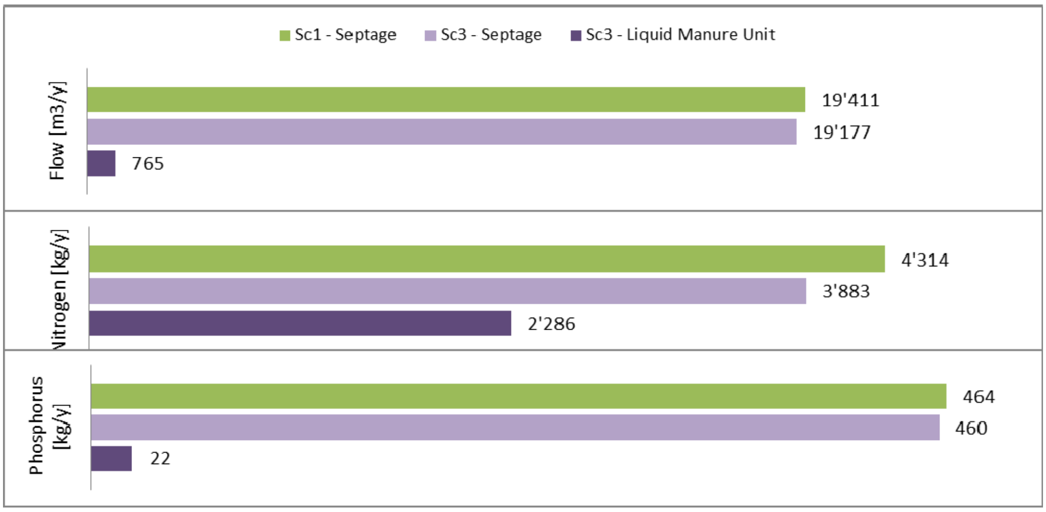


Figure 17: Volume and nutrient loads of liquid manure collected through a centralised management unit; impact on the volume and loads in septage (1000 inhabitants)

Table 20: Comparison of the flow volume, loads and concentrations in septage with and without a centralised liquid manure storage unit (comparison of Scenarios 1 and 3)

	Flow		**Nitrogen**				**Phosphorus**			
	Septage	Liq. Man. unit	Septage		Liq. Manure unit		Septage		Liq. Manure unit	
	m3/y	m3/y	kg/y	mg/L	kg/y	mg/L	kg/y	mg/L	kg/y	mg/L
Scenario 1	19'411	-	4'314	222	-	-	464	23.9	-	-
Scenario 3	19'177	765	3'883	203	2'286	2'988	460	24.0	22	29.0
Difference (+% in Sc3)	**-1.2%**	-	**-10.0%**	**-8.9%**	-	-	**-0.9%**	**0.3%**	-	-

Figure 18 and Table 21 compare Scenarios 2 and 4 and show the impact of the implementation of a centralised liquid manure management on the volume and nutrient loads of sewage; the volume and loads collected through the centralised management of liquid manure are shown in the third bar in Figure 18. It shows that a reduction of the amount and the concentration of nutrients of about 20% can be achieved in sewage. The organic matter in sewage (linked directly to the COD) is reduced of 17% with the unit. However, the construction of the unit has only an insignificant impact on the volume of sewage, as well as for the loads of phosphorus.

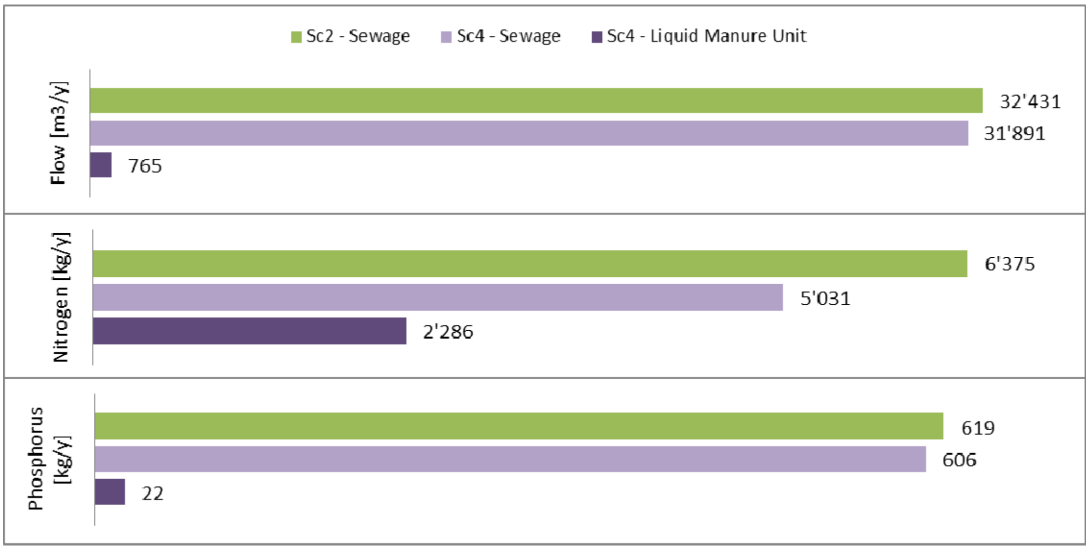


Figure 18: Volume and nutrient loads of liquid manure collected through a centralised management unit; impact on the volume and loads in sewage (1000 inhabitants)

Table 21: Comparison of the flow volume and nutrient loads and concentrations in sewage with and without a centralised liquid manure storage unit (comparison of Scenarios 2 and 4) (1000 inhabitants)

	Flow		Nitrogen				Phosphorus			
	Sewage	Liq. Man. unit	Sewage		Liq. Man. unit		Sewage		Liq. Man. unit	
	m3/y	m3/y	kg/y	mg/L	kg/y	mg/L	kg/y	mg/L	kg/y	mg/L
Scenario 2	32'431	-	6'375	197	-	-	619	19.1	-	-
Scenario 4	31'891	765	5'031	158	2'286	2'988	606	19.0	22	29.0
Difference (+% in Sc4)	**-1.7%**	-	**-21.1%**	**-19.8%**	-	-	**-2.1%**	**-0.4%**	-	-

