# Blackwater and greywater reuse system Chorrillos, Lima, Peru

**Fig. 1**: Project location

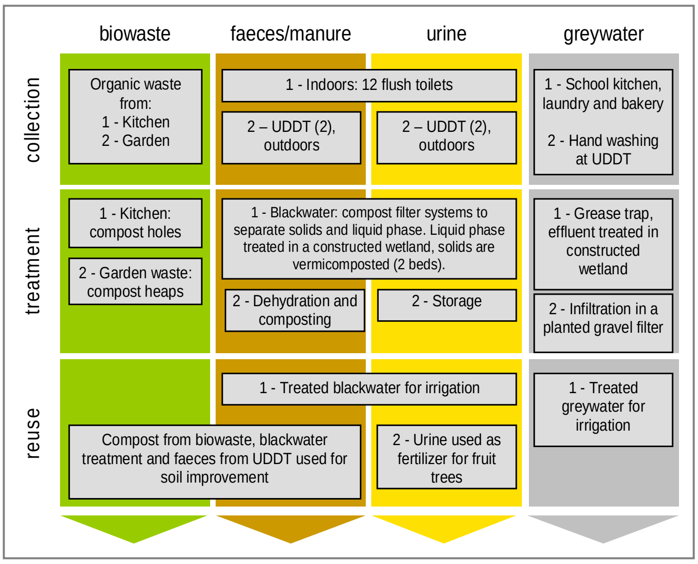


**Fig. 2:** Applied sanitation components in this project (numbers 1 and 2 refer to different flow streams)

## 1 General data

**Type of project:**
Urban upgrading - school demonstration project

**Project period:**
Start of planning: February 2007
Construction period: July 2007 - October 2008
Start of construction:
Grey- / blackwater treatment: July 2007
Urine diverting dehydration toilets (UDDTs): May 2008
Start of operation:
Greywater treatment system: September 2007
Blackwater treatment system: November 2007
UDDTs: May 2008
Extension for blackwater treatment (reed bed): October 2008

**Project scale:**
53 population equivalents (35 handicapped pupils plus personnel)
Capital costs unknown

**Address of project location:**
Avenida de los Faisanes No. 950,
La Campiña, Chorrillos,
Lima, Peru

**Planning institution:**
Rotária del Perú, Lima, Peru

**Executing institution:**
Centro Educativo Básico Especial (education centre) “San Christoferus”, Lima, Peru

**Supporting agency:**
Private donors (mostly for financing)
Work-camp volunteers (during construction period)
Pro Niño (school board of San Christoferus)

## 2 Objective and motivation of the project

The objectives of the project are:

1. Reduction of the water consumption (and the cost for it).
2. Reduction of the dusty areas by creating more extensive planted areas (which need irrigation and fertilization) to improve aesthetics and micro climate.
3. Demonstration of a closed-loop system with reuse of treated wastewater, nutrients and organics, adapted to the environmental necessities of a populated desert area and the technical possibilities.
4. Showcasing a dry sanitation system (urine-diversion dehydration toilets - UDDTs).

**Fig. 3:** Drain tube on the base of the constructed wetland for blackwater treatment during covering with gravel. To avoid perforation caused by the gravel, the 0.5 mm PVC liner (in black) needed a special protection. A second liner (in blue) was put inside.[1]

[1] All photos by H. Hoffmann, taken in 2007/2008

## 3 Location and conditions

The Peruvian capital Lima (8 million inhabitants) is situated in one of the world's driest areas (9 mm rainfall per year). 15% of the total Peruvian area is a desert, but unfortunately 60% of the population of Peru lives there, 30% thereof in Lima. All of them are affected by water limitation; especially the poorest people live with an extreme water stress situation: 1.5 million inhabitants are using only 20 litres water per capita per day.

About 80% of the wastewater in Lima (60% in Peru) is collected in sewers, but only 9% of the collected wastewater receives treatment. That means, 91% is discharged untreated into the ocean, or used directly for irrigation in agriculture, whereas green areas in the city centre are irrigated with drinking water. The possibilities for safe reuse of treated wastewater are generally unknown. There are no water saving policies at all as the price for water is very low.

