Solids-Free Sewer and Ponds Provide Sustainable Sanitation for a Sri Lankan Hospital

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ABSTRACT
International assistance following the Civil War includes a wastewater collection and treatment system for a hospital in northern Sri Lanka.

The hospital is located on an extremely congested site with no room for conventional sewerage or sewage treatment on site. Existing septic tanks are failing and polluting the groundwater while sullage drains untreated from the site causing significant nuisance and health hazards.

The solution adopted uses an ingenious combination of simplified and solids-free sewerage to convey the wastewater, without the need for pumping, to the facultative and maturation ponds located 2 km away on a small site, which floods seasonally.

KEY WORDS
Waste Stabilisation Ponds, Simplified Sewerage, Solids-free Sewerage, Sri Lanka

INTRODUCTION
The United Nations Office for Project Services (UNOPS) is implementing an EU funded programme to improve medium scale infrastructure in three towns in northern Sri Lanka: Batticaloa, Mannar and Vavuniya. As part of the improvements to Vavuniya Town, a project is being implemented to provide wastewater collection and treatment facilities for the regional hospital, which serves a population of 500,000. Under a long-term agreement for consultancy services with UNOPS Arup International Development (Arup ID) were requested to assist.

Numerous difficult constraints were overcome to provide a simple solution utilising simplified sewerage, a solids free-sewer and waste stabilisation ponds, which did not require any pumping or mechanical plant.

BACKGROUND

Vavuniya Town
Vavuniya Town is located in the Northern Province of Sri Lanka within the Vavuniya District (see **Figure 1Error! Reference source not found.**). During the Sri Lankan Civil War from 1983 to 2009, Vavuniya was near the front lines, which resulted in a large number of internally displaced people (IDPs) passing through or staying in the town.

Vavuniya is located in the dry zone of Sri Lanka, with most of the rain coming in the 2nd inter-monsoon and NE monsoon periods between October – January (60%). The average annual rainfall is approximately 1,300mm. The average temperature is 28^{o}C with a mean temperature of the coolest month (January) of 25^{o}C. The lowest elevations of the town lie to the north east with the natural drainage flowing that direction.

Figure 1. Location of Vavuniya

Figure 2. Aerial view of Vavuniya District Hospital

The 2011 census of Sri Lanka found the population of the Vavuniya Division of Vavuniya District to be 117,153 (Department of Census and Statistics, 2012), of which it is thought about 50-60% live in the town. There is no centralised wastewater system. Virtually all sullage water is discharged to surface water drains or to the ground, causing significant nuisance and health risks as wastewater quickly becomes septic and much of it finds its way into the Thandi Kulam irrigation tank, grossly polluting it. Most premises have water seal toilets that discharge to septic tanks or leach pits. There are at present no plans for a centralised sanitation system for the town.

The National Water Supply and Drainage Board (NWS&DB is building a new reservoir which is to provide the bulk of the water needed for expanding the water supply system for the town.

Vavuniya Hospital

This District Hospital serves a population of about 500,000 and is located on an approximately 7-hectare site close to the commercial centre of Vavuniya Town. The site is very congested partly because a number of 'semi-permanent' buildings were constructed to deal with the influx of internally displaced people (IDPs) during the civil war (1983 – 2009) (see **Figure 2**). The current capacity of the hospital is approximately 700 beds. In addition, the site is estimated to have approximately 5000 people (staff, patients, and visitors) on site at some point each day.

Sanitation on-site is provided by flush toilets, which discharge to numerous septic tanks that discharge in turn into circular soakaways. Virtually all sullage water is discharged to surface water drains or to the ground. This is causing significant nuisance and health risks as wastewater draining from the hospital boundary at several locations quickly becomes septic and contaminates the roadside stormwater drains and an irrigation canal (see **Figure 3**).

The septic tanks are overloaded and the soakaways clogged so that it is necessary to empty them frequently, with a team working continuously making an average six trips a day. The effluent and sludge is transported to a disposal point located at the municipal solid waste disposal site located approximately 12 km from the hospital using a 6m³ tanker donated by UNICEF.

