

## Centralised or Decentralised Sanitation in Swedish Summerhouse Areas in Transition to Permanent Living?

E. Kärrman\*, Å. Erlandsson\*, D. Hellström\*\*, B. Björlenius\*\*, P. Tidåker\*\*\*

\* Ecoloop AB, Brännkyrkagatan 35, Stockholm, SE-118 22 Stockholm, Sweden  
(E-mail: erik.karrman@ecoloop.se)

\*\* Stockholm Vatten AB, SE-106 36 Stockholm, Sweden  
(E-mail: daniel.hellstrom@stockholmvatten.se)

\*\*\* Department of Biometry and Engineering, Swedish University of Agricultural Sciences,  
Box 7032, SE-750 07 Uppsala, Sweden (E-mail: pernilla.tidaker@bt.slu.se)

### Abstract

The standard of the wastewater management is high in Sweden. Around 90 % of the population is connected to central wastewater treatment plants with high requirements of nutrients removal. Still the problem with algae blooms in the Baltic Sea exists. The aim with VeVa project was to develop a simple and user-friendly Excel-based model to support environmental decisions of how to select wastewater systems for housing areas where no central sewer system exists. The VeVa model deals with two types of environmental issues: substance flow analysis and energy analysis. Six system structures were studied for the transition area Lillängsdal in Värmdö municipality sorted in three categories: 1) On-site systems for single households, 2) Local collective systems 3) Connection to central systems. All studied system structures except for a Sand filter system fulfilled the goals of reducing phosphorus and BOD<sub>7</sub> according to Swedish guidelines for on-site systems in sensitive areas. All studied systems except for the Sand filter system has the potential to fulfil the Swedish National Environmental goal to recycle 60 % phosphorus to productive land. The systems with Central wastewater treatment plant and Local wastewater treatment are the most energy efficient alternatives that also fulfilling requirements of discharges and environmental goals regarding phosphorus recycling

### Keywords

Environmental systems analysis; on-site systems; URWARE; wastewater management; wastewater treatment

## INTRODUCTION

The standard of municipal wastewater management is high in Sweden. Around 90 % of the population is connected to central wastewater treatment plants with high degree of removal of nutrients. Still, problems with algae blooms in the Baltic Sea occur in the summer, which call for further actions. After a period of improving the removal efficiency in centralised wastewater treatment plants, the focus is now on the remaining 10 % of the households with on-site wastewater treatment. The level of treatment in these systems is often inadequate and the Swedish government considers giving subsidies to house owners in order to improve the treatment. The situation is immense in the Stockholm region where 90 000 households have single systems and at least 30 000 are insufficient. Karlsson (2005) concluded that these households cause larger phosphorus flows to the Baltic Sea than the 1.8 million people in the same region which are connected to four advanced large scale treatment plants. A tendency is that the population are growing fast in areas with summer-houses in municipalities with commuting distance to Stockholm. These summer-houses normally have simple water and sanitation systems only designed for summer use. It is a challenge for these municipalities to be able to serve these people with sufficient water supply and proper sanitation.

One municipality within the Stockholm County is Värmdö. Värmdö has 40 000 inhabitants, of which around 40 % has on-site wastewater systems. Including also summer houses, there are 20 000

on-site wastewater systems in Värmdö, of which at least two third have insufficient treatment. These on-site systems shall be connected to central systems according to the Värmdö's city plan. The problem is however that this sewer system takes more than 30 year to complete. It is also not ensured whether or not all peripheral areas with on-site systems could be connected to the central systems.

The Swedish research programme Sustainable Urban Water Management developed tools for planning of sustainable urban water and sanitation (Malmqvist *et al* 2006). One of the tools, URWARE, is used for environmental systems analysis for a given urban area (Jeppsson *et al* 2005). A following project was initiated to develop a new tool - the VeVa model - based on knowledge from URWARE for selection of appropriate solutions in former summerhouse areas. This paper presents the VeVa model applied to Lillängsdal – a case study area in the municipality of Värmdö.