	COD	
	Sewage	Liq. Manure unit
	mg/L	mg/L
Scenario 2	1'201	-
Scenario 4	1'007	15'178
Difference (+% in Sc4)	**-16.1%**	-

The number of cattle per capita has a significant impact on the liquid storage unit. In both scenarios, where the number of animals per capita amounts to 0.19, 2.3 tons of nitrogen could be isolated each year, which is 2.4 times more than what is brought to field in Scenarios 1 and 2 (0.9 ton). However, some villages do have 2.5 times more animals per capita (0.5 cow/cap). In that specific case the quantity of nitrogen recovered could amount to 6 tons per year, which would be higher than the quantity present in septage (see Figure 19), and more than half of the nitrogen generated in the village (from human beings and animals). On the other hand, in a village with a low number of cattle (0.04 cow/cap) the storage unit will recover less than 1 ton per year and leads to reduce the nitrogen concentration in septage of about 2.5%.

Thus, the number of cattle per inhabitant is a critical decision-making factor for the feasibility of such a unit, as illustrated in Table 22.

Table 22: Volume of liquid manure and amount of nutrients that could be collected in a centralised liquid manure storage unit, as a function of the number of cattle per capita in a village of 1000 inhab.

Nb. of cattle [cow/cap]	**Vol** [m3/y]	**N** [kg/y]	**P** [kg/y]
0.04	161	481	4
0.19	765	2’286	22
0.5	2’013	6’015	59

The number of cattle has also an impact on the potential reduction of nutrients and COD in sewage: in a village with a high number of cattle (0.5 cow/cap), the construction of the unit leads to a reduction of nitrogen and COD of respectively 39% and 33%. In a village with a low number of cattle (0.04 cow/cap), the reduction reach only about 5% and 4% respectively.

Figure 19 shows the impact of a storage unit on the nitrogen load in septage, in the case of 0.5 cow per capita instead of 0.19. The nitrogen load would be 20% lower than without the storage unit.

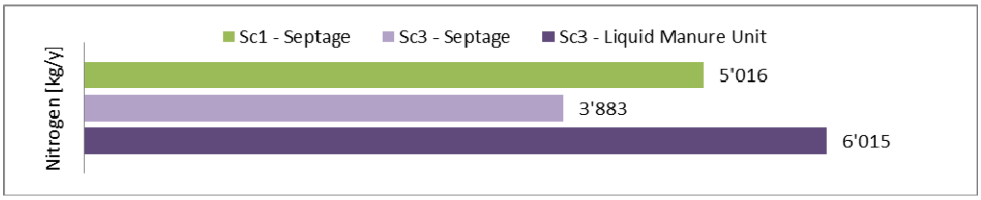


Figure 19: Impact of the construction of a centralised liquid manure management unit on the nitrogen load in septage in the case of a high number of cattle (0.5 cow/cap), and for 1000 inhabitants

The comparison of these scenarios shows that, depending on the number of cattle, the implementation of a liquid management unit leads to a reduction of 5% to 40% of the nitrogen and COD concentration and loads in sewage. In average, it permits a reduction of about 20% in both. However, it has no significant impact on the volume of sewage to be treated and the phosphorus load in sewage.

In villages with bayaras the implementation of a liquid management unit leads to a reduction of 0% to 20% with an average of 10%. The impact on the volume of septage and its phosphorus loads is negligible.

In terms of nutrient recovery, the construction of a manure management unit allows to recover from 0.4 to 6 tons of nitrogen per year with an average of 2.2 tons per year. This flow is highly concentrated (2988 TN mg/L), which eases the nutrient recovery.

4.2.3 Greywater diversion

Greywater is the total volume of water generated from washing food, clothes and dishware, as well as from bathing, but not from toilets. Greywater is hardly contaminated with pathogens and has low organic concentrations. Separating greywater from the blackwater (i.e. the mixture of urine, faeces and flushwater along with anal cleansing water and/or dry cleansing materials) has thus a number of advantages:

(i) Greywater can be discharged without risk into the drains; as it represents more than 60% of the total amount of wastewater (up to 80%, see Table 23), it is a huge amount that does not need to be treated, thus reducing drastically the size and the cost of treatment infrastructure.

(ii) Because it is hardly contaminated and has low organic concentrations, it can be conveyed through low-cost shallow or even small-bore sewer systems; in some cases, the otherwise often dysfunctional “informal” sewer systems built by the villagers could be used for that; alternatively, in case of deep groundwater table and permeable soil, greywater can be infiltrated into the ground through soak pits.

(iii) In villages relying on bayaras, diverting the greywater will dramatically reduce the filling rate of the bayaras and thus the amount of money spent for emptying, which is a major incentive.

(iv) Diversion of the greywater means that only blackwater and liquid animal manure still end up in the bayara, thus forming a very concentrated septage/faecal sludge. This high concentration makes treatment (with anaerobic systems) more cost-effective. In case there are enough animals and space, a biogas digester can be built instead of the bayara and biogas can be produced for domestic use, as happens already in Fayoum (see Figure 20). The digester slurry can be used as a very high value fertiliser.

Table 23: Percentage of the greywater in the total wastewater in different scenarios

	Good water supply	Bad water supply
Onsite sanitation	75%	60%
Sewer network	80%	75%

These considerations lead to different technical scenarios:

a. In case bayaras are present, a simplified sewer system can be constructed to convey the greywater; the blackwater and liquid animal manure continue to be discharged in the bayara. The construction of the network leads to an increase of water consumption.

b. If the villagers already built "informal" sewer networks and still have their bayaras, these sewer networks can be used and the bayaras put again in activity. Where bayaras cannot be used, prefabricated storage tanks could be installed instead.

The implementation of a regular septage collection service based on monthly fees is crucial for the success of both scenarios. Otherwise, people may be tempted to derive blackwater and liquid animal manure as well into the sewer network.

Both situations are identical and have been modelled through Scenario 5, which has the following features:

- **Scenario 5**

Scenario 5 has the same characteristics as Scenario 2 (cf. section 4.2.1), but the sewer network is used only for the transport of the greywater; the blackwater and liquid manure are diverted into an onsite system, either bayara or biogas reactor. In this scenario, 100% of houses are assumed to have their stable and toilets connected to the onsite system. The storage tank are assumed to be sealed (no infiltration) and fully emptied at each emptying event.