The education centre "San Christoferus" is located in a desert area in urban Lima. It is a care facility for 35 handicapped children in the age range of 5 to 18 years. The 0.6 ha school area includes an outdoor area and six separate buildings at two locations, including a bakery, a laundry and a kitchen.

The children are mentally disabled and many of them also have physical disabilities and birth defects of various kinds (sadly, there are only few institutions and opportunities for disabled children and adults in Peru). Six teachers supported by international volunteers take care of them from 8.00-14.30 o'clock. They spend their time playing music, baking, doing handicraft, cooking and since 2007 cultivating the garden, or just playing indoors and outdoors.

Before the start of the project, wastewater from 12 flush toilets (15 litres per flush), from bathrooms with showers and 3 kitchens, 1 laundry and 1 bakery was disposed to the public sewer system.

## 4 Project history

The initial idea was to upgrade the outdoor area by installing an irrigation system and to build a new playground. Initiated by the employees of the education centre and the parents, project planning for wastewater treatment with a special focus on reuse started in 2006.

The consultant Rotária del Perú was contracted in February 2007 for the planning of a new sanitation system as well as the supervision of its installation because of the company's experience in this area. At that time, composting of organic garden and kitchen waste was already practised. This experience with operation and reuse of organic material in the school garden was helpful for the consultants to convince the teachers and the school board to implement further reuse components.

In July 2007, construction of the playground and the constructed wetlands started with the support of a group of work-camp volunteers. More specialized installations were erected by two Peruvian workers. A lot of explanations and supervision was necessary, because most of the technologies were unknown in Peru. Finding adequate materials, such as the right sand or the lining for the wetland, filter bags for the composting filter or drain tubes was difficult.

Already the first weeks of operation for the wastewater treatment system were a success. Everybody was impressed by the excellent treatment results and later surprised by the intensive plant (papyrus) development in the constructed wetland.

**Fig. 4:** Outlet of the blackwater compost filter (pre-treatment) (left) and effluent of the constructed wetland (papyrus reed bed) for blackwater treatment (right).

**Fig. 5:** Vertical flow constructed wetland for greywater treatment during pumping (a day after planting and before the protection of the distribution pipes with a 10 cm gravel layer) (left) and after two months, with storage tank for irrigation of treated greywater (right).

Interested in the new playground, many families and school classes came to visit the school. It became necessary to have an additional outdoor toilet for visitors near the playground. In March 2008, Rotária del Perú provided the idea for a waterless urine diversion dehydration toilet (UDDT) and financed all materials. The objective was to demonstrate the applicability of this type of toilet for schools and to showcase a dry sanitation system as a possibility to reduce water consumption and avoid water pollution. Also, the construction of an outdoor flush toilet and its pipe connection to the wetland would have been much more expensive.

## 5 Technologies applied

For the purpose of treatment and irrigation, two independent treatment systems were built:

**Constructed wetland for greywater treatment:**
Greywater (wastewater without faecal matter) from the laundry, bakery and kitchen is treated in a vertical flow constructed wetland (sub-surface), also called reed bed. The greywater passes a grease trap and is pumped in intervals (time regulated) to the papyrus reed bed (see Fig. 5, left).

**Compost filter for blackwater treatment:**
Blackwater from the flush toilets mixed with greywater from two private kitchens, showers and washing basins of all bathrooms is treated separately. It is led to a well ventilated double-chamber compost filter ("Rottebehälter" - see Fig. 6, left). The two chambers are used alternately in intervals of 6 months.

This compost filter acts as a solid-liquid separation device: Solids are retained in a special (custom-made) filter bag which is filled with straw. During the six months in use and the following 6 months, where the second chamber is in use, some composting of the solid material in the filter bag is achieved. After removing the filter bag from the chamber (Fig. 6), a secondary treatment for the retained solids is realized in a separate vermicomposter (see Fig. 7).