### THE VEVA MODEL

The aim with VeVa project was to develop a simple and user-friendly Excel-based model to support environmental decisions of how to select wastewater systems for housing areas where no central sewer system exists. The VeVa model deals with two types of environmental issues: substance flow analysis and energy analysis. The substance flow analysis includes the fluxes of phosphorus, nitrogen, BOD<sub>7</sub> and cadmium and is focused on the discharge from the treatment systems to recipient. (Leakage from agricultural land not included). These parameters were selected based on the wastewater sector relative importance to various environmental issues (Kärman and Jönsson, 2001). For the energy analysis both construction and operation phases are included. Schematic flow-chart of the substance flow analysis and the energy analysis is given in Figure 1.

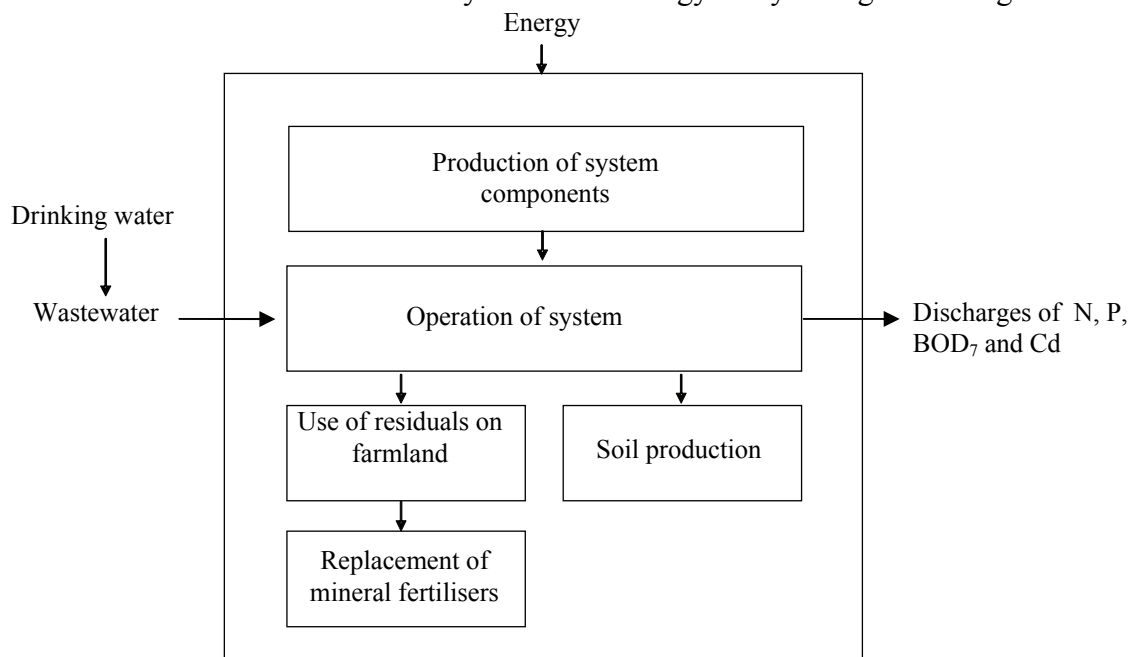


Figure 1. Flow-chart for analysis with the VeVa-model

The VeVa model consists of substance flow models of components in wastewater systems, such as pre-treatment tanks, filter bed, small wastewater treatment plants etc. These sub-models are linked together to form complete systems structures for management of wastewater. Some of the models are taken from the URWARE model (Jeppsson *et al* 2005; Löfqvist 2006), while other models are designed for the first time in the VeVa-model. These models are described in detail by Erlandsson (2007) and Kärman *et al* (2007). All modelling results are given in annual average values.

The characterisation of the input flow of wastewater taken from Jönsson *et al* (2005) is given in Table 1.

Table 1. Substance flows of COD, N<sub>tot</sub>, P<sub>tot</sub> and Cd in household wastewater and in the fractions urine, faeces and toilet paper and greywater (Jönsson *et al* 2005).