Figure 20: A household biogas reactor in Fayoum

Table 24 and Figure 21 compare the flow volumes and nutrient amounts in onsite systems with and without greywater diversion (comparison of Scenarios 1 and 5). It shows that the total volume (greywater + septage) increases because of the higher water consumption. However, the quantity of septage decreases considerably. The concentration of nutrients in septage increases significantly, making nutrient recovery much easier. The construction of the network leads to more liquid manure ending up in the bayaras as before.

Table 24: Comparison of the flow volumes and nutrient amounts in onsite systems with and without a sewer system for greywater diversion (comparison of Scenarios 1 and 5)

	Flow		**Nitrogen**				**Phosphorus**			
	Sewage	Septage	Sewage		Septage		Sewage		Septage	
	m3/y	m3/y	kg/y	mg/L	kg/y	mg/L	kg/y	mg/L	kg/y	mg/L
Scenario 1	-	19'411	-	-	4'314	222	-	-	464	23.9
Scenario 5	22'923	8'373	651	28	7'069	844	168	7.3	464	55.4
Difference (+% in Sc5)	-	**-56.9%**	**-**	**-**	**63.9%**	**279.9%**	**-**	**-**	**-0.1%**	**131.7%**

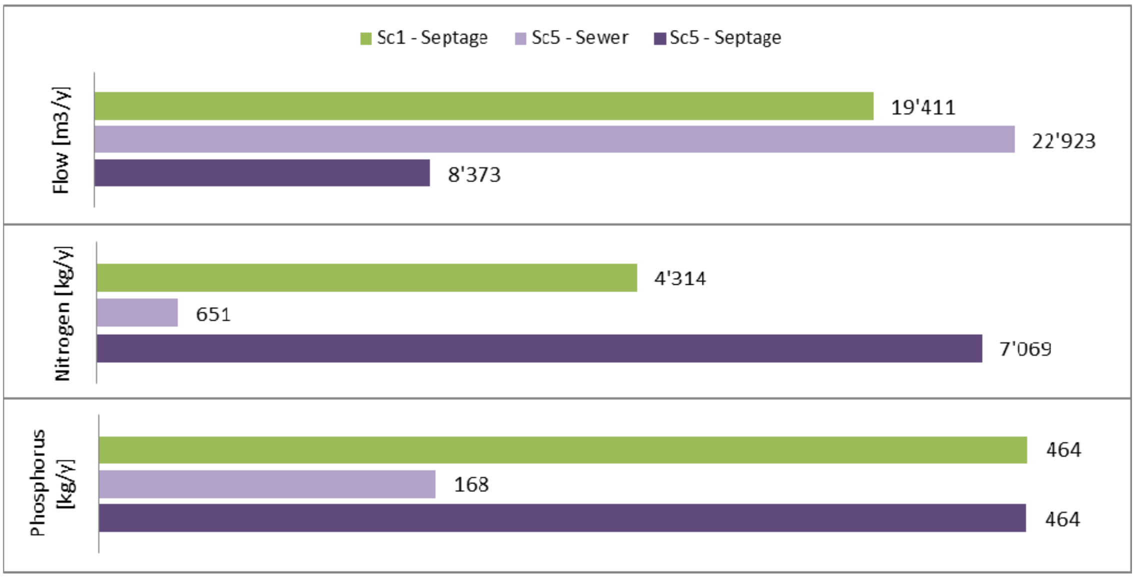


Figure 21: Comparison of the flow volumes and nutrient amounts in onsite systems with and without a sewer system for greywater diversion (comparison of Scenarios 1 and 5)

Table 25 and Figure 22 compare the flow volume and nutrient amounts in sewage, with and without blackwater and liquid manure (comparison of Scenarios 2 and 5). In Scenario 2, the sewer system conveys all flows; in Scenario 5, the sewer system conveys only greywater and the blackwater and liquid manure are stored in an onsite system. This comparison allows to quantify the effect of such a measure on the volume and loads to treat, provided that, in Scenario 5, only the septage would be treated, and not the sewage anymore, which is composed in that case exclusively of greywater.

Table 25: Comparison of the flow volume and nutrient amounts in sewage, with and without blackwater and liquid manure (comparison of Scenarios 2 and 5)

	Flow		Nitrogen				Phosphorus			
	Sewage	Septage	Sewage		Septage		Sewage		Septage	
	m3/y	m3/y	kg/y	mg/L	kg/y	mg/L	kg/y	mg/L	kg/y	mg/L
Scenario 2	32'431	-	6'375	197	-	-	619	19.1	-	-
Scenario 5	22'923	8'373	651	28	7'069	844	168	7.3	464	55.4
Difference (+% in Sc5)	**-29.3%**	-	**-89.8%**	**-85.6%**	-	-	**-72.8%**	**-61.5%**	-	-

	COD	
	Sewage	Septage
	mg/L	mg/L
Scenario 2	1'201	-
Scenario 5	700	3'549
Difference (+% in Sc5)	**-41.7%**	-