Here earth worms (taken from the already existing compost system) break down the organic matter and improve the composting process. The liquid passes the filter bag to the bottom of the chamber and is pumped to the constructed wetland (see Fig. 8).

In October 2008, a second vertical flow constructed wetland started operation which is now used alternating with the existing wetland to improve treatment efficiency.

**Fig. 6:** Double-chamber compost filter ("Rottebehälter") for blackwater pre-treatment (left) and removal of a filter bag (right)

**Fig. 7:** Spreading of the retained solids from the filter bag, after 6 month (see Fig. 6) on the vermicomposting bed on a concrete slab

**Double-vault urine diversion dehydration toilets (UDDTs):**
The UDDTs which are constructed as outdoor toilets near the playground have two cubicles (girls / boys) with ventilated vaults for dehydration of faeces (see Fig.). When one faeces vault is full, the content (then already dehydrated for about one year) will be composted in the vermicomposter (together with the solid material filtered from the blackwater). Urine and greywater (water from hand washing) are collected separately. Greywater from the hand washing facilities is infiltrated directly into a gravel filter bed with bamboo plants next to the building (see Fig. 9). Urine is collected in two 25 litre jerricans which are located directly behind the entrance area (see Fig. 12).

**Composting systems:**
Besides the compost filter system and the vermicomposter, two other composting systems already existed before 2007: compost holes for organic kitchen and garden waste and compost heaps for biowaste from agricultural production and gardening.

**Fig. 8:** Vertical flow constructed wetland (reed bed) for treatment of the liquid phase of blackwater (after 6 months of growth)

**Fig. 9:** Outdoor UDDT with gravel filter bed for greywater (right hand)

## 6 Design information

The greywater treatment system was designed for 23 population equivalents, a hydraulic load of 2.5 m³ per day and an organic load of 0.58 kg $BOD_5$ per day. The blackwater treatment system was designed for 30 population equivalents, a hydraulic load of 3.3 m³ per day and an organic load of 2.1 kg $BOD_5$ per day. As blackwater and greywater were not separated before, there were no flow measurements or chemical analyses to verify these design assumptions.

**Greywater pre-treatment:**
- 1 grease trap of 1 m³ for grease and oil separation from wastewater from the kitchen and bakery. Achieved BOD reduction: 10%.
- 1 tank with a pump for the storage of the effluent from grease separation and laundry.

**First constructed wetland (greywater treatment):**
- Sub-surface, vertical-flow wetland with papyrus plants.
- Surface area: 16 m² (4 m x 4 m) = 0.7 m² per capita.
- Total depth: 1.1 m (from bottom to top: 20 cm gravel with drainage pipe (4"), 60 cm sand, 10 cm gravel with 3 distribution pipes (1") and 20 cm freeboard).
- 3 m³ storage tank for the treated greywater with a pump for irrigation.

**Compost filter system for blackwater pre-treatment:**
- 2 compost filter beds, each with 2 chambers with an active volume of 1.44 m³ (1.2 m x 1.2 m, 1 m deep).
- Each chamber has a removable cover and a 3 m long ventilation tube (3”).
- 4 filter bags of 0.7 m³ (1 m x 1 m x 0.7 m) (custom-made product made out of a resistant plastic material normally used to shade greenhouses).
- Estimated BOD reduction: 30%.
- For the liquid collection, every unit has a deeper tank with pump.
- The liquid phase from the first unit is pumped to the second unit and from there to the constructed wetland.

**Vermicomposter:**
- Two composting beds of 0.3 m³ (0.5 m x 1 m x 0.6 m).
- The two beds are separated by a brick wall.
- The bottom is made of cement.