Parameter	Urine	Faeces and toilet paper	Greywater	Household wastewater
COD (kg/pers,yr)	3	23	23	49
N <sub>tot</sub> (kg/pers,yr)	4.0	0.5	0.6	5.1
P <sub>tot</sub> (kg/pers, yr)	0.33	0.18	0.25	0.76
Cd (mg/pers,yr)	0	4	18	22

### CASE STUDY AREA

The case study area is Lillängsdal, currently an area in transition from a holiday camp to permanent living. An inventory from 2003 showed that the area consisted of 95 summer-houses, 22 houses for permanent living and 9 not yet settled lots. An investigation made by the environmental department of Värmdö showed that 80 % of the houses had closed collection tanks, 7 % had conventional systems with pre-treatment tank followed by a sand filter and 13 % had inferior systems (e.g. only pre-treatment tanks).

### SYSTEM STRUCTURES

Six system structures were studied for the transition area Lillängsdal in Värmdö municipality sorted in three categories: 1) On-site systems for single households, 2) Local collective systems 3) Connection to central systems. The six systems are given in Table 2. More details about the systems are given by Erlandsson (2007). Alternative 5 is also more detailed described by Löfqvist (2006).

Table 2. Systems structures of studied systems

Alternative	System	Category
1	Sand filter systems	Single system
2	Filter bed system (expanded clay)	Single system
3	Urine separation + filter bed	Single system
4	Local wastewater treatment plant	Local collective system
5	Aerobic membrane bioreactor + reverse osmosis	Local collective system
6	Connection to large scale wastewater treatment plant	Central system

### Sand filter system

The sand filter system is a conventional solution for one single household according to previous Swedish standards. Wastewater is pumped or transported by gravity through a pre-treatment tank followed by the sand filter. The sand filter is an excellent system to reduce organic matter (90 % removal of BOD<sub>7</sub> is expected) but only moderate for reducing nitrogen, phosphorus and Cadmium. In the study 50 % removal of Nitrogen and Phosphorus is assumed and 30 % for Cadmium. Sludge from pre-treatment tanks is transported to a central wastewater treatment plant to be mixed with the municipal sludge and utilised as soil improver on farmlands. When the sand filter is saturated, the filter sand is assumed to be used as a technical soil in ground constructions.

### **Filter bed system (expanded clay)**

This system is similar to the sand filter system except for the use of expanded clay as the filter media in order to remove phosphorus to a higher degree. This filter media is also expected, when it is saturated, to be used as a fertiliser in agriculture. The expanded clay filter reduces organic matter to the same high degree as the sand filter (90 % removal of BOD<sub>7</sub>). It is also excellent in phosphorus removal (96 %) while moderate in treatment of nitrogen (50 %). The filter bed is assumed to reduce cadmium to the same degree as the Sand filter. Sludge from pre-treatment tanks is expected to be transported to a central wastewater treatment plant to be mixed with the municipal sludge and utilised as soil improver on farmlands.

### **Urine separation + filter bed (expanded clay)**

In this system urine separation toilets are introduced and the urine is stored and used as a fertiliser in agriculture. The filter bed with expanded clay is smaller than the Filter bed system dependant on the lower phosphorus content in wastewater without urine. In all other part this system is similar to the Filter bed system.

### **Local wastewater treatment plant**

The collective system with a local treatment plant is a Sequencing Batch Reactor (SBR) including mechanical, biological and chemical treatment. Used figures for the reduction are 93 % for phosphorus, 40 % for nitrogen, 95 % for BOD<sub>7</sub> and 91 % for cadmium. The sludge is transported to a central wastewater treatment plant where the sludge is mixed with municipal sludge and used as a fertiliser in agriculture.

### **Aerobic membrane bioreactor + reverse osmosis**

The combination of aerobic membrane bioreactor and reverse osmosis treats the wastewater according to high-tech technology. The process line consists of a drumfilter for suspended solid removal, an aerobic membrane bio reactor oxidizing BOD<sub>7</sub> and nitrogen (nitrification), and a reversed osmosis (RO) filter for nutrient recovery and re-use. The sludge from both drumfilter and membrane are further treated by thickening, anaerobic digestion and dewatering processes. Rejected water is led from thickener and digester to the influent of the bio reactor and the rotary drum filter, respectively. As the main reduction of phosphorus occurs in the reversed osmosis filter, the generated concentrate, after stabilisation in storage, is used as fertiliser for agricultural purposes. The removal efficiency of the different system components are given in Table 3.