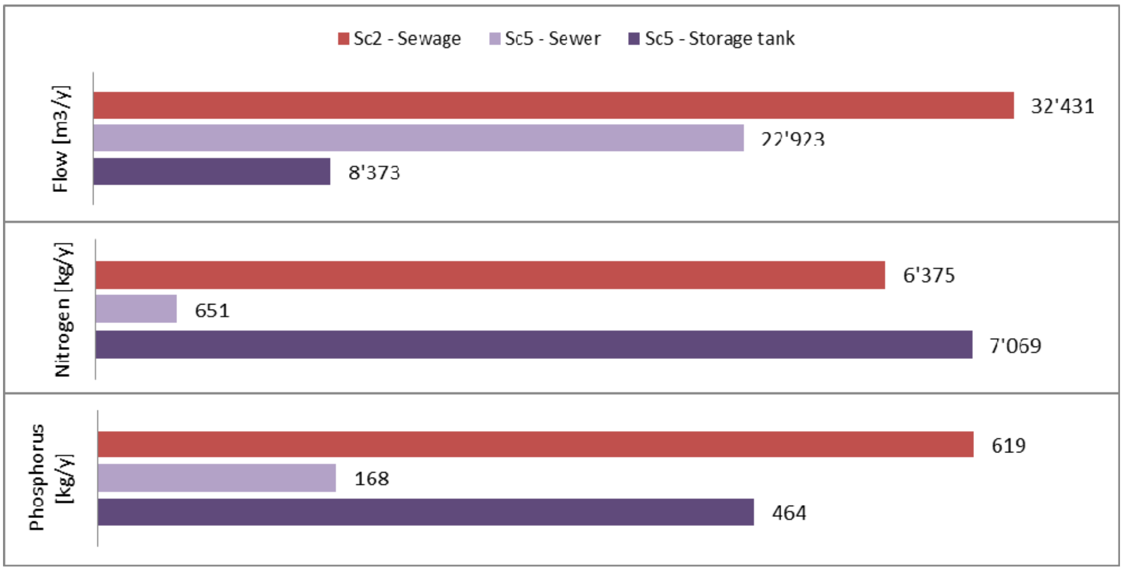


Figure 22: Comparison of the flow volume and nutrient amounts in sewage, with and without blackwater and liquid manure (comparison of Scenarios 2 and 5)

The use of the sewer network exclusively for greywater has several impacts:

- It permits to reduce of approximately 57% the flow volume ending up in the on-site sanitation systems in the case of a village equipped with bayaras.
- What remains in the on-site sanitation system is then highly concentrated (TN: 850 mg/L, TP: 55 mg/L and COD: 3000-4000 mg/L). This is due to the fact that only liquid animal manure and black water end up in the tanks/bayaras.

- In the case of a village which already had as sewer network, the sewage is much less concentrated than before, with a reduction of 42% in COD (reduced to 700 mg/L), a reduction of 85% in nitrogen concentration and 61% in phosphorus concentration (reduced to TN:28 mg/L and TP: 7 mg/L), and a reduction of 90% of the nitrogen loads. As for the flow volume, it is reduced of about 29%.

These conclusions would be the same for a village with a better water supply, the only difference would be lower nutrient and COD concentrations in the greywater.

A village with a higher number of cattle would allow to collect more nutrients in the onsite unit but would not impact the concentrations in the sewer network.

4.2.4 Value range of flow volume and nutrient loads in the different scenarios

The scenarios described in this chapter are based on average values. In what follows, the minimum and maximum values for each parameter are considered in order to quantify the minimum and maximum flow volume and nutrient loads for each scenario. Table 26 shows the different values for each of the most sensitive parameters.

Table 26: Minimum and maximum values chosen for the different scenarios

	Min	**Typical**	**Max**
Water consumption [L/cap.day]			
- Village with bayara	60	**85**	90
- Village with sewer network	90	**100**	110
Nb. of animals [cow/cap]	0.04	**0.19**	0.5
% of liquid manure discharged in sanitation system: [%]			
- Sc.1: Village with bayara	10%	**20%**	40%
- Sc.2: Village with sewer network	10%	**50%**	80%
- Sc.3-4: Village with liq. manure storage unit	0	**0%**	30%
- Sc.5: Village with greywater separation	90%	**100%**	
% of liquid manure discharged in liquid manure storage unit (Sc.3-4): [%]	50%	**85%**	90%
% of greywater discharged in sanitation system [%]			
- Village with bayara	40%	**50%**	60%
- Village with sewer network	80%	**90%**	100%
% of blackwater and liquid manure discharged in the onsite sanitation system in the greywater separation scenario [%]	90%	**100%**	

The scenarios were computed in the MFA model with all minimum, respectively maximum values. Figure 23 presents the flow volume and nutrient loads for each key flow for treatment and reuse, with the maximum and minimum value indicated with an interval. The detailed results can be found in APPENDIX 5.

Scenario 2 (everything into the sewer network) leads to the highest amount of nutrients at the outlet, as most of the greywater, blackwater and liquid animal manure are discharged into the network. However, the high volume of water discharged into the sewer networks dilute the nutrients and lead to low concentrations (TN 175 mg/L and TP 17 mg/L). This means that, even if the amount is the highest, it is much more difficult to recover than in the liquid manure storage unit or greywater diversion scenarios. Table 27 shows how similar the concentrations of nitrogen and phosphorus are in septage and sewage, which results from the higher loads of nutrients in sewage being compensated by the higher dilution.

Scenario 3 shows how large an amount of nitrogen can be isolated with the construction of a centralised liquid manure management, in a concentrated product (average TN in liquid manure is about 2988 mg/L). If the number of cows per household is high, the amount can be as high as in septage; it means that, potentially, half of the nitrogen can be recovered with such a measure. It has to be noticed also that management measures increase the amounts to be recovered because volume that would else not end up in the sanitation system are then diverted to a centralised location (i.e. the sum of nitrogen loads in Scenario 3 is higher than in Scenario 1). Because only about 20% of liquid manure end up in the bayaras in Scenario 1 (existing situation), the nitrogen loads and concentrations are not very different in the septage for both scenarios. The implementation of a centralised liquid manure management scheme has also little impact on the flow volume and phosphorus loads of the septage in both scenarios.

The diversion of greywater (Scenario 5) allows the collection of the highest nitrogen loads of all scenarios in the onsite systems, in a form that is 5 times more concentrated than in septage and sewage (TN 844 mg/L and TP 55 mg/L – see Table 27). The phosphorus load is similar to the one in the other scenarios based on onsite systems. A significant amount, about 25% of the total, is however diverted together with the greywater.