**Second constructed wetland (blackwater treatment):**
- Sub-surface, vertical-flow wetland with papyrus plants.
- Surface area: 45 m² (5 m x 9 m).
- Total depth: 1.3 m (from bottom to top: 20 cm gravel with a single drain pipe (4”), 80 cm sand, 10 cm gravel with 6 distribution pipes (1.5”) and 20 cm free board).
- 6 m³ storage tank for the treated blackwater with a pump for irrigation

**Urine diversion dehydration toilets (UDDTs):**
- Two separate cubicles for boys and girls with a size of 1.6 m x 1.5 m (2.3 m²) each.
- Each cubicle is equipped with a sink for hand washing, a double-vault UDDT (with two urine-diversion-pedestals) and two ventilation pipes.
- The two toilet pedestals are made of ferro-cement, because the use by handicapped children requires a stable solution with space for a second helping person.
- The toilet pedestal in use has a movable plastic (polypropylene) insert for urine diversion, while the other toilet pedestal remains closed (see Fig. 12, left and middle).
- Toilet paper is collected in a waste bucket.
- After defecation, the user has to put some sawdust into the toilet. The sawdust comes from the schools own carpentry.
- The vaults for faeces collection consist of two separate chambers with an active volume of 0.21 m³ (0.6 x 0.7 m, 0.5 m depth) each. Each vault has a black metal cover at the back of the building (sunny side) (see Fig. 11).
- The men’s bathroom additionally has a classic urinal, where the siphon was removed in order to connect it directly with the urine outlet pipe. Thus it is a waterless urinal.
- The UDDTs and the waterless urinal are directly connected to two 25-L jerricans for storage (see Fig. 12, right).

**Fig. 10:** Inside one UDDT cubicle (Two colourful urine diversion pedestals; only one is in use at a time, for about one year).

**Fig. 11:** Two double-vaults for faeces collection at the backside of the UDDT building (4 vaults in total).

**Fig. 12:** Toilet seats without (left) and with (middle) plastic insert for urine separation. Pipe from UDD toilet to 25 L urine jerrican (right).

## 7 Type and level of reuse

2 m³ treated greywater per school day are reused for irrigation of the garden. 4-5 m³ treated blackwater per school day are reused for irrigation of the lawns, fruit trees and flowers.

Today the school has doubled the irrigated green areas, but reduced by half the water consumption compared to 2007. Comparing the school area with the surroundings, the advantage of reusing treated black- and greywater for irrigation becomes obvious (see Fig. 13 and 14).

**Fig. 13:** Behind the fence: Desert living areas in the direct neighbourhood of the San Christoferus education centre.

**Fig. 14:** Urban agriculture at school, irrigated with treated blackwater

(Vermi-) composted organic material from the kitchen and the garden as well as solid material and dehydrated faeces from the UDDTs is reused for soil improvement.

After storage of about 1 month (longer during school holidays), urine from the UDDTs is used for fertilization of fruit trees (directly followed by watering to reduce odour during application); if the urine jerrican is not emptied then an infiltration of urine in a gravel filter bed is provided.

## 8 Further project components

The project is helping the school to develop more outdoor activities for the handicapped children, which was lacking in the past due to the school grounds being extremely dry and dusty. The new playground was built in 2007 and today, the whole school area (0.6 ha) gets irrigated and was turned into green space (see Fig. 15). The presence of trees, flowers and herbs gives the possibility to develop the senses of the children.

**Fig. 15:** Recently planted soccer field irrigated with treated blackwater (formerly a dusty area)

The higher production of vegetables and fruits which are sold for sale helps to increase the income of the school and to give scholarships to poor families with handicapped children.

This project was demonstrated and discussed during the first university course about ecological sanitation at the University for Agricultural Science UNALM (Universidad Agraria de La Molina) in May 2008 in Lima, Peru which was sponsored by the GTZ Peru water and sanitation program (PROAGUA).

## 9 Costs and economics

**Constructed wetland (for greywater treatment):**
The material costs for the wetland, including a grease trap for pre-treatment and a 3 m³ storage tank were about PEN 8,000 (Soles Peruanos) ≅ EUR 1,860.[2]

**Compost filter, vermicomposter and constructed wetland (for blackwater treatment):**
Material costs for the composter with two double-chamber composting filters for pre-treatment, the vermicomposter, the constructed wetland and a 6 m³ storage tank were about EUR 3,250.