Table 3. Removal efficiency in the components of the Aerobic membrane bioreactor + reverse osmosis

	<b>N</b>	<b>P</b>	<b>BOD<sub>7</sub></b>	<b>Cd</b>
Drumfilter	6 %	19 %	50 %	35 %
Aerobic MBR	22 %	41 %	100 %	84 %
Reverse osmosis (RO)	98 %	100 %	100 %	98 %

### **Connection to large scale wastewater treatment plant**

This system can be considered as the most common for transition areas. It demands pipes to be built long distances to as in this case remote locations. The treatment process has been chosen as to correspond to a conventional one. Nitrogen is reduced with 77 % mainly by the activated sludge to nitrogen gas with mainly oxidized species in effluent. Phosphorus is mostly removed due to precipitation and particle separation in the pre-settler and sand filter units. The combination with further microbial assimilation in the activated sludge reactor gives a satisfactory total removal.

Phosphorus is in total removed with 97 %. BOD<sub>7</sub> is removed to a very high degree - 99% - mainly in activated sludge process. Cadmium follows the suspended solid pathway and mainly ends up in the sludge (92 %). The sewage sludge produced is assumed to be used as a fertiliser in agriculture.

## RESULTS AND DISCUSSIONS

### Discharges to water

The VeVa model provides total massflows of N-tot, P-tot, BOD<sub>7</sub> and Cd to water and soil. In Table 4 the discharges to water are expressed as percentage of inflows to the system (Table 1).

Table 4. Discharges of N-tot, P-tot, BOD<sub>7</sub> and Cd expressed as percentage of inflows to the systems

System structure	N-tot	P-tot	BOD <sub>7</sub>	Cd
<i>Lillängsdal's existing system</i>	37	48	40	69
Sand filter	27	34	7	49
Filter bed	27	3	7	49
Urine separation.	10	2	6	49
Local WWTP	39	5	4	8
Aerobic MBR	1.0	0.0	0.0	0.2
Central WWTP	15	2	1	9

In Table 2, the six system structures are compared. The situation of Lillängsdal's existing system is also given as a reference. Regarding nitrogen to water, only 37 % of nitrogen is discharged, mainly dependent on a high number of sealed tanks for closet water in Lillängsdal. National guidelines regarding small scale wastewater systems from 2006 state that 50 % of nitrogen should be removed in sensitive areas (Swedish EPA, 2006). This requirement is already fulfilled today and will be even improved for all systems except for the Local wastewater treatment plant modelled in this study since this did not include nitrogen removal. The aerobic Membrane Reactor with following Reverse Osmosis has the ability to remove 99 % of nitrogen and is the superior system. Also the urine separation system is very efficient in removing nitrogen due to the separation of the nitrogen-rich urine and in combination with the filter bed that removes approximately half of the nitrogen. Regarding phosphorus, it is clearly shown that the situation will change in a beneficial way whatever systems chosen for Lillängsdal. The national guidelines also state that on-site systems should remove 90 % of phosphorus in wastewater in sensitive areas (Swedish EPA, 2006). This high standard can be fulfilled with all system structures except for the sand filter system. Even more obvious is the improvement of discharging BOD<sub>7</sub> independent which system is introduced. The discharge of cadmium to water is not an issue that has been much focus on. The current situation will however be improved with all systems, where especially the aerobic MBR is superior followed by systems with the local and central wastewater treatment plants.

### Phosphorus recycling

In Sweden there is a national environmental goal stating that at least 60 % of phosphorus compounds present in wastewater should be recovered for use on productive land by 2015. At least half of this amount should be returned to arable land. Figure 2 shows the calculated recycling of phosphorus in different alternatives. All system structures except for the Sand filter recycle

phosphorus to a high degree (around 70 %) and could therefore fulfil the goal. There is, on the other hand, a large amount of phosphorus in sludge and filter materials which is not easily available for plants. Independent if this availability aspect is taken into consideration, the aerobic MBR + RO is the most beneficial system followed by Urine separation + Filter bed.