At present, water supplies are very restricted. The hospital relies on water from a number of wells and boreholes. The site's boreholes and wells have low yields and the water quality is poor due to hardness and faecal contamination. The water treated by chlorination in the hospital's storage tanks using hypochlorite granules.

One section of the site is currently being re-developed with a new building that will include two wards with a total of 200 beds. Unfortunately, no drawings or details of the building, water, or sanitation system have been given to the hospital management.

INITIAL FINDINGS

Original proposals

The initial commission was merely to review the two feasibility studies and advise on their appropriateness. The main conclusions of the review were that the proposals were inappropriate because:

- Conventional sewerage proposed – quite deep excavation and pipes larger than necessary
- Ignored the presence of an irrigation canal which cannot be removed or easily diverted
- An activated sludge plant would be in the middle of hospital
- Sludge drying beds would be near housing and medical stores
- Disinfection of effluent using chlorine proposed – this raises concerns over the reliability (maintenance and chemical supplies) and disinfection by-products.

Findings from field investigations

At the conclusion of an initial field visit by Arup staff during August 2013, Arup's commission was extended to include detailed design and the preparation of tender documents. A second field visit was undertaken at during June 2014 prior to the commencement of the detailed design phase. Inspection of the hospital site revealed several critical factors that had not been addressed in the two feasibility studies:

- The site is very congested with little space available for locating the necessary sewerage infrastructure (see **Figure 4**)
- Most buildings are surrounded by an elevated plinth that contains storm water channels and the majority of pipes that discharge sullage into the storm water drains emerge from the buildings above plinth level
- There are a very large number of individual sullage discharge points (see **Figure 5**)
- Construction of conventional sewer connections would require extensive demolition and reinstatement of storm water drainage channels
- The proposed site for the treatment works is very small and although not immediately adjacent to any medical treatment facilities, it is very close to staff housing
- The Irrigation Board will not permit the irrigation canal that crosses the site from east to west to be relocated because it would have to include a siphon, which would create additional maintenance requirements.
- In addition to hastily constructed semi-permanent buildings erected during the civil war, new buildings continue to be designed and built by different donors without adequate planning or consultation with the relevant stakeholders. Some of the partially completed buildings can be seen on **Figure 2**.

Figure 5. Septic sullage draining from the hospital

Figure 4. Limited space for sewerage reticulation

Figure 3. Numerous sullage discharge pipes

Site for the main wastewater treatment works

It was clear from the initial review of the two feasibility studies that locating the treatment plant on the hospital site would be difficult and require a very compact and highly mechanised process. It was therefore proposed that an alternative site would be required and several were proposed. The most convenient site would have been close to the hospital on rice paddy land, but it was clear that this was not an option because it taking irrigated paddy land out of cultivation would not be acceptable

Due to the complexities of procuring private land, it was agreed that it would be necessary to find suitable land in public ownership and a number of sites were proposed, most of which would require the pumping of wastewater and one that was very distant and did not have suitable geology or soils.

The initial choice of site turned out to be in private ownership, so the Department of Agrarian Development was approached and approximately 1.6 ha of land within the reserve of the Thandi Kulam irrigation reservoir was made available for the treatment works. The land lies below the highest water level of the Thandi Kulam irrigation reservoir and so floods seasonally. There is a precedent for this choice of site; waste stabilisation ponds were built close to the commercial centre of Vavuniya, within the confines of the Vavuniya irrigation reservoir in an attempt to mitigate the pollution caused by the septic runoff from the town into the tank. The Department of Agrarian Development also sanctioned the removal of material from within the reservoir for construction of earthworks. This would more than compensate for the loss of storage volume due to the construction of the ponds. The site lies approximately 2 km from the hospital, close to the main road leading from Vavuniya towards Jaffna (see **Figure 6**).

The site is partly cultivated in un-irrigated rice, but the majority is covered in vegetation, mainly water-loving herbs, shrubs and small trees, but also with many mature trees.