**UDDTs:**
Material costs for the two toilets with infiltration of the hand washing water were about EUR 910. The toilet had to be tailored to the particular needs of the handicapped children (with additional space for a carer). For example, two separate pedestals were build instead of one ferro-cement bank with two holes, and this made the toilets more expensive.

The total construction costs of the project (including labour costs) were not determined, because it was financed by diverse donations and supported by volunteers.

## 10 Operation and maintenance

The operation of the facilities is done by the gardener (housekeeper) of the school, who is living with his family on the school compound. He has to organize the control of all pumps. Once a week, he has to put straw in the compost filter, after 6 months he has to swap the filter chambers and to remove the solids from the filter bag for secondary composting in the vermicomposter (see Fig. 6 and Fig. 7). Once a year, he has to clean all drainage pipes of the constructed wetlands.

An even more important task is the organization of the daily reuse of the treated grey- and blackwater (see Fig. 16), because unfortunately the irrigation system is not working automatically. In the beginning of the project, the effluent tanks often overflowed and the water in the wetland dammed up due to irregular irrigation practices. The operation is organized by the gardener (housekeeper) and by German volunteers, who work there for a year.

**Fig. 16:** Daily garden irrigation (in this case with treated blackwater) in the dry climate of Lima.

[2] Exchange rate July 2007: EUR 1 ≅ PEN 4.3.

## 11 Practical experience and lessons learnt

The implementation of ecosan components always needs qualified engineering staff with sufficient experience, especially in countries where the technology, here constructed wetlands, is not well known yet. The system is relatively complex with many sub-components, whilst only a population equivalent of 53 people is served.

**The following two points are important to consider:**

- In case of flow stream separation (blackwater / greywater), the load can differ extremely from reference values. This can lead to overloading and clogging of the wetland.
- The selection of materials and the construction process have to be controlled to avoid irreparable mistakes, like for example the perforation of the plastic liner (water loss), too fine or too coarse sand (clogging or bad efficiency), unequal distribution of wastewater, no possibility to clean the distribution and drainage system, wrong plants, etc.

In this project, the total wastewater flow was calculated correctly, but the constructed wetland for greywater only receives 1.5 $m^3$ per day and the constructed wetland for blackwater more than 4 $m^3$, sometimes up to 6 $m^3$ per day, mainly because the seals in the flush toilets do not close tightly or the flushing device is not used correctly. The high water flux to the compost filter bag dissolves a lot of solids, which are then transported to the wetland (see Fig. 17).

**Fig. 17:** Increased blackwater flow in the composting chamber (filter bag) due to water leakage in the flush toilets.

Unfortunately, this wetland also has very fine sand. In Lima, finding sand in the right grain size is very difficult and there was not enough money available to wash it.[3] The effluent quality is excellent, but clogging can only be controlled by alternately disconnecting a third of the wetland for one week in order to recover the permeability. Valves for regulating the inflow to the wetland were included in the design after the decision for the fine sand was made, because the wetland tends to clog (see Fig. 18).

**Fig. 18:** Distribution system on the second constructed wetland (for blackwater treatment) before planting, showing valves on the left (in red) to avoid clogging (intermittent loading).

The compost filter system for blackwater pre-treatment was never used before in Peru. Operation showed that it is a very good system for warm climates. The composting process is rapid. If used for post-treatment, a three-month composting period without adding further blackwater is enough to properly treat the content of the filter bag.

Because of the clogging problems of the wetland sand, a second wetland for the treatment of the liquid phase of the blackwater was built in late 2008. Linked to these measures, the old valves in all flush toilets were exchanged with new, tightly closing valves with a water economizing low flush function. This measure reduced the production of blackwater by approx. 50%. Now only 3 $m^3$ blackwater per school day have to be treated, and this enabled the additional connection of a neighbouring house to the wetland.

The “harvest” of the compost is not a problem. It does not smell at all and the gardener enjoys mixing the humid, obviously nutrient-rich compost with his always dry garden compost. Four filter bags in two double-chambers operating in three-month cycles would improve the process.