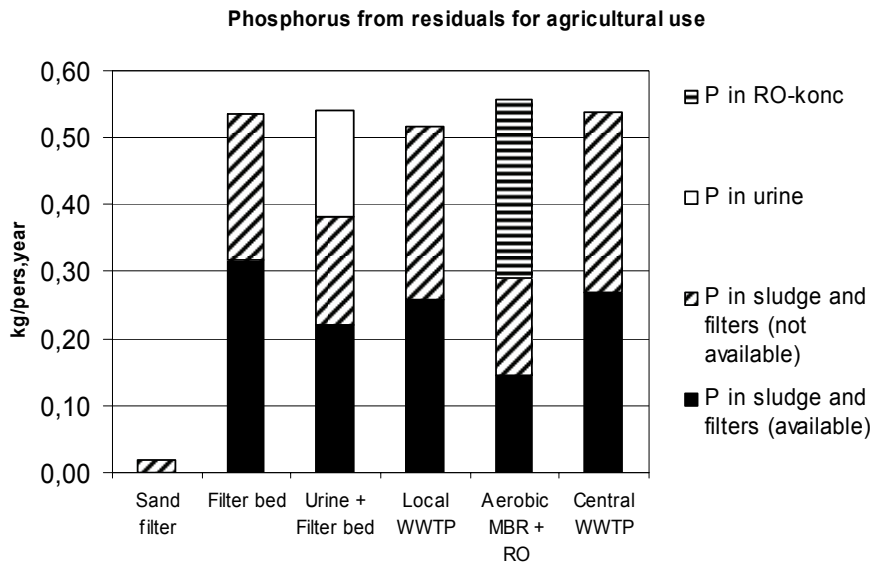


Figure 2. Phosphorus recycling to agriculture

It is an inevitable fact that the use of products from wastewater systems means that also some pollutants will follow to agriculture. Cadmium flows to agriculture is a debated subject. All wastewater products here studied can be recycled to agriculture according to Swedish regulations. The most problematic product is sludge from pre-treatment tanks, but mixed with large amounts of municipal sludge in central wastewater treatment plants makes it possible to fulfil the regulations. Leaving the Sand filter system aside - which has almost no phosphorus recycling at all - the urine separation and filter bed systems are the superior alternatives. They both recycle phosphorus-rich products with small amounts of cadmium (the cadmium bar for urine in Figure 3 is not even visible). Also the concentrate from the reverse osmosis is a phosphorus-rich product with low amounts of cadmium, but here also the sludge from the MBR is assumed to be recycled, giving the system as a whole a drawback for the cadmium aspect.

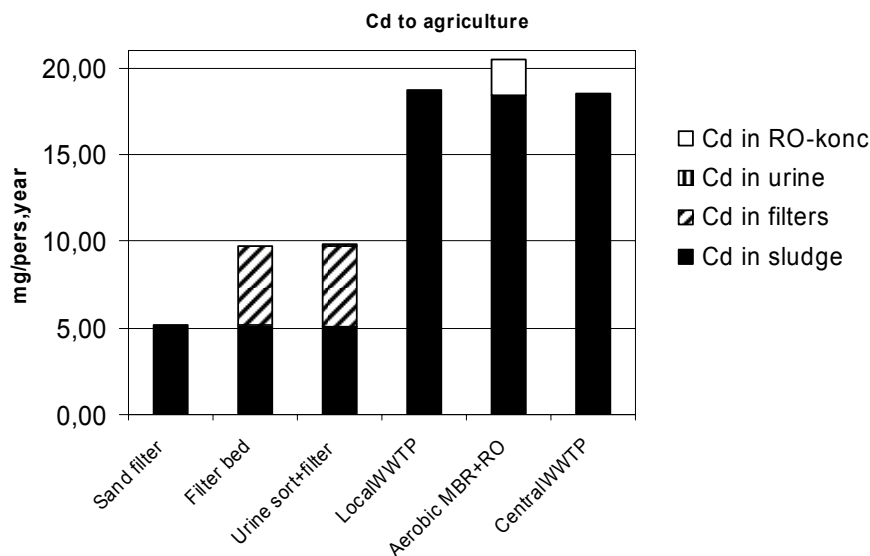


Figure 3. Cadmium to agriculture

## Energy use

The energy use was analysed both regarding production of materials and construction (Figure 4a) and operation (Figure 4b).