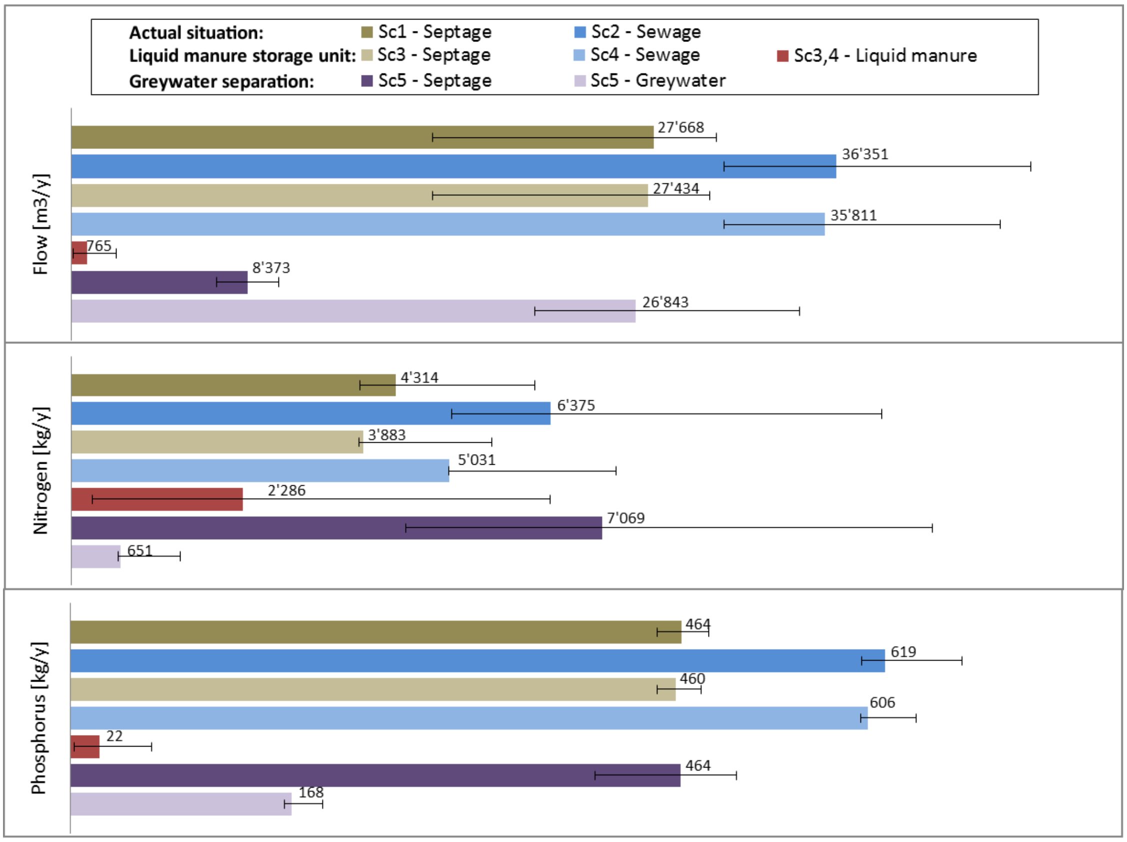


Figure 23: Flow and nutrient loads in the different scenarios

Table 27: Average nutrient concentrations in the different scenarios

Average concentrations	Nitrogen [mg/L]	Phosphorus [mg/L]
Scenario 1 - Septage	156	16.8
Scenario 2 - Sewage	175	17.0
Scenario 3 - Septage (with a liquid manure storage unit)	142	16.8
Scenario 4 - Sewage (with a liquid manure storage unit)	140	16.9
Liquid manure storage unit	2988	29.0
Scenario 5 - Blackwater and liquid manure (greywater diversion)	844	55.4
Scenario 5 - Greywater	24	6.3

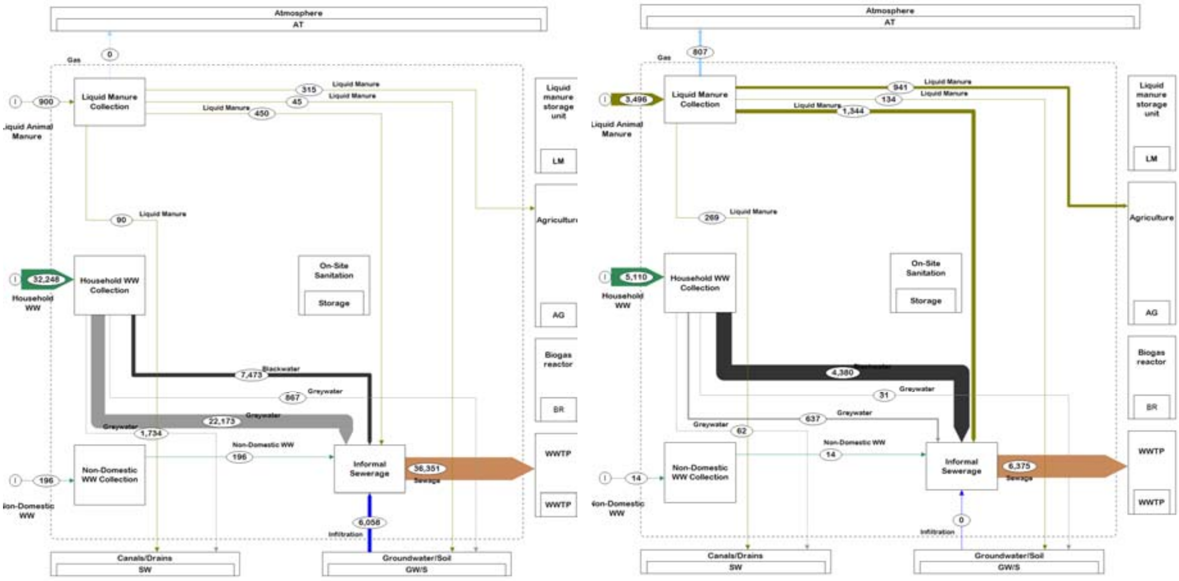


Figure 24: Sankey diagrams of scenario 2 – Wastewater [m3/an] (left) and nitrogen flow [kg/y] (right) in a typical village of 1000 inhabitants equipped with a sewer network connected to a wastewater treatment plant.