A neglected maintenance task is to put a little bit of straw into the active compost filter once per week. It seems that the gardener and all the other staff members do not like to see the fresh faeces. After 2-3 weeks without any straw, the chamber begins to smell, and even if they know why this happens, nobody feels responsible.

During the construction time, the project was met with mistrust by all employees and teachers. First, they mentioned the danger of accidents for the children and later the odour from the wastewater which supposed to appear with the new system – and everybody who looked once into the compost filter bag complained even more.

People were wondering what would happen in summer, because during this time the wastewater always used to smell before. The first summer came and nothing bad happened: The plants on the wetlands were growing, no wastewater was visible and the treated effluent was clear. Those employees who did not have to operate the system forgot about their complaints after half a year.

The operation of the UDDT began in May 2008, but experience already has shown that at least one year of frequent explanations, orientations and help or sometimes

[3] „Washing” means sieving and washing sand to remove dust and obtain a certain grain size.

even “do it yourself” by the trainer is necessary before a UDDT is fully accepted.

**Fig. 19:** Constructed wetland (reed bed) for greywater treatment planted with two species of Papyrus, after 1 year of operation.

## 12 Sustainability assessment and long-term impacts

A basic assessment (Table 1) was carried out to indicate in which of the five sustainability criteria for sanitation (according to SuSanA Vision Document 1) this project has its strengths and which aspects were not emphasised (weaknesses).

**Table 1:** Qualitative indication of sustainability of system
A cross in the respective column shows assessment of the relative sustainability of project (+ means: strong point of project; o means: average strength for this aspect and – means: no emphasis on this aspect for this project).

| | collection and transport | | | treatment | | | transport and reuse | | |
|---|---|---|---|---|---|---|---|---|---|
| **Sustainability criteria**: | + | o | - | + | o | - | + | o | - |
| • health and hygiene | X | | | X | | | X | | |
| • environmental and natural resources | X | | | X | | | X | | |
| • technology and operation | X | | | | X | | X | | |
| • finance and economics | | X | | | X | | | X | |
| • socio-cultural and institutional | X | | | | X | | | X | |

**Sustainability criteria for sanitation:**

**Health and hygiene** include the risk of exposure to pathogens and hazardous substances and improvement of livelihood achieved by the application of a certain sanitation system.

**Environment and natural resources** involve the resources needed in the project as well as the degree of recycling and reuse practiced and the effects of these.

**Technology and operation** relate to the functionality and ease of constructing, operating and monitoring the entire system as well as its robustness and adaptability to existing systems.

**Financial and economic issues** include the capacity of households and communities to cover the costs for sanitation as well as the benefit, e.g. from fertilizer and the external impact on the economy.

**Socio-cultural and institutional aspects** refer to the socio-cultural acceptance and appropriateness of the system, perceptions, gender issues and compliance with legal and institutional frameworks.

For details on these criteria, please see the SuSanA Vision document "Towards more sustainable solutions" (www.susana.org).

The main impact of the project is the reduction of potable water consumption by 50% through complete grey- and blackwater reuse and therefore reduction of costs. The higher production of vegetables and fruits for sale helps to increase the income of the school and to give scholarships to poor families with handicapped children. Furthermore, the children benefit from greener surroundings (50% of the school area) and more outdoor activities.

It is an important demonstration project for environmental education purposes. Schools, teachers, students, public authorities, architects, engineers and private persons are invited to see that saving water through dry sanitation methods, reuse of treated wastewater and the use of composted organic waste can improve the quality of life.

## 13 Available documents and references

Rotária del Perú and the Colegio San Christoferus provide a project description (in Spanish), which was published at the first national sanitation conference PERUSAN 2008 in Lima, Peru. Rotária del Perú made a short description (in German) of the construction for a sponsor group in Switzerland. On the recently inaugurated website of the Colegio San Christoferus information is available in English, German and Spanish.

## 14 Institutions, organisations and contact persons

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**Case study of SuSanA projects**
***Blackwater and greywater reuse system.***
**SuSanA 2009**

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