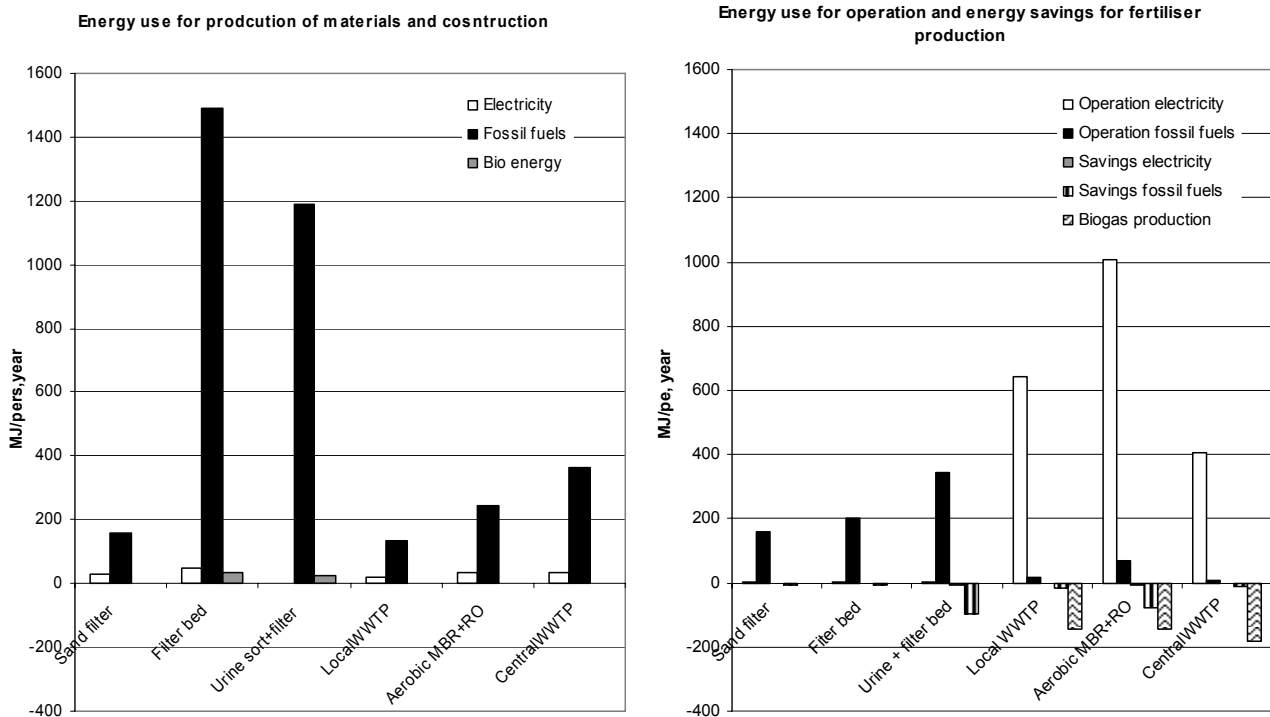


Figure 4a-b. Energy use for production materials and construction (4a) and for operation (4b).

In the production and construction phase, the use of fossil fuels dominates the energy use. Most significant is the heating process for production of expanded clay in the two systems with filter beds. Also production of pipes for connection of Lillängsdal to a central wastewater as well as production and construction of treatment plants and other facilities is related to considerable use of fossil fuels. In the operation phase, the aerobic MBR + RO use considerably amount of electricity. The reverse osmosis is the component that consumes the largest part of electricity. Also the local wastewater treatment plant and the Central wastewater treatment plant uses electricity for operation but more moderate compared to the Aerobic MBR + RO. Three systems use mostly fossil fuels for the operation, i.e. Urine separation + filter bed, Filter bed and sand filter. This is due to large amount of transports and spreading of residuals on agricultural land.

There are also some potential of recovering energy in the systems. In Figure 4b the potential saving of fossil fuels and electricity for fertiliser production is presented. These savings are however small compared with the energy use in the systems. Recovery of energy through biogas is more considerable and reduces the total energy use with around 25 % for the system with central wastewater treatment plant.

Comparing energy use with the potential energy recovery and with the assumption that 1 MJ electricity is comparable to 1 MJ fossil fuels, the Sand filter system is by far the most energy efficient alternative. This system does however not fulfil the discussed requirements regarding discharges of nutrients and phosphorus recycling, so therefore this type of system is not recommendable for new buildings in Lillängsdal. The systems with Central wastewater treatment plant and the Local wastewater treatment are both relatively energy efficient compared to the other alternatives fulfilling requirements regarding discharges.