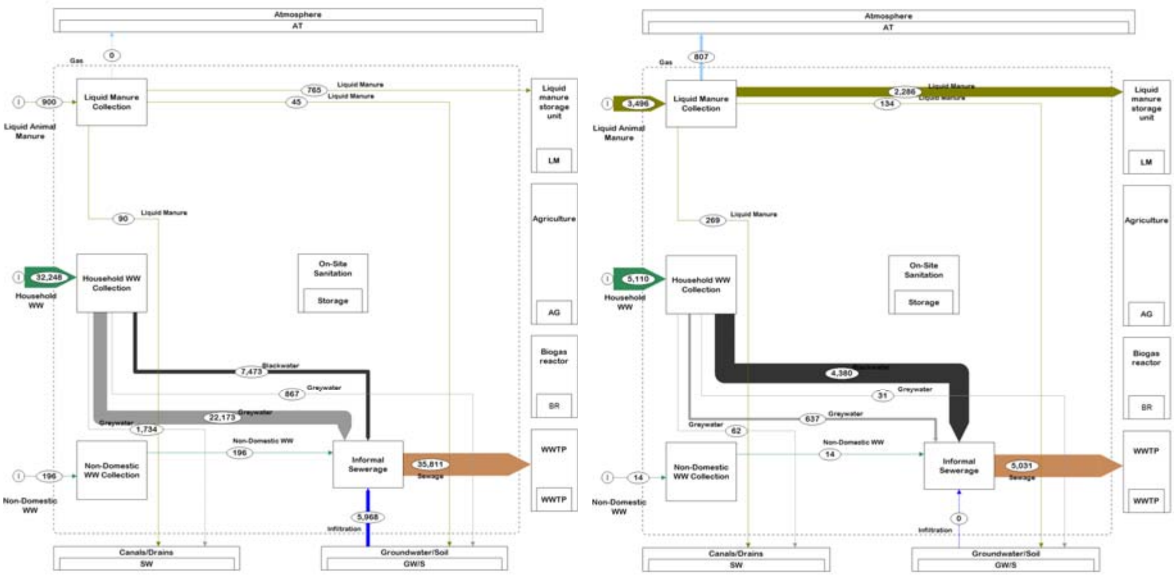


Figure 25: Sankey diagrams of scenario 4 - Wastewater[m3/an] (left) and nitrogen flow [kg/y] (right) in a typical village of 1000 inhabitants equipped with a sewer network connected to a wastewater treatment plant and having a liquid manure management unit.

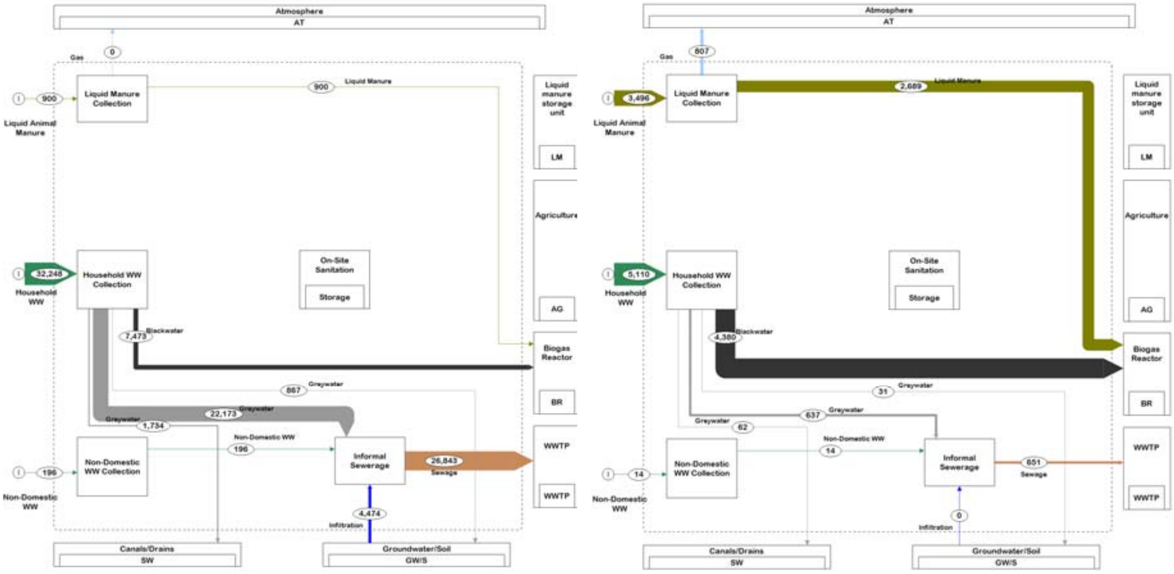


Figure 26: Sankey diagrams of scenario 5 – Wastewater [m3/an] (left) and nitrogen flow [kg/y] (right) in a typical village of 1000 inhabitants equipped with a sewer network connected to a wastewater treatment plant and separating blackwater from greywater

5 Conclusions and further developments

Modelling small-scale sanitation in Nile delta villages is not an easy task. It requested a very important amount of field work, consisting mainly of household surveys and sampling campaigns, in order to provide local values for the different flows, necessary for a proper *Material Flow Analysis*. The baseline data created during this process is available in the ESRISS Report *Baseline Data and Current Practices*. The model could be built based on this data baseline and extensive literature review. It is available in Excel format. It was only when the model was calibrated and validated that scenarios could be tested.

The model allows the estimation and illustration of wastewater, nitrogen and phosphorus flows in small villages up to 2,000 inhabitants in the Nile delta, as well as the comparison of different scenarios. It gives a clear understanding of the most significant flows and most important parameters influencing the loads and concentrations of nutrients. From there, it is possible to optimise the management of these flows in a nutrient-recovery perspective and quantify the benefits of each scenario.

The MFA methodology alone does not allow to provide insights into all the design parameters necessary for the design of treatment units. In order to do that, there is a need for a combined approach, mixing results from the MFA and baseline data. The ESRISS team developed such a tool as an extension of this study. This tool allows to predict village-specific design parameters (BOD, COD, TS, TSS, TN, TP) based on a minimal field data collection, without taking any samples. Based in Excel, the tool adds a user interface to the model described here, which allows the user to enter his data, cross-check it and get the estimated design parameters with accuracy range. The tool can be downloaded at www.sandec.ch/esriss ,as well as the other documents mentioned above.

Nutrient reuse does not stop with the flows going out from the village boundary, as defined in our MFA model. It is actually where it really starts. The nutrients still have a way to go before reaching the fields and, in-between, many losses have to be expected. Optimising nutrient reuse means also selecting appropriate treatment options and field application methods, which conserve the nutrients and make them bioavailable to the plants. This part, however, is out of the scope of this report and is well described in the literature.

The study showed that nutrient reuse is something very important for the Egyptian farmers (see *Baseline Data and Current Practices* Report), at a time when the price of chemical fertilisers is raising and the latter become as much a pollution as a help. However, so far, the farmers only use the solid part of animal manure and, sometimes, dry sludge from the WWTPs. There is a big margin for improvement, which a well-thought nutrient management at village-level can highly support. It however requests a strong political will and awareness to sustain the efforts and behaviour changes that it implies.

5.1 Main observations from the material flow analysis

The analysis of the situation in the selected villages (§ 3.4) and the elaboration of scenarios (see chapter 4) provide a good understanding of the different flows and parameters influencing them. The main observations are:

- **The blackwater from households is by far the main contributor of nutrients**: 66% of the nitrogen and 71% of phosphorus in average in a typical village with sewer network
- **Greywater is the main contribution in terms of liquid volume**. The villages consume between 60 to 110L/cap/day of drinking water and most of his water is discharged as greywater (70% to 82%, which represents 65% of the sewage volume). In villages having onsite sanitation systems, people tend to reduce the amount of greywater discharged into the sanitation system by dumping it in the drain/canal or street (cf. also the *Baseline Data* Report), the amount of greywater contributing to septage drop down to around 50%.
- **The nutrient loads of greywater are low but non-negligible** (~10% of total sewage/septage)
- **The liquid animal manure production has a negligible impact in terms of volume and phosphorus load but can contribute considerably to the nitrogen load**, which can be higher than the amount produced by households when the number of cattle is high, the equilibrium point lying at 0.24 cows per inhabitants. The liquid manure is most of the time collected in the morning from a collection hole in the stable and discharged into a drain/canal, street, field or sanitation system. No consistent generalisation could be drawn about the different discharge locations in the different villages investigated; because this flow can have a big impact, it needs to be estimated in each village on a case-by-case basis.
- **The phosphorus concentration in liquid animal manure is low and does almost not contribute to total phosphorus in the system**: 4% in a village with an average number of animals per capita, 10% if the number of animals is high.
- **Non-domestic buildings, such as mosques, schools and health centres do not have a significant contribution** either in term of flow as in term of nutrients (both less than 1% in the total wastewater).
- **Settling occurs in the sewer network and has an impact on the measured concentrations:** settling leads to a considerable reduction of the amount of phosphorus measured in sewage (30% reduction according to the model). These 30% should reappear during the unclogging events, when most of the settled sludge is washed out. More samples would be needed in order to precise this process. The same process should also impact the concentration of TSS. It seems however that settling has less impact on nitrogen concentrations, probably because most nitrogen is in a dissolved form.

- **The infiltration/exfiltration and storage in bayaras are still unclear:** so far, their impact is based on assumptions and still need to be confirmed. However the storage rate of nutrients seems to amount up to 40%. If a similar storage rate is confirmed in other villages, this sludge could be a key product for nutrient recovery.

5.2 Conclusions about nutrient management measures at village-level

5.2.1 Source separation measures

It is clear that in a nutrient-reuse perspective, source separation should be favoured. The study shows that separating the blackwater and liquid manure from the greywater leads to a very nutrient-rich (both in nitrogen and phosphorus) and concentrated product in the onsite systems, which can be either treated offsite or digested onsite in a biogas reactor. In some cases, only a few adjustments to the existing situation are needed. The optimal situation for this scenario, and also the situation where it is the most cost-effective, is a village of low-density, with spaces next to the buildings and a higher number of cows per households (at least 3 cows per building if biogas is to be produced). In case of domestic biogas production, the households would add the solid animal manure into the onsite system which would increase the nutrient content even more. This scenario is being currently developed in Fayoum (cf. factsheet “on-site sanitation systems – Fayoum and Upper Egypt” in the ESRISS *Factsheet Report*). The digested and stabilised slurry can be used directly on the field without further treatment, in the same way as solid animal manure. This is not the case for septage, which needs a dedicated treatment plant.

The other alternative for source separation is the centralised management of liquid manure. The study shows that very high amounts of nitrogen can be collected this way, equivalent to about one third of the amount present in sewage and half of the amount present in septage. What is more, it builds upon an existing practice, as most farmers use to collect the liquid manure separately. Liquid animal manure, after being stored for a given period, can be applied on the field diluted with irrigation water. Regarding the implementation of such an alternative, it is of utmost importance to have a liquid manure collection scheme, as villagers cannot be expected to transport liquid manure on more than a few dozen meters.

Many Egyptian farmers already use right measures at stable-level to optimise nutrient reuse. First, of course, they bring all the solid manure to their fields. Besides, many of them also use ample bedding on the stable floor (straw, earth) to absorb liquid manure, which is then converted into a solid product which can be transported with the solid manure itself. Besides, they keep livestock often directly on the fields.

The feasibility and costs of the source separation measures should be studied in greater details.

5.2.2 Measures at the treatment stage

If source separation is not possible, nutrient management is shifted at the offsite treatment stage. It is very difficult and expensive to recover nutrients from wastewater. However, what can be done is to remove the undesirable components of wastewater while conserving the nutrients in the perspective of a direct reuse of the effluent for irrigation. For this purpose, it is recommended to use anaerobic treatment systems such as anaerobic baffled reactors and anaerobic filters. Effluent from anaerobic treatment will have comparatively high nutrient content. Nitrogen content is mainly in the form of ammonium (NH4); the ammonium will be oxidized into nitrate by nitrifying bacteria in the soil and then become bioavailable to plants. Therefore the anaerobically treated effluent is ready to be used for irrigational purposes. As the effluent then still contains pathogen, it has to be used with appropriate crops, according to the Code of Practice for Reuse.

An obstacle for direct reuse of treated effluent in the Nile delta is the lack of space for effluent storage and dedicated agricultural land for reuse. Indeed, a WWTP produces effluent 24/7, whereas farmers need irrigation water at specific times. Thus, storage is necessary, which implies extra costs and space for the storage infrastructure. In some cases, nutrients can be reused indirectly for fish farming in ponds: the nutrients are consumed by algae which are then consumed by the fish. This is already practiced in some parts of the Nile delta and does not request extra space if fish ponds are already present.

5.2.3 Measures for the reuse of sludge

The study shows that a big amount of sludge (around 30%) is stored in the bayaras: a lot of nutrients accumulate in the sludge, which has settled and is not removed during emptying. Proper emptying followed by faecal sludge treatment would allow the production of safe dried sludge, which, besides being rich in nutrients, is also rich in organic matter, useful for soil structure. It has however to be mentioned that, while the product is still rich in nutrients, many nutrients are lost during the sludge treatment process.

In general, the reuse of sludge from wastewater treatment plants (WWTP) is recommended: building treatment units, either for sewage sludge or for septage, is an important step towards safe reuse. The sludge, once properly dehydrated and stored, can be spread on the fields, and the treated effluent can be used for irrigation. However, to have a good quality sludge, not contaminated by heavy metals and other contaminants, it is important not to mix it with industrial wastewater.

This advocates for decentralised treatment of wastewater and sludge, where the wastewater remains domestic and where the treated effluent and sludge can be reused directly in the surrounding agricultural land.

5.2.4 Equivalence with chemical fertilisers

The scenarios analysed in this report provides numbers about nitrogen and phosphorus loads and concentrations. A legitimate question is how much chemical fertiliser these loads could replace in agriculture, and thus, how much money could be saved by reusing nutrients from sanitation products.

The main chemical fertilisers used in agriculture to provide nitrogen are nitrate and urea. Urea contains 45% of nitrogen and ammonium nitrate 35% of nitrogen (% of total mass). Table 28 features the prices of the main chemical fertilisers and the average consumption as expressed by the farmers during the household surveys. It shows a large use of mineral fertilisers (around 500 kg of nitrogen per hectare).

Table 28: Average prices and consumption of the main chemical fertilisers

Fertiliser	Average price in the Agricultural Assoc. (EGP per 50 kg bag in 2013)	Average price on the market (EGP per 50 kg bag in 2013)	Average consumption (number of bags per year)	N-Content (% of total mass)
Nitrate	73	155	11	34%
Urea	75	151	9	45%
Potassium	63	178	ND	-
Phosphate	48	52	8	-

These numbers allow to make a first estimation of how much chemical fertiliser could be saved. For example, through the implementation of a centralised liquid manure storage unit, 607 kg of nitrogen per 100 inhabitants could be saved in Haderi. This represents 30-50 bags of nitrogen as mineral fertiliser (mineral fertiliser contains 20 to 45% of nitrogen).

Urine is as efficient as mineral fertilisers. In some cases it even leads to better yields than mineral fertilisers (Richert et al., 2010).

5.3 Further development of the model

5.3.1 Model simplification

The MFA model presented in this report encompasses a lot of parameters. This complexity makes its use by local practitioners difficult. In order to simplify the use of the model, the number of parameters to enter must be reduced to a minimum. To this aim, the parameters that are constant under certain conditions (i.e. which can be anticipated without any measurements) must be identified. Then, the practitioner is left with only a limited number of data to collect with quick field surveys in order to run the model on a site-specific basis.

Parameters which can be considered as constant were identified based on literature review, results from the field surveys, interviews, observation, sampling campaigns and a sensitivity analysis, as described in Section 2. The most important constant parameters are:

- The concentrations of nutrients, COD and TSS in the flows entering the system, i.e. blackwater, greywater and liquid manure.
- The volume of blackwater
- The proportion of greywater produced in the bathrooms in comparison to the total amount of greywater.
- Quantity of liquid manure produced per cow and the time that cattle spend in the fields.

The constant parameters do not need to be measured again and they are directly derived from the baseline data (cf. *Baseline Data* Report). The most sensitive of the variable parameters are those which need to be studied on a site-specific basis, namely:

1. Number of inhabitants
2. Type of sanitation system
3. Water consumption
4. Liquid animal manure
5. Groundwater interaction
6. Discharge location of greywater

This simplification work led to the development of a tool combining the MFA model and the baseline data (please refer to the separate booklet entitled “*A Model-Based Tool to Quantify and Characterise Wastewater in Small Nile Delta Settlements*”, for download at www.sandec.ch/esriss). The purpose of the tool is to help designers and consultants to estimate quickly (max. 3 days) the quantity and characteristics of the raw wastewater to be treated, on a site-specific basis, in settlements of up to 5,000 inhabitants, without industry, served or to be served by a sewer network. It is a planning tool which permits to estimate the wastewater quantity and characteristics both in the existing situation and in future scenarios, for example in order to anticipate the sewage characteristics in villages not yet served by sewer networks.

5.3.2 Further research

Above all, the model needs to be applied to more villages in the Nile Delta in order to provide more evidence of its validity and further calibrate it if needed. So far, it was validated on six villages with sewers and one with onsite sanitation systems.

The flow dynamic throughout the day and throughout the year should be further investigated, for the former with 24h-sampling campaigns and for the latter with sampling campaigns both in summer and winter. So far, the model does not reflect seasonal variations.

The model is based on many assumptions, some of which are still too empirical. In particular:

- The interaction of groundwater (infiltration/seepage) with the sewers and bayaras, especially as a function of its depth.
- Sludge storage in the bayaras
- The loss of nitrogen in the bayaras might not be null as assumed
- The estimation of nutrients in human excreta is so far only theoretical and is not specific to the Egyptian context.
- The model estimates that all the excreta of the inhabitants are produced within the village. This may vary depending on the main activity of villagers
- More samples could also be taken during the night in order to estimated infiltration into the sewer system and during a full day in order to better estimate the impact of the settling into the sewer network.

Another further development concerns the estimation of septage/faecal sludge characteristics. Due to the high variability of septage, the numerous factors influencing sludge storage and digestion in the bayaras and the limited data baseline, it could not be integrated within this model. However, with the rise of the concept of septage/faecal sludge treatment plant, which would contribute significantly to pollution reduction with a lower investment from the government, a better characterisation and quantification of the sludge will become crucial.

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