DESIGN PRINCIPLES

Based on the technical design review that Arup conducted of the two feasibility studies and information collected during the site visit, the following general principles were adopted for the sewerage system and treatment process design:

- Require all buildings and wastewater flows to be connected to the sewerage system
- Include septic tanks as a first stage of treatment in locations with easy access for vacuum tankers
- Shallow sewerage design principles would be used for the on-site sewerage network
- Location of the main treatment works on a site away from the hospital and human habitation
- The principles of solids-free (small bore) sewerage will be followed for the design of the sewer linking the hospital to the sewage treatment works
- A series of waste stabilisation ponds to treat the effluent from the septic tanks to meet CEA quality requirements for the discharge of industrial waste to inland surface waters
- Designs should minimise reliance on electricity and pumps
- Designs should minimise the operation and maintenance requirements for the system

An additional major constraint was that the rate of sewage generation will increase dramatically during the lifetime of the scheme. Initially the collection and treatment system will have to cater for a low flow of high strength waste, but in the future, once the hospital is connected to the piped water supply that is under construction and the hospital facilities are expanded, the system will have to accommodate a far larger volume of more dilute wastewater.

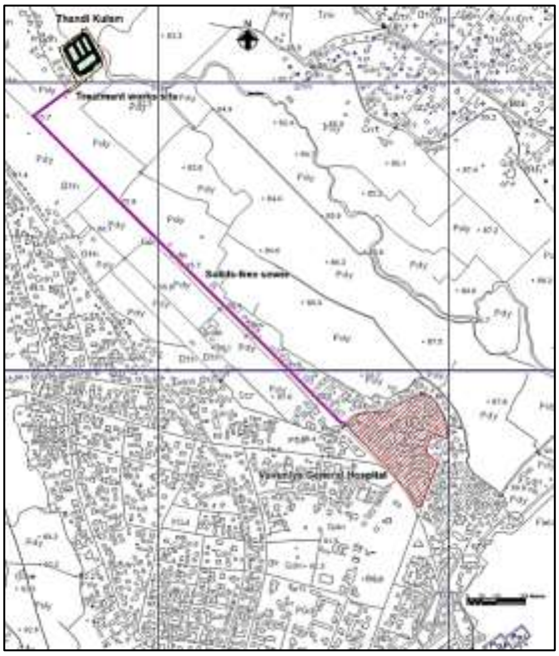

Figure 7: plan showing the locations of the hospital, treatment works and solids-free sewer

Figure 6: Layout of the main sewers and septic tanks

Developed design

These design principles were used to produce a Developed Design and report for acceptance by UNOPS and the other affected authorities. The developed design consisted a system with primary treatment on the hospital site using septic tanks, a solids free sewer and one facultative pond and three maturation ponds (see **Figure 6**).

DETAILED DESIGN

The Developed Design as accepted without any substantial changes and detailed design commenced in June 2014.

Sewage collection and primary treatment

The sewage collection and reticulation system was designed to accommodate a large increase in flow during the life of the system It was not feasible to collect representative samples of effluent from the hospital due to the many different sources, some of which were not accessible for sampling. The sewage generation rates and the biological loads for the various parts of the hospital were therefore estimated based on a variety of sources. The derived initial and final wastewater flows were 139 and 398 m^3/day and the BOD load 127 and 165 kg/day.

The sewer reticulation was designed using the simplified sewerage principles outlined in Mara and Broome (2008). In the upper reaches of the collector sewers the gradients are generally in line with traditional design parameters, but some of the lower sections are designed with a minimum gradient of 1:230. This was necessary to allow the collector sewers to pass under the irrigation channel without forcing the septic tanks lower than would have allowed gravity flow to the waste stabilisation ponds.

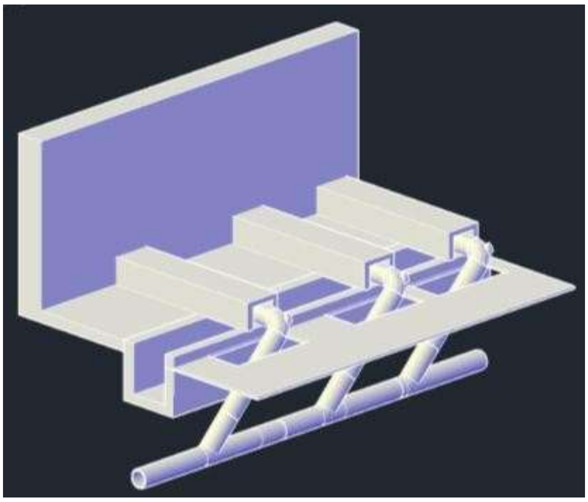

Figure 8: Typical sullage connections

The design of the sewerage reticulation system attempts to reduce disruption to the extensive surface water drainage system of the hospital as much as possible. For most of the existing foul sewers, it is straightforward to intercept them upstream of the septic tanks. For the vast majority of the more than 500 sullage discharge points that are above the building plinths a new pipeline will be laid outside the stormwater drains. The pipes will be extended to the edge of the plinth and the connection made with an inspection elbow and an inclined branch connecting into the soffit of the new sewer (see **Figure 8**). Due to the large number of sullage connections to be intercepted, it was not considered feasible to carry out the necessary investigations and detailed design for each branch sewer. Instead, this is to be the responsibility of the contractor, as will be identifying sources of hazardous liquid waste and providing collection and retention tanks for each area of waste generation, such as the X-ray department, laboratory and blood bank.

Primary treatment

The design of the septic tank is based on the design parameters laid out in: 'Rational design of septic tanks in warm climates' (Mara and Sinnatamby, 1986). The calculations resulted in two septic tanks built as one structure at the end of sewer serving the main areas of the hospital with a combined volume of 149 m^3. The volume of the septic tank at the end of the third sewer main serving the administrative and residential areas to the west of the site is 13.7 m^3.

Solids-free sewer

The invert level of the outlet from the upstream pair of septic tanks was set at 86.175 m. This level was governed by the need for the sewers on site to pass under the irrigation canal and to drain the buildings located at the north eastern corner of the site. To ensure that there could be no backflow from the irrigation tank into the ponds, the water level of the facultative pond at Thandi Kulam was set at 83.900 m based on the assumed maximum flood level in the adjacent tank and a fall of 50 mm between each pond in the series. This turns out to be about 400 mm higher than necessary, but fortunately, this allowed the proposed discharge pipeline to operate under gravity.

These levels give an average gradient of 1:895 along the chosen alignment parallel with the main A9 road from Vavuniya towards Jaffna. A conventional gravity sewer would have required deep excavation and a pumping station at the treatment works. The alternative of locating the pumping station at the hospital site with a pressure pipeline to the ponds would also have presented difficulties due to the complications of pumping against a negative static head and the large range of flow to be accommodated during the design life of the system. The pipeline was therefore designed as a solids-free (small bore) sewer, in accordance with the recommendations of Otis and Mara (1985).

The pipeline could not be laid to a continuous falling gradient without some sections of deep excavation being required and so the vertical alignment has been selected to be, as far as is practicable, parallel with the ground surface. There is therefore a need to release gases at the high points and changes of gradient. Conventionally this would be accomplished using sewerage air valves, which unfortunately have a tendency to leak in service. However, the gradient is flat enough to allow four 3 m high ventilation columns to be used in their place. Even a complete blockage at the inlet to the ponds would result in effluent backing up in the septic tanks before any spillage would occur from the ventilation columns.

The hydraulic design was based on passing the future peak flow through the full pipeline with a gradient lower than the average of 1:895. This led to the selection of a uPVC DN225 PN6 pipe, which gave a hydraulic gradient of 1:999 at peak flow for the sections where the pipe runs full or surcharged. At maximum flow this means that for the majority of its length, the pipe is running full, with a number of lengths of part-full flow.

At the ponds, the pipeline rises up the embankment and discharges into a manhole on the crest of the embankment and via a submerged inlet into the facultative pond. The manhole makes it possible to check the flow through the pipeline and into the pond.

Waste stabilisation ponds

The wastewater treatment system was designed to produce a final effluent that would comply with the requirements for the discharge of industrial effluent into inland water bodies following the methodology of Mara (1997). There is at present no standard applicable to treated municipal or domestic waste so that for industrial effluent has been used instead (Ministry of Environment and Natural Resources, 2008). The principal requirements are for faecal coliforms of 40 per 100 ml, a BOD of 30 mg/l and suspended solids of 50 mg/l. Other characteristics are more relevant to industrial effluent. It is anticipated that the quality standards will be met, without the need for disinfection, although to meet the BOD standard test would probably only be met if the samples are filtered to remove algae before testing, as is permitted in Germany and some other countries.

To ensure that the anaerobic septic tank effluent entering the facultative pond is mixed quickly and to reduce short-circuiting of flow, the inlet pipe discharges below the normal water level and the flow is directed at a baffle wall. The inter-pond connections have been designed with submerged inlets, which eliminates the need for tees or scum boards and weirs. Instead, the flow passes through a chamber located on the centreline of the embankment, which incorporates a weir to control the level in the upstream pond.

The initial assumption was that it would be acceptable to discharge the effluent into the adjacent irrigation reservoir, but due to objections by the NWS&DB, a pipeline is to be constructed to carry the effluent a further 9 km downstream to discharge below a water supply dam that is under construction. The outlet structure of the final pond therefore incorporates both an outlet pipe, and an overflow to prevent overtopping of the embankment in case of any blockage or closure for maintenance of the effluent pipeline.

Site layout
The site is very constrained and so the plan of the ponds had to be skewed to fit within the site boundaries. Due to the seasonal flooding, it was not possible to locate the facilities building at the existing ground level and so an extension of the embankment was included to provide a platform for this. There was also little room for access roads around the site and so two ramps were provided to allow maintenance vehicles to access the top of the outer embankments without having to turn round or reverse. The ramps and embankment are to be provided with a gravel running surface to allow for this occasional vehicle access.

Construction
Because the ponds are to be built largely above the existing ground level, fill material will be excavated from within the confines of the irrigation tank. It was not possible to sample and test soils from the likely borrow areas during the investigation and design phases of the project, but it was assumed that material would be found that fulfilled the requirements of the specification. Testing was carried out on the in-situ soils at the treatment works site and these were found to have permeabilities in the range 1×10^{-9} m/s to about 1×10^{-8} m/s. Mara (1997) states that with a permeability of less than 1×10^{-8} m/s that the ponds will seal naturally, and so the ponds should not require a lining at this site.

The fill material will be selected, placed and compacted in accordance with the Specifications for Irrigation and Land Drainage Works (ICTAD, 1999) for low permeability material. To minimise soil erosion the IEE recommends that the exterior slopes should be turfed as construction proceeds. Internal erosion protection will be by an in-situ concrete strip at the waterline.

IMPLEMENTATION

A large number of agencies needed to give their acceptance before construction of the scheme could progress, the key agency being the Central Environmental Agency (CEA). Because the project is a ‘prescribed project’, under the National Environmental Act (Central Environmental Authority, 1980) an Initial Environmental Examination Report (IEE) must be prepared. UNOPS commissioned a local consultant to prepare it in accordance with the terms of reference issued by the CEA (Environmental Management and Assessment, 2014).

The consultants concluded that ‘the environmental and social benefits of the project overweight the impacts on ecology, natural and physical conditions of the project areas’ but noted the that the project must be ‘acceptable to the community’ and that the risks of pollution or flooding from a breach of the pond embankments were minor.

Initial contact had been made with many of the key agencies at the inception of the project and broader consultations were initiated prior to the detailed design phase through a meeting hosted by the Regional Director of Health Services. UNOPS and Arup also held separate meetings with the Central Environmental Agency and National Water Supply and Drainage Board in Colombo. More extensive consultation by the IEE Consultants during the approval process included meetings with users of the Thandi Kulam irrigation reservoir, farmers and local residents. This showed that there was general support for the project, but there were concerns regarding pollution from the treatment ponds. The IEE Consultants concluded that because of the lack of pumping and mechanised equipment to be employed, that there was only a remote risk of pollution.

NWS&DB had severe reservations about the discharge of effluent to the Thandi Kulam, despite the large dilution in before there would be any spill from the reservoir and the fact that large quantities of untreated effluent from Vavuniya drain into the catchment. This combined with the general resistance to discharging effluent into the Thandi Kulam led to the proposal to construct a 9 km long effluent pipeline from the treatment ponds to discharge of the water supply reservoir that is currently being built. Arup confirmed the feasibility of constructing a gravity pipeline that would operate in a similar manner to the solids-free sewer between the hospital and Thandi Kulam. This part of the works is to be financed by the Asian Development Bank and will be designed by others.

The other factor that contributed to the delay in gaining CEA approval for the project was whether the ponds needed lining. Once the results of the in-situ permeability testing of the site were available, the assumption that permeabilities would allow the ponds to be left without a lining could be verified and it was eventually accepted by the CEA and other parties that lining was not necessary.

Operations and maintenance

The operations and maintenance of the entire system is to remain the responsibility of the hospital authorities because the NWS&DB were not willing to take it over. The burden of maintenance would in any case be reduced because there will no longer be a need for frequent emptying of the septic tanks, or for the cleaning of the surface water drainage system that becomes a source of serious nuisance where the sullage is stagnant and anaerobic.

It is recommended that the hospital retain their vacuum tanker for desludging the three new septic tanks every six months and for transporting the hazardous waste. It is assumed that there will continue to be a provision for disposal of septic tank sludge and other liquid waste for as long as there is no comprehensive centralised sewerage system for the town.

The maintenance of the solids-free sewer should be simple. It proved impractical to provide access points for flushing or rodding and so an alternative strategy was adopted. This consists of installing penstocks on the septic tank outlets to allow the pipeline to be flushed periodically by allowing the liquid level in the septic tanks to build up and releasing it by opening the penstocks. It will also permit the pipeline to be isolated in the unlikely event that maintenance work has to be carried out.

CONCLUSIONS

Frequently the expectation of clients and users is that a complex, mechanical and energy consuming solution is the simplest way to solve a problem. However, both UNOPS and the hospital authorities in Vavuniya were receptive to the idea of using the simplest technology possible to provide a lasting solution that would minimise operations and maintenance costs and would not require any specialised skills or imported spares or consumables.

The principal conclusions that can been drawn from the development of this scheme are:

- The use of waste stabilisation ponds should not be ruled out, particularly in warm climates and even when the site conditions do not seem to be suitable
- The support of the client and future beneficiaries of the scheme are vital to ensure that suitable technology choices are made
- The avoidance of mechanical plant was an important factor in gaining the approval of the CEA for the scheme
- Combining the principles of simplified sewerage and solids-free sewerage was critical to the feasibility of the overall design of the project

ACKNOWLEDGEMENTS

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REFERENCES

Central Environmental Authority (1980). National Environmental Act, No 47 of 1980.

Department of Census and Statistics (2012), Sri Lanka Census of Population and Housing, 2011 Sri Lanka. http://www.statistics.gov.lk/PopHouSat/CPH2011/index.php?fileName=Northern&gp=Activities&tpl=3

Environmental Management and Assessment (2014). Initial Environmental Examination (IEE) Report, Environmental Management and Assessment Consultants (Pvt) Ltd., Sri Lanka.

ICTAD, 1999, Specifications for Irrigation and Land Drainage Works, 2nd Edition. Institute for Construction Training and Development, Ministry of Construction and Engineering Services. ICTAD Publication No: SCA/3/1.

Mara, D. (1997). Waste Stabilization Ponds: Design Manual for India. Lagoon Technology International, http://www.personal.leeds.ac.uk/~cen6ddm/WSPmanualindia.html

Mara, D and Broome, J. (2008). Sewerage: a return to basics to benefit the poor, Municipal Engineer 161, December 2008. http://www.personal.leeds.ac.uk/~cen6ddm/pdf%27s%202008+/muen.2008.161.4.pdf

Mara, D and Sinnatamby, G. (1986). Rational design of septic tanks in warm climates, The Public Health Engineer 14 (4), 49−55 http://www.personal.leeds.ac.uk/~cen6ddm/pdf%27s%201972-1999/e7a.pdf

Ministry of Environment and Natural Resources (2008). National Environmental (Protection and Quality) Regulations, No. 1 of 2008, The Gazette of the Democratic Socialist Republic of Sri Lanka, 1534/18 – 2008

Otis, R and Mara, D. (1985). The Design of Small Bore Sewer Systems, TAG Technical Note 14. http://documents.worldbank.org/curated/en/1985/05/439302/design-small-bore-sewer-systems