A central wastewater system is already planned for connecting a large share of the single systems in Värmdö. The use of the VeVa model shows that this is also a quite beneficial alternative from an

environmental point of view. A critical point is the acceptance of using sludge in agriculture in the future. Today only around 10 % of the sewage sludge in the Stockholm County is used on agriculture.

In some peripheral areas it will however be very costly to build the sewer system to connect to the Central wastewater treatment plant. In these areas a collective system with a local wastewater treatment plant can be a beneficial solution from environmental point of view, fulfilling requirements without using very much energy. On the other hand, requirements of discharges can be stricter in the future and promote technologies like filter beds with expanded clay, sorting systems or membrane technologies. These systems are however by far more energy demanded than more common systems of today.

## CONCLUSIONS

- All studied system structures except for the Sand filter system fulfilled the goals of reducing phosphorus and BOD<sub>7</sub> according to Swedish guidelines for on-site systems in sensitive areas.
- All studied systems except for the Sand filter system has the potential to fulfil the Swedish National Environmental goal to recycle 60 % phosphorus to productive land.
- The systems with Central wastewater treatment plant and Local wastewater treatment are the most energy efficient alternatives that also fulfilling requirements of discharges and environmental goals regarding phosphorus recycling.

## ACKNOWLEDGEMENTS

This project was financially supported by the Stockholm County Councils Office for Regional Planning which is greatly acknowledged. We will also send our gratitude to Majken Elfström and Staffan Olsson, Värmdö municipality, for providing information about Lillängsdal and to Henrik Löfqvist for URWARE modelling and simulations.

## REFERENCES

- Erlandsson, Å. (2007). Environmental Assessment of Wastewater Handling in Transition Areas. (Miljöbedömning av VA-lösningar i omvandlingsområden), Master thesis, Swedish University of Agricultural Sciences (manuscript in Swedish)
- Jeppsson U., Baky A., Hellström D., Jönsson H. and Kärrman E. (2005). *The URWARE wastewater treatment plant models*. Urban Water Report 2005:5, Urban Water, Chalmers University of Technology, Göteborg, Sweden.
- Jönsson H., Baky A., Jeppsson U., Hellström D., and Kärrman E. (2005). *Composition of urine, faeces, greywater and biowaste for utilisation in the URWARE model*. Report 2005:6, Urban Water, Chalmers University of Technology, Göteborg, Sweden.
- Karlsson, P. (2005). Closing the loop with filter beds – an environmental systems analysis of small-scale wastewater treatment in the county of Stockholm (Kretsloppsanpassade filterbäddar – En miljösystemanalys av småskaliga avlopp i Stockholms län). Master thesis, Department of technology, University of Kalmar, Sweden (in Swedish).
- Kärrman, E., Björleinius, B., Elfström, M., Erlandsson, Å., Hellström, D., Löfqvist, H., Olsson, S. (2007). Tool for Environmental Assessment of Wastewater Handling in Transition Areas (Verktyg för miljösystemanalys av VA-lösningar i omvandlingsområden), Stockholm County Councils Office for Regional Planning (manuscript in Swedish)
- Kärrman, E., Jönsson, H. (2001). Normalising impacts in an environmental systems analysis of wastewater systems. *Water Science and Technology* **43** (5) 293-300.
- Löfqvist, H. (2006). Environmental Systems Analysis of New Developing Wastewater Treatment – Local Solutions in Transition Areas. Report no 15, Stockholm Vatten AB, Stockholm, Sweden.
- Malmqvist, P.-A., Heinicke, G., Kärrman, E., Stenström, T.A., Svensson, G. (ed). (2006). Strategic Planning of Sustainable Urban Water Management. IWA Publishing. ISBN13:9781843391050.
- Swedish EPA (2006). Swedish guidelines for small-scale wastewater systems. (Naturvårdsverkets allmänna råd om små avloppsanordningar för hushållsspillvatten). NFS 2006:7, Swedish Environmental Protection Agency, Stockholm Sweden (in Swedish).