What are municipalities doing with their municipal sludge? Understanding the current practices and the cost associated with municipal sludge disposal with case studies



Report to the Water Research Commission

by

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Executive Summary

> *I would say let us talk together and cross [pollinate] on the successes as well as challenges that [we] experience in sludge management… I think [we] can work together and [make South Africa] a better place.*
>
> – Municipal representative

In 2010, just after the *Guidelines for Utilisation and Disposal of Wastewater Sludge* were updated, on-site disposal was most widely used by South African municipalities, and beneficial use of sludge was limited (Snyman, 2010). In 2024, this reality remains largely unchanged. While understanding and awareness of the *Guidelines* is widespread due to the regulatory requirements to follow them, the gap between policy and implementation remains. This is evidenced by the results of the 2022 Green Drop assessment, which found that approximately 80% of wastewater treatment plants (WWTPs) in South Africa were either stockpiling or storing their sludge in lagoons (i.e., on-site disposal).

In 2023, the DWS signed the *National Faecal Sludge Management (FSM) Strategy,* which presents an important step forward to increasing the active management of faecal sludge from on-site sanitation systems in South Africa. The first of its kind in South Africa, the FSM Strategy provides a 10-year roadmap to safely manage faecal sludge along the entire service chain, including containment, emptying, transport, treatment, and reuse or disposal (DWS, 2023a). The strategy also introduces key roles for municipalities to play in planning for and implementing FSM. The strategy should stimulate action by municipalities to actively operate and maintain their on-site sanitation systems. Since this has been historically neglected, municipalities need practical solutions for FSM that can be implemented immediately.

To close the gap between policy and implementation, this study aimed to provide an understanding of how some municipalities in South Africa are actively managing their wastewater and faecal sludge. By gathering information on the practical experiences of South African municipalities, these findings could help other municipalities to overcome their barriers to effectively managing their sludge.

This study aims to provide an understanding of how municipal sludge, including faecal sludge, is managed in South Africa and identify the challenges associated with sludge handling and disposal across the country. This was done through a series of case studies with municipalities. The outputs of this research should stimulate an increase in active planning for sludge management and sludge valorization. This study investigated the status quo of the costs associated with the management of wastewater sludge and faecal sludge in municipalities across the country and unpacked the financial implications associated with municipal sludge interventions across the full sludge management chain. The study considers the costs associated with collection, transport, treatment, disposal / recovery / reuse, monitoring, and quality control.

Methodology

As mentioned above, this study relied on a case study methodology to understand sludge management deeply. Case studies look at a single issue in-depth, with the goal of developing an intensive understanding of the topic. Due to the small sample size in case study research, results are

not generally used to draw broad general conclusions but rather point to key lessons and considerations for application in other contexts. The following process was followed to conduct these case studies:

1. **Desktop review:** At the start of the research, and throughout, the researchers reviewed existing documents to understand the current sludge management situation in the country. This also included reviewing existing legislation and guidelines.
2. **Key informant interviews:** When the research began, semi-structured key informant interviews were conducted with individuals working within the sludge management sector. These interviews aimed to understand policies driving sludge management in South Africa; structures that support sludge management; monitoring and regulation of sludge management; and gaps in sludge management practices. These were conducted virtually, and the interviews were recorded and transcribed verbatim. The aim of these interviews was to paint a general picture of sludge management in South Africa and gain information on potential case studies. The following individuals were interviewed:
    a. 2x National Department of Water and Sanitation (DWS) officials
    b. 1x Municipal Engineer
    c. 1x Provincial official
    d. 2x private sector representatives
3. **Identification of potential case studies:** The researchers drew on their existing contacts as well as recommendations from the key informant interviews to reach out to municipal officials who might be willing to participate in the case study research. In addition, PID presented about the research in some meetings with several municipalities in order to recruit participants. While a target was to conduct a total of 20 case studies under this research, the final number was dictated by participant willingness and existing data on sludge management. The final number of case studies completed was 13 (8 WW and 5 FS).
4. **Data gathering for case studies:** All case studies involved at least one semi-structured interview with individual(s) involved in the project. These interviews allowed participants to describe the approach, their motivation, and the challenges and successes of the approaches. Participants were also asked to elaborate on costs associated with the approach. During these interviews, the researchers requested additional data and documents to be shared, and these were shared by the participants afterwards where available. This included, inter alia, classification data, budgets, tender documents, and reports. In addition, where a metro-wide case study was done, the participant was asked to fill in a municipal questionnaire.
5. **Data analysis and preparation of case study reports:** The interviews and additional data were analysed and the case study reports prepared using a standard template. The drafts were shared with participants were their review and comment before finalising. Furthermore, in the final draft of the case studies, information on participating municipalities was anonymised, based on feedback from the Reference Group.
6. **Combined analysis of results:** The results from the various case studies were consolidated to allow for comparison and some generalised guidance. This led to the preparation of both the status quo analysis and the overview of sludge management costs. Analysis looked in depth at the cost of different aspects of the sludge management service chain. In the case of wastewater sludge, the cost of different sludge disposal methods was compared to the overall production cost as published in the Green Drop 2022 report.

7. **Preparation of summary briefs:** Once data was collected and analysed, the researchers prepared general briefs on the findings for wastewater and faecal sludge management respectively. One brief focuses on the costs of sludge management, including a resource for assessing different options. Another summary brief provides an overview of recommendations for improving and supporting sludge management efforts by municipalities.
8. **Preparation of dissemination videos:** The primary dissemination method identified for this research was the production of videos highlighting case studies (Deliverable 5). One video was produced on wastewater sludge management and a separate one was produced for faecal sludge management. These videos include interviews with the researchers and experts in the field, as well as interviews and footage of case study participants. These videos complement the report by providing visuals and making the findings real. These videos can be disseminated by the WRC and the researchers.

Sludge Management Case Studies

Table 1 summarises the 13 case studies conducted for this research. As mentioned above, these have been anonymised, but general details are provided. A total of 8 wastewater sludge and 5 faecal sludge case studies have been conducted, and the full case study reports can be found in Annexures A through M. The brief case study reports provide a description of specific approaches and the reported costs thereof. The individual case studies also describe the type(s) of data provided for each.

Table 1: Description of sludge case studies included in this study

No.	Municipality Type	Sludge type	End use/disposal description	Description of technology/approach
1	Metro	WW	Agriculture	Transport of sludge to sugarcane farms (retrospective, municipal contract)
2	Metro	WW	Landfill	Disposal of sludge in landfill (retrospective, municipal contract)
3	Metro	WW	Agriculture	Municipal-wide case study including agriculture application, and drying-composting (current, municipal contracts)
4	Metro	WW	Agriculture	Production of saleable fertiliser by a company using solar-dried sludge from the municipality (current, long-term municipal contract)
5	Metro	WW	Agriculture Landfill	Municipal-wide case study, including agriculture application and hazardous landfill disposal (current, municipal contracts)
6	Local	WW	Industrial crops	Application of sludge for turf grass production (current, lease agreement with private company)
7	Local	WW	Agriculture	Transportation of dried sludge for land application or composting (current, done internally by municipality)
8	Local	WW	Agriculture	Removal of sludge for agriculture (current, municipal contract)
9	District	FS	Agriculture	Dehydration toilet with heat treatment, product donated to community (current, private sector pilot)

No.	Municipality Type	Sludge type	End use/disposal description	Description of technology/approach
10	Local	FS	Burial	Manual emptying and transport/ burial on site (current, private company)
11	Metro	FS	Burial	Manual emptying of UDDTs with burial on site (retrospective, municipal contract)
12	Metro	FS	Agriculture	Transport of UD sludge to black soldier fly treatment (retrospective, municipal contract with private sector/academia partnership)
13	Metro	FS	WWT process	Emptying of chemical, container, and other sealed containment and treatment in WWTP (current, municipal contract)

Key findings

Key findings are summarised below for wastewater and faecal sludge management respectively.

Key findings on wastewater sludge management:

1. Status quo: A majority of South African WWTPs are currently stockpiling or storing sludge in lagoons on site. Most sludge is not classified, and in general, municipalities do not have sludge management plans in place. Where sludge is being disposed of, agricultural application is most common.
2. There is considerable interest in reuse opportunities for wastewater sludge. This is true among municipalities that see it as a vehicle for reducing costs and also among the private sector who sees market opportunities.
3. Procurement is seen as a main barrier to innovative partnerships between municipalities and the private sector, which is primarily due to a lack of awareness and understanding around the PPP process. Municipalities are reticent to pursue unconventional procurement options for fear of noncompliance. At the same time, innovative procurement solutions can unlock cost effective, circular economy options for wastewater sludge management.
4. The cost of transportation of wastewater sludge has the greatest bearing on the overall cost of sludge management. Keeping the transportation distance below 50km can keep costs down, as can reducing the weight of sludge to be transported.
5. The cost of compliance is not too high, but it is often neglected in planning. This includes classification of sludge as well as additional compliance requirements described in the *Sludge Guidelines* based on the given disposal method.
6. Performance of upstream WWT processes impacts the quantity and quality of wastewater sludge produced. Optimising existing WWT processes should be the starting point for improving sludge management.
7. Municipal representatives are eager to learn from one another about effective methods for managing their wastewater sludge. Studies like this one provide one platform, but additional platforms for municipalities to share with *one another* are required to enhance this process of learning.

Key findings on faecal sludge management:

1. Very few case studies on municipal faecal sludge management exist in South Africa. While some municipalities implement emptying on an "as-needed" basis, active planning for this activity is limited. As municipalities start implementing the *FSM Strategy*, this should change.
2. Roles and responsibilities for FSM are unclear within municipalities. The *FSM Strategy* defines the role of municipalities in FSM service delivery, but the specifics at the municipal level have not yet been fleshed out (i.e., who *in the municipality* is responsible for these things?). An effort to define these roles may require housing FSM within an existing unit and/or increasing personnel to cover the additional tasks.
3. The most common practice where faecal sludge is emptied from on-site sanitation systems is to discharge faecal sludge at the headworks of the WWTP. The quantities of faecal sludge discharged in this way are not well documented, and this has the potential to negatively impact the WWT process. This needs further oversight and monitoring to avoid this impact.
4. South Africa has considerable research and pilot-scale work going on in the FSM space. This provides a good starting point for implementing FSM at scale, but the transition from pilot to full scale is challenging. One pilot FSM project included in this study is cost-effective and can be scaled up, but getting the municipality fully on board has proven a challenge.

Limitations of the study

The case study approach limits the broad applicability and ability to make generalised conclusions. An online questionnaire was distributed to WSAs with the help of DWS colleagues, but only 2 responses were received. The Green Drop process could provide a much better opportunity to gather this type of information than individual researchers with very little sway with WSAs. To deepen the understanding of practices across the country, the Green Drop process should be utilised.

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1 Status Quo: Wastewater Sludge Management in South Africa

1.1 Understanding Wastewater Sludge Management

1.1.1 Definition and classification

According to the *Guidelines for the Utilisation and Disposal of Wastewater Sludge* (hereafter referred to as the *Sludge Guidelines*), wastewater sludge is defined as "material removed from wastewater treatment plants designed to treat predominantly domestic wastewater", including (Snyman & Herselman, 2006a):

- Raw or primary sludge from a primary clarifier
- Primary sludge from an elutriation process
- Anaerobically digested sludge
- Oxidation pond sludge
- Septic tank sludge and other sludge from on-site sanitation units
- Surplus or waste activated sludge
- Humus sludge
- Pasteurised sludge
- Heat-treated sludge
- Lime-stabilised sludge
- Composted sludge

Sludge characteristics vary widely based on the processes in the treatment plant to deal with sludge streams, as well as the initial source of wastewater being treated. Sludge can be characterised by three different key aspects, namely: stability, microbial contamination, and pollution (i.e., heavy metals contamination) (Snyman & Herselman, 2006a). According to the *Sludge Guidelines*, the characteristics of sludge in terms of these aspects determine the appropriate methods for managing the sludge. The National Norms and Standards for Domestic Water and Sanitation Services defines *sludge management* as follows (Department of Water and Sanitation, 2017):

> *Sludge management entails the emptying, transport, treatment, and disposal of wastewater, products of municipal wastewater treatment and effluent.*

According to the South African *National Water Act* (2017), the core norms and standards relating to sludge management include **prevention of pollution** and **reuse**. Sludge management must, first, ensure protection of the environment and the public by protecting water resources, disposing of sludge safely, and safely managing all waste streams. By encouraging reuse, sanitation services can ensure sustainability (Department of Water and Sanitation, 2017).

1.1.2 Regulatory Framework for Wastewater Sludge Management

The *National Water Act* states that wastewater and sludge must be managed by local authorities and service providers in accordance with the *Sludge Guidelines* (Snyman & Herselmen, 2006). These

guidelines importantly provide a framework for classifying sludge in terms of microbiological content, stability, and organic and inorganic pollutants, and then determining appropriate use or disposal options based on the classification. The *Guidelines* encourage reuse and acknowledge that reuse will not be possible in every instance, thus providing guidance for safe disposal. Importantly, the 2022 *Green Drop National Report* (DWS, 2022) required that solids/sludge must be classified as per these *Guidelines*. In the most recent Green Drop assessment, a bonus point was introduced for the first time for sludge reuse.

Furthermore, sludge disposal and reuse are governed by the National Environmental Management: Waste Act (Act no. 59 of 2008) (NEMWA). NEMWA includes Norms and Standards for Disposal of Waste to Landfill (2013) and Norms and Standards for Organic Waste Composting (2021). The Norms and Standards for disposal of waste to landfill limit the disposal of wastewater sludge in landfills, which has led municipalities to try to find other methods for dealing with sludge. The Norms and Standards for Organic Waste Composting apply to sewage sludge that adheres to the National Water Act, which requires that sludge meet the minimum requirements for beneficial use specified in the *Sludge Guidelines*.

1.2 Current WW Sludge Management Practices in South Africa

1.2.1 Quantities of WW sludge being generated

The Department of Water and Sanitation (DWS) IRIS database includes data from 1162 wastewater treatment plants (WWTPs) in South Africa. The 2022 Green Drop Report provides data for 850 WWTPs owned by 144 WSAs, 115 WWTPs owned by the Department of Public Works, and 30 other WWTPs. Considering the WSA-owned WWTPs, the design capacity is 6 972 Mℓ/day, and the actual capacity utilised in 2022 was 4 902 Mℓ/day.

Using one metro as an example, Abdelmegeed (2022) found that, on average, 115 dry tonnes of WW sludge are produced per day by 24 WWTPs. According to the 2022 Green Drop report, these 24 treatment plants have a combined design capacity of 714 Mℓ/day, of which only 427 Mℓ/day capacity is utilised. Thus, approximately 0.27 dry tons of sludge are produced per Mℓ of wastewater treated. Extrapolating this situation across the country based on actual capacity utilised, approximately 1 320 dry tons of WWTP sludge are produced per day in South Africa, or 482 000 dry tons per year. If the full design capacity were utilised, sludge production would be approximately 1 880 dry tons per day, or 686 200 dry tons per year. Furthermore, it should be noted that flow data was not available for all WWTPs in the 2022 Green Drop report; thus, sludge tonnage can be expected to be even higher.

1.2.2 WW sludge management in South Africa

Sludge management in WWTPs includes treatment approaches and disposal or use approaches. The 2022 Green Drop Report provides an overview of the main sludge treatment approaches at all 850 WSA-run WWTPs across the country, and this is shown in Figure 1. It is most notable that at 312 out of 850 WWTPs, sludge treatment is listed as “none (insufficient info)”. The Green Drop Report acknowledges this gap and notes that future audits must clarify this missing information. The most common treatment method is solar/thermal drying beds, which are used at 256 out of 850 treatment

plants. Other treatment methods include sludge lagoon/ponds (99), belt press dewatering (73), anaerobic digestion (50), gravity sludge thickening (8), rotary/centrifugal sludge thickeners (3), and composting (1). These different treatment approaches lend themselves to different end use or disposal routes.

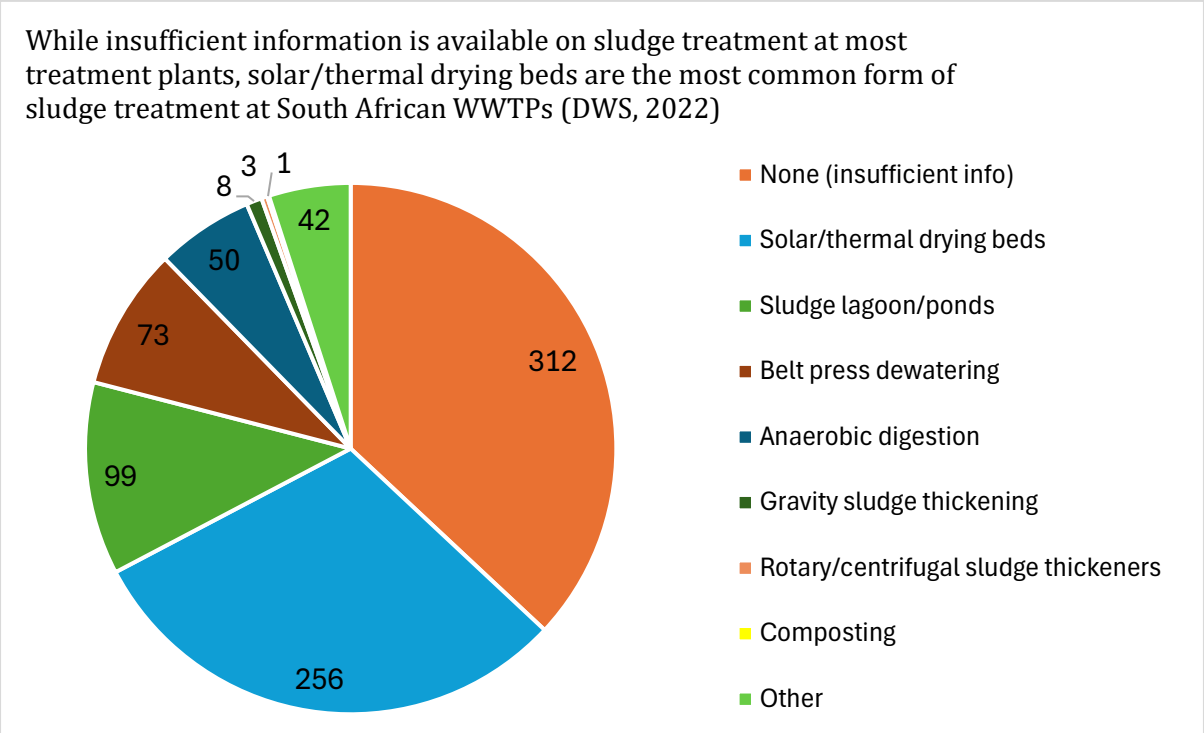


Figure 1: Treatment technologies for wastewater sludge in SA (DWS, 2022)

The Green Drop report provides only a high-level summary of how many treatment plants across the country do something (reuse or disposal) with their sludge, stating that "165 plants (19.4%) use sludge mostly for agricultural purposes, landfill, thermal sludge practice, and commercial products." The approaches used by these treatment plants are elaborated on below. While the Green Drop Report does not provide further information on the number of WWTPs using each approach, it is assumed that agricultural use and landfill are the most common. According to the report, 3% of WWTPs have sludge reuse projects in place.

- Agricultural use: This use is covered by Volume 2 of the *Sludge Guidelines* and encompasses appropriate use of sludge in agricultural practices (Snyman & Herselman, 2006b). This includes use of sludge as a nutrient source and/or soil conditioner at agronomic rates; managing compost produced with sludge that is not sold or distributed to the general public; and use of sludge in municipal parks. Agricultural use of sludge may be done internally on a municipality's own land, or it may involve external users applying sludge to their land for crop production.
- Landfill: This is covered by Volume 3 of the *Sludge Guidelines*, which discusses disposal of sludge (Herselman & Snyman, 2009). It is important to note that developments in 2013 in the National Environmental Management: Waste Act (NEMWA) 59 of 2008 have led to certain restrictions on disposal of sludge to landfill, depending on the quality of the sludge. Furthermore, finite space in landfills has also led landfills to reject sludge from WWTPs.
- Thermal sludge practice: This is covered by Volume 5 (section A) of the *Sludge Guidelines* and includes combustion (sludge only or co-combustion) and pyrolysis. Thermal treatment is most

appropriate for sludge with a low microbial class (B or C); high stability class (3); and low pollutant loads (a).

- Commercial products: This is covered by Volume 5 (section B) of the *Sludge Guidelines*, which discusses fertiliser products (e.g., compost, pellets) and construction materials (e.g., bricks, cement) containing sludge.

The above means that the remaining 685 (80.6%) plants are not using their sludge, suggesting long-term storage in lagoons or stockpiling on the WWTP land. In 2006 when the *Sludge Guidelines* were first published, the DWS had already deemed indefinite storage of sludge, or "stockpiling", as unacceptable. For many of the small treatment plants in the country, sludge production is low, and the cost of dealing with the sludge is high, which is why this practice is widespread. The Green Drop Report states that 23% of WWTPs classify their sludge according to the *Sludge Guidelines*. It can be assumed that most of those *not* classifying their sludge are also stockpiling their sludge, because to move sludge off site, it must be classified.

The Green Drop Report highlights the importance of monitoring of sludge compliance for improving processes, presenting the following concerning results based on 850 systems audited (DWS, 2022):

- 13% monitor sludge streams
- 15% have sludge management plans in place

Without data on sludge streams, it is not possible to plan for what should be done with sludge. It appears from these results that the important first step is to institute monitoring and classification of sludge streams to enable informed decision-making, as outlined in the *Sludge Guidelines*, which are currently being updated.

The sections below provide examples of specific WW sludge management approaches throughout the country. These descriptions are based on data collected through this study as well as previously published information. The detailed wastewater sludge case study reports are provided in Annexures A through H.

1.2.2.1 Agricultural application and landfill disposal (metro)

This metro municipality has gone through several different sludge management approaches in the past 2 decades. They operate 27 wastewater treatment plants treating 460 Mℓ/day. In the past, these produced 100 dry tons of sludge, but the reality has changed over time, according to an internal municipal report.

According to Alcock, in 2009, 46% of sludge was disposed of to sea outfall; 43% was stockpiled on site; 6% was sent to landfill; and 5% was composted. In response to large stockpiles, in 2009, tenders were invited for removal of 80,000 cubic metres of sludge from two of the large WWTPs (internal municipal report). This sludge was applied to agricultural land. This contract continued for 3 years, and in 2012, a new tender was advertised. This tender included delivery of sludge to sugarcane farmers and all necessary monitoring as per the *Sludge Guidelines* and ran for 3 years. In 2015, an emergency sludge transport contract was initiated, and sludge was disposed of to agriculture or landfill.

As of early 2021, sludge production in the municipality decreased to zero, due mainly to dysfunctional sludge treatment equipment. In the absence of functional treatment units for sludge (drying and dewatering primarily), wet sludge is transported to Southern Works where it is sent to sea outfall. In

2022, Abdelmegeed conducted an independent study on the municipality's sludge management and found that 71% of sewage sludge was sent to sea outfall, followed by 18% sent to landfill, 10% disposed of on-site, and 0.17% used in agriculture. This represents a large shift from the practices in 2015, when much of the WW sludge was used in agriculture.

While several different approaches have shown potential in the municipality, the current approach of sending sludge-to-sea outfall is not cost-effective and paints a picture of sludge as a waste to be removed, rather than a potential resource. In an internal 2023 report on sludge management in the metro, the following key recommendations to improve sludge management were made:

1. Repairing all sludge treatment plants and equipment to allow production of dewatered sludge.
2. Developing a sludge master plan to inform management and disposal of sludge
3. Using sludge as a resource, considering a "basket of technologies" that would suit different types of sludges
4. Improving sludge classification through effective sludge treatment

The following case studies provide further details on past sludge management efforts in the metro, including cost implications:

- Case Study 1: Application of sludge in sugarcane farms (Annexure A)
- Case Study 2: Landfill disposal of sludge (Annexure B)

1.2.2.2 Coordinated sludge management for agricultural application (metro)

Case Study 3 includes a city-wide look into sludge management in another metro municipality. The metro operates 6 WWTPs with a combined design capacity of 1,058 Mℓ/day. Respondents in this study indicated that a total of 1 430 cubic metres of wastewater sludge are produced per day. The municipality has prioritised reuse of wastewater sludge through agricultural application and composting. They have demonstrated a commitment to planning for and improving sludge management by appointing a Sludge Manager, who focuses solely on sludge treatment and disposal. According to data provided, the metro handles approximately 45,360 dry tons of WW sludge per year, or 124 dry tons per day. In 2010, when 980 Mℓ were treated per day, the municipality noted that ideal sludge production would be 260 dry tons each day (Boyd et al., 2010). Thus, sludge production now is low, due to various operational challenges, as stated by the sludge manager.

At present, 60% of WW sludge is solar dried and then composted, while the remaining 40% is delivered to farmers and applied in line with the *Sludge Guidelines*, Volume 2. The aim is to increase the drying/composting operation to cover the entire metro.

The method of drying and composting without the use of a bulking agent began in 2009, with the aim of producing an A1a sludge that can be safely reused and sold. At present, the limitations to the drying/composting approach covering the whole city include necessary upgrades to the treatment works, particularly digesters to ensure stabilisation, and improving drying to achieve effective composting. The main barriers to improving drying are climatic factors and having sufficient drying space.

This case study, while exemplifying a relatively simple reuse opportunity through agricultural application, highlights the high cost of sludge transport and limitations of agricultural use. According to Volume 2 of the *Sludge Guidelines*, the maximum application rate is 10 dry tons per hectare per year. Based on current quantities, this means that approximately 1,800 hectares of farmland are required per year for agricultural application of sludge. According to the Sludge Manager, the space limitation means that they sometimes must take sludge to farms that are far away from the treatment works, and the cost of transporting the sludge becomes exorbitant.

Coordinated planning for sludge management across the metro is commendable. While the ultimate goal of producing a saleable product is noteworthy, even if the final product is not sold, there is an opportunity to reduce the cost of transport through the low-tech option of drying and composting.

1.2.2.3 Beneficiation of WW sludge by private contractor (metro)

This municipality has 16 wastewater treatment plants serving a population of 3.28 million people. The combined design capacity of these treatment plants is 600 Mℓ/day. According to the 2022 Green Drop report, the average Green Drop score for these treatment plants was 60%, ranging from 29% to 98%. Sludge management in this municipality varies, with most plants drying and stockpiling digested sludge, while some treatment plants have arrangements with private parties that take the sludge for their own use. At two of the treatment plants, the metro has an arrangement with a private company specialising in beneficiation of sewage sludge.

The company utilises dewatered sewage sludge to produce a fertiliser, which is enhanced by the organic matter in the sewage sludge and blended to meet specific farms' fertiliser needs. Dewatered sewage sludge is received by the private company and then undergoes a process of further drying, granulation, and then blending with chemical fertiliser to meet the nutrient needs. While the processing of sludge to dried granules takes place on site at the given WWTP, blending takes place at specific blending facilities that are located closer to the farms that purchase the fertiliser.

The company currently only receives 6 dry tons of sludge per day from one of the treatment plants, which is far below the potential capacity of 70 dry tons per day. This can partly be explained by the fact that the specific treatment plant is currently using only 50% of its design capacity of 54.5Mℓ/day. With a Green Drop score of 69%, this plant is also not certified in terms of Green Drop criteria, which suggests that the treatment process is not operating optimally, and this can influence sludge production. According to the company representative, this plant also has the option to apply digested sludge on sacrificial land, which may divert some from the beneficiation process.

This project has been in operation since 2012, and the company has a 15-year contract to conduct the work. The project originally went out on a 2-stage tender process. Typically, service contracts are only awarded on 3-year bases, due to restrictions in the Municipal Finance Management Act (MFMA). However, in this case, no funds are paid by the municipality to the contractor, which makes this limitation fall away, according to the municipal representative. Rather, an arrangement is made for the contractor to pay the municipality either for the sludge itself or through a monthly rental fee for the land.

Case Study 4 (Annexure D) provides more detail on the sludge beneficiation arrangement between the private company and the municipality.

1.2.2.4 Agricultural application of sludge and plans for beneficiation (metro)

In 2021, one province published the *Sewage Sludge Status Quo Report,* which is one of a kind in the country. This report provided a detailed analysis of sewage sludge management across the province's municipalities. The report highlighted the types of sludge being handled across the province, treatment methods utilised, and disposal or beneficiation efforts in use. The report states that in 2016, 191 000 tons of WW sludge were produced by the metro. At that time, sludge was generally either disposed of at hazardous landfills or applied to land for agricultural use. The report estimated that the metro would potentially run out of suitable agricultural land in 5-10 years, which necessitated the plan for beneficiation facilities.

The metro worked with consultants to conduct feasibility studies to understand the options for sludge beneficiation, settling on a recommendation for 3 regional Biosolids Beneficiation Facilities (BBFs), which include anaerobic digestion and combined heating and power generation. The report from 2021 highlighted that these facilities are intended to reduce sludge quantities, produce a beneficiated A1a product, and recover nutrients from sludge. In addition, these facilities would produce electricity.

The primary barrier to implementing these three BBFs is the high capital cost. For this reason, the plan is to phase these facilities in over time. While the first facility was meant to be operational in 2015, budget cuts and reprioritisation due to drought led to this project being delayed. At present, planning and financing for the first facility is underway. This demonstrates the challenges with limited budgets and sludge management competing with other critical services, such as water supply and wastewater treatment.

Case Study 5 (Annexure E) presents further details about the current practices and future plans for sludge management in this metro municipality.

1.2.2.5 Water Services Provider managing sludge for several municipalities

A water services provider (WSP) has operation and maintenance agreements with three municipalities. Under these agreements, they operate and maintain 9 WWTPs, all of which vary in size. The largest treatment plant utilises high-rate continuous application of sludge (Volume 4) for production of turf grass. The land belongs to the municipality and is leased by a private business that grows and sells the turf grass. This operation began as a research study in 2005 and has been maintained ever since, with the WSP investing in new capital equipment as well as operation and maintenance of the site, and the private company paying rent on the land, which covers the cost of maintenance. This approach is mutually beneficial because sludge transport costs are negligible, thus reducing the cost to the water services provider, and the private business has built up a clientele over a long period of time that enables the business to continue to operate.

In 2018, changing legislation around disposal of sludge in landfills led the WSP to find a new solution for sludge disposal for their smaller treatment plants. They saw an opportunity to use the existing facilities at the larger WWTP to handle sludge from the smaller treatment plants. In agreement with the private company, the WSP began transporting sludge from 5 of the smaller treatment works to

the turf grass site, where it is spread on a flat area to dry. The private company then either uses the dried sludge on their turf grass lands or composts it as part of an ongoing research study in collaboration with a local university.

This operation demonstrates the different challenges faced by treatment plants of different sizes and highlights a solution that benefits both the water services provider and a private company. While some complications exist around contracts for such an arrangement, the way the company has been able to build a business is promising, demonstrating an appetite for sludge reuse. The following case studies will provide further detail on the operations described here:

- Case Study 6: High-rate continuous application of WW sludge for turf grass production (Annexure F)
- Case Study 7: Transport of WW sludge from small treatment plants for drying and reuse (Annexure G)

1.2.2.6 Sludge Stockpiling (local municipality)

This local municipality operates 3 WWTPs, one with a design capacity of 32 Mℓ/day and 2 with approximately 8Mℓ/day design capacity. In general, WW sludge is treated in digesters and then pumped to drying beds before being stockpiled on site. Sludge is removed from drying beds manually by general workers. According to the acting assistant manager for wastewater management, there are some local individuals and businesses that collect stockpiled sludge from the WWTPs, though this is not formalised. No classification of sludge is done.

The interviewed representative from the municipality indicated that they had discussed their sludge management options with the Department of Water and Sanitation (DWS), and the DWS was supporting them to understand how to classify their sludge and what options would be feasible for beneficiating their sludge. The motivation for investigating alternatives to stockpiling is primarily to comply with the DWS's regulations and prevent pollution of the environment.

Based on the results from the Green Drop report on sludge compliance, this municipality presents a case like most treatment plants in the country that are stockpiling sludge and not classifying it. For small treatment plants, the financial burden of this practice is not so much, but the need to comply would be the motivator to find alternatives. This would be especially true if penalties for sludge non-compliance were introduced to the Green Drop assessment.

Only one interview was conducted with this municipality, and no additional data was received. Thus, there is no standalone case study report.

1.2.2.7 Agricultural application of sludge (local municipality)

This local municipality operates seven WWTPs with a combined total capacity of 18 Mℓ/day. All these treatment plants are activated sludge plants with no anaerobic digestion, ranging from 0.2 Mℓ/day to 5 Mℓ/day. Historically, most of the sludge from these plants has been stockpiled. The municipal engineer stated that their goal as a municipality is to get 5 Green Drops out of 7 WWTPs, and sludge compliance is seen as an "easy" way for them to get points.

> *… because the Green Drop scoring chart gives points for sludge removal, it was one of the motivating factors for us to do it because we're focusing on all the elements that we can score easy points.* – Municipal engineer

To achieve their goals, the municipality classifies sludge from all their treatment plants. Furthermore, in 2022, the municipality advertised a tender for removal of sludge from their two largest WWTPs. Sludge is collected from these two treatment plants and then disposed of for agriculture, as per the *Sludge Guidelines*.

The tender advertised in 2022 stated that the municipality has B1a sludge that needs to be dealt with in accordance with the *Sludge Guidelines* and requested solutions from potential bidders. According to an engineer from the municipality, they received a wide range of solutions, from agricultural application to disposal in landfill, and a wide range of prices from R1 million to R14 million (landfill disposal being the highest cost option). This contract was only initiated for 1 year, as it was a new project, and if it is successful, they will re-advertise on a 3-year basis.

While the solution is working in terms of compliance, it costs the municipality a considerable amount of money due to the transport costs. Due to the small size of the treatment plants, economies of scale are limited to attract more cost-effective business opportunities. The participant mentioned that arrangements with beneficiation businesses were in place in the past, but it proved not cost-effective for the business entity. Therefore, the municipality ends up paying someone to remove the sludge for them, and that person/business sells the products. It is lucrative for the business, but a cost burden for the municipality.

The details of sludge management in this local municipality are provided in Case Study 8 (Annexure H).

1.3 Discussion of WW Sludge Management in South Africa

1.3.1 Discussion of successes

1.3.1.1 Interest in sludge reuse

The interviews conducted point to a general interest in sludge reuse, both from the municipal perspective and from the private sector. From the municipal perspective, there is interest in how reuse of sludge can aid in addressing compliance issues and reduce the cost of sludge transport.

> *There's an acceptance in municipalities that they have a problem with sludge management. And they are therefore looking for solutions. I mean, you could just see with the stockpiling some of them, some of them are really, huge, huge, huge heaps of wastewater [sludge]. So, we've seen that … there is an interest in re-use, because by doing that, we'll also be solving their problems.* – DWS National Representative

For the private sector, there is an interest in the business opportunities surrounding sludge reuse. The municipal representative for Case Study 8 noted that the private business that is contracted to remove their sludge sometimes phones him to ask if there is sludge to be removed, suggesting he likely has

demand for the final product. Similarly, private businesses in Case Studies 4 and 6 both noted that the sludge production cannot keep up with the demand for their products. Provincial representatives interviewed shared that a company based in Namibia was importing sludge to South Africa, highlighting the high demand for beneficiated sludge.

1.3.1.2 Compliance driving sludge management action

Interviews with municipalities and water services providers pointed to the effectiveness of the Green Drop Audit for motivating some to improve sludge management. A bonus point is issued for sludge reuse, and there are requirements for classifying sludge. Particularly in one local municipality, achieving Green Drop status was highlighted as an important factor driving innovation in the sludge management space, and particularly, moving away from stockpiling of sludge. This demonstrates that the Green Drop audit process is playing its role, and its effectiveness may be increased by introducing penalties for sludge non-compliance.

In a similar way, provincial representatives within the waste department highlighted that people began thinking more about reuse of sludge due to targets set for diversion of organic waste from landfill as well as the banning of liquid waste in landfills. This highlights the power of policy to drive shifts in practice. While some motivation comes from interest and desire to improve cost-effectiveness, additional motivation comes from complying with regulations. In other words, "Necessity [to comply may be] the mother of invention." (Plato)

1.3.1.3 Research on sludge

While municipalities and water services providers are pushing to comply with the regulations, some are also engaged in research that can improve their own practices and inform approaches by others in the wastewater sector. For one WSP, the approach of applying sludge to turf grass began as a research project and has now become the go-to approach for sludge management. One metro, while focused on getting WW and sludge management up to standard, is also pressing forward with their own innovations and research:

> *[We are] groundbreaking because we try to do things in parallel, even though [infrastructure] may be falling apart… on the right-hand side, on our left-hand side we, we are still doing our research. We're still pushing ahead; we're still trying…because when things…get back online, we need to have a vision and a plan.*

Finally, another WSP in a metro exemplifies a commitment to improving sludge management through the appointment of a Sludge Manager for all treatment plants. He oversees the solar drying/composting approach that has been in development for over a decade and is currently being optimised. This is a good example of applied research and a commitment to improving sludge management incrementally and in a way that is informed by research.

1.3.1.4 Planning processes in place

Particularly in large metros, planning is critical to ensuring effective sludge management. In one metro, this is being done through the creation of a sludge management strategy. The municipal representative suggested that they need "a basket of options for sludge disposal because it's not a

one-size-fits-all [problem]". Another metro is similarly involved in a sludge management planning process to ensure that they apply the most appropriate solution in their treatment plants. Planning for sludge management works in contrast to an emergency approach to sludge management, in which stockpiles are dealt with as and when they become too big to handle or contain.

1.3.2 Discussion of obstacles

The 2022 Green Drop Report highlights sludge non-compliance as one of the most prominent risks to treatment plant compliance. While anaerobic digesters play a significant role in sludge treatment in South Africa, results of the Green Drop assessment show that many anaerobic digesters are either fully committed or have limited spare capacity, while others are facing operational issues (DWS, 2022). The report states that sludge and liquid treatment are interdependent, which means that failures or lack of capacity with regard to sludge treatment will impact the overall treatment capability. The report also highlights the importance of sludge handling, stating, "Sludge handling is often the rate limiting step and the highest risk in the wastewater treatment process." This section summarises some of the key obstacles to sludge compliance and sustainable solutions. The obstacles most mentioned by interviewed participants are shown in Figure 2, with larger words indicating more mentions.

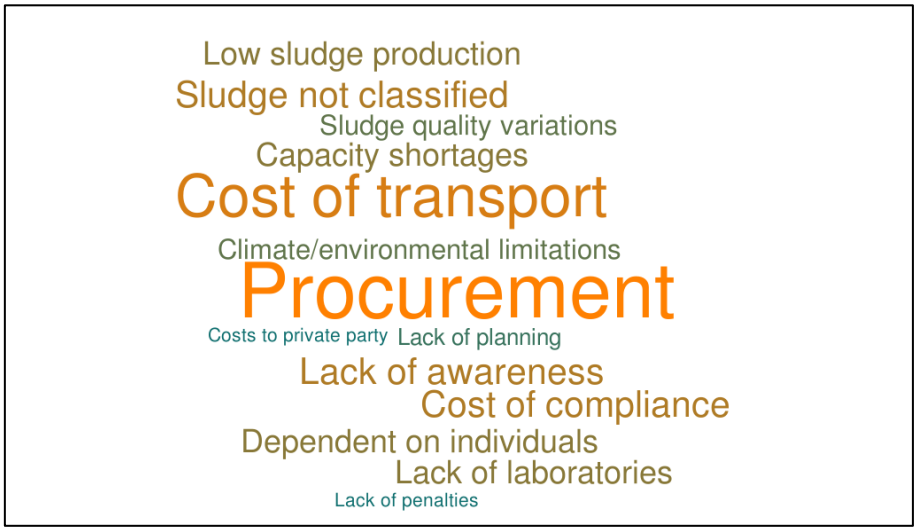


Figure 2: Primary barriers to sludge management identified by interviewed participants

1.3.2.1 Procurement challenges

> *I think procuring services for managing of sludge can be quite tedious. We're put under the same legislation that manages the procurement of books and papers and services and all of that, whereas… there's not a big pool of contractors that [can manage sludge]…*
>
> - WSP representative

Procurement challenges were particularly mentioned with regard to mutually beneficial partnerships with private businesses interested in beneficiating sludge. The Municipal Finance Management Act (MFMA) limits contract periods to 3 years, and any contracts that are longer require special permission and processes. In the case of one local municipality, where the contractor is being paid to take the sludge away, this contract time limit makes perfect sense to ensure a transparent and equitable

process. However, in the cases of two other municipalities, where the contractor is expected to pay the water services provider for the sludge and/or use of municipal land, the 3-year period is limiting.

One WSP representative highlighted that 3 years is simply not long enough for a business to get up and running, which makes these types of contracts unappealing to new businesses and contractors. She highlighted that the current business using their sludge to produce turf grass took "12 years to become fully established", and "if you were to find somebody else, it will take them that much time." As a result, while they have made multiple attempts to advertise a tender for the beneficiation of sludge on their behalf, no contractors have responded save for the business currently operating there. In addition to the 3-year limitation, she also highlighted the lengthy process of pursuing alternative arrangements, such as public-private partnerships.

In the case of the metro municipality where sludge is beneficiated, the municipality has entered into a longer-term contract with the business under the premise that money is not being paid to them, but rather that the business is paying the municipality in the form of land rental. Given a longer-term contract (15 years), there is more motivation for businesses to tender as long as they can see the opportunities to beneficiate sludge. The compliance of this approach with the MFMA needs to be clarified, but it presents an innovative approach that benefits both parties while observing the MFMA. According to one business beneficiating sludge, other municipalities have been risk-averse and unwilling to consider such an arrangement.

1.3.2.2 Cost of sludge transport

One likely reason that so many WWTPs stockpile sludge is the high cost of transporting sludge. Sludge removed from WWTPs is transported either in tankers or tipper trucks, and the distance to the end use/disposal site has an impact on the cost of sludge transport. In this study, several participants reported costs for transporting sludge, either to a landfill or to agricultural land. The reported transport costs per ton are shown in Figure 3. This figure shows that the cost of sludge transport typically ranges from R300 to R500 per ton, up to a haulage distance of 50 kilometres. For the one treatment plant beyond that radius, the cost is higher, suggesting that beyond 50km, the distance to the disposal point starts to have a larger impact on the transport cost. One WSP reported a target of limiting sludge transport to farms within 60 kilometres.

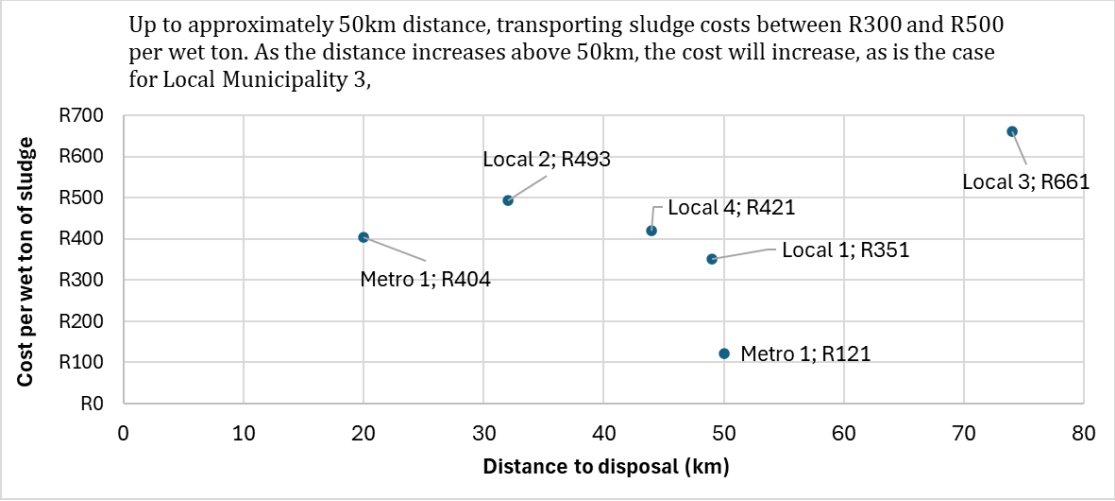


Figure 3: Transport costs per ton, reported by 3 water services providers

Another factor that will impact the cost of sludge transport is the characteristics of the sludge being transported, as described by one WSP representative "if the sludge is not… the right consistency, it costs us more [because] you have more loads…It definitely gets affected by the quality of the sludge that we produce in the performance of those dewatering machines." Transport costs are typically reported in rands per ton, as the weight limit of trucks transporting sludge will determine how much sludge can be transported. Therefore, if the weight of sludge is reduced, it can be assumed that the cost of transport would be reduced as well.

Rates provided by one metro for an emergency sludge removal contract in 2015 were listed as rate per cubic metre, rather than per ton. Rates were provided for 8 different WWTPs and for 3 different kinds of sludge, namely: waste activated, digested, and drying beds. The average rate per cubic metre for each type of sludge is shown in Figure 4. The average cost per cubic metre of transporting activated sludge is higher than for transporting dried sludge. This is likely due to the reduced weight of dried sludge and therefore more efficient transport. For this reason, metros are focused on improving their drying process. They also believe that by drying their sludge more effectively, they will be able to ask farmers to collect the sludge from their WWTPs, thus negating the transport cost altogether.

> *Three truckloads of 30 tonnes of wet sludge will be reduced to 1 truckload after you've dried it… when we transport…we are trying to avoid transporting more dry than wet… [transporting 80% water is] not feasible [or] profitable for the company.* – Sludge Manager

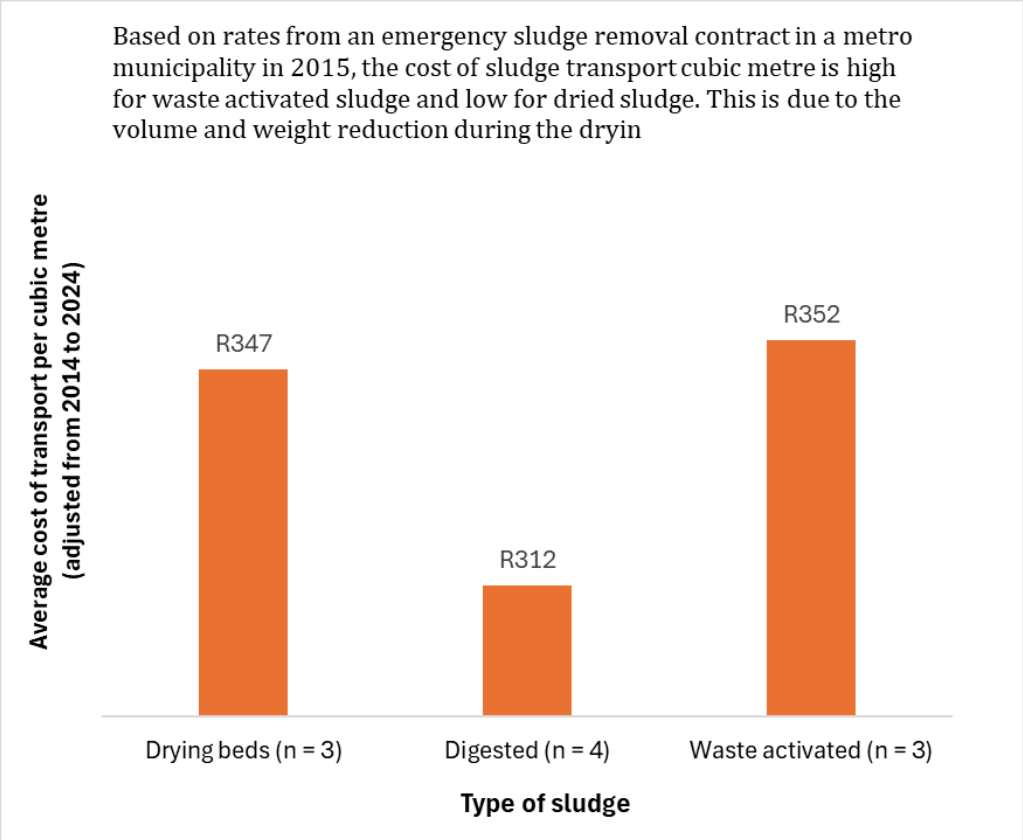


Figure 4: Rates for sludge removal per cubic metre, reported by a municipality for a 2015 contract, adjusted to 2024 prices (note: distances unknown)

1.3.2.1 Lack of awareness/attention to sludge

In this study, only one individual from a WSP with a specific responsibility around sludge management was interviewed. The other individuals, while knowledgeable and qualified, had a much larger portfolio to focus on. This points to the fact that sludge management is competing with several other responsibilities for the attention of municipal and water service provider representatives. According to one participant, sludge is generally a neglected aspect of wastewater treatment, and the cost of managing it is underestimated.

> *We tend to understate the cost of managing sludge. I know back then you would look at a… process flow diagram for a wastewater treatment plant and you will just see a line saying 'sludge'... and I think… we've woken up and to the reality that actually managing sludge is…a very big cost and it's not properly factored in even when we do the designs… the engineer will just say, '… the sludge will be dewatered and then then what? You know so it's not part of the project lifecycle it's like you will have a different component for dealing with sludge later on whereas it's a lifetime cost....*
>
> – Operational Director at a WSP

Sludge is often just treated as an operational challenge to address, placed on treatment plant operators, rather than being systematically planned for. This is evidenced in the fact that only 12.5% of treatment plants audited in the Green Drop process had sludge management plans in place.

1.3.2.2 Lack of monitoring of sludge management

The Green Drop report (2022) highlighted the gap in data on WW sludge, which limits municipalities' abilities to make decisions about their WW sludge. The report highlighted that only 13% of treatment plants monitor sludge streams. In 2009, Alcock conducted a study to define what municipalities were doing with their wastewater sludge at the time. Poignantly, the author stated, "No sooner has a city developed a plan to deal with a certain quantity of sludge then the plan is no longer sufficient", thus acknowledging that his study would quickly become out-of-date. This emphasises the need to collect and continuously update data on sludge management.

> *[Sludge treatment is] not really rocket science but it requires constant attention. You have got to monitor temperatures, …the feeding rate… in the public sector the environment, if the attention is not there you, after a few months or years you find that these things will just collapse.*
>
> – Municipal representative

1.3.2.3 Sludge not being classified

Similarly, the Green Drop report identified that only 23% of treatment plants classify their sludge as per the *Sludge Guidelines* (DWS, 2022). Classification of sludge is an important part of sludge management, because sludge classification determines appropriate reuse or disposal options (Snyman & Herselman, 2006a). So, why don't municipalities classify their sludge?

- Cost limitations: According to one municipal representative, classification "will add to the cost of sludge management, and the municipality is not currently in a good financial position to go out and pay for additional services just to be compliant."
- Lack of awareness of laboratories: Municipalities that do not get sludge classified do not necessarily know where they can send their sludge for analysis. This is particularly true for smaller, more remote municipalities who look to national or provincial offices for guidance. The Green Drop Report 2022 states that 64% of WSAs have access to credible laboratories and the remaining WSAs are unable to access services that will help them to comply with the sludge classification requirement.
- Lack of awareness about the classification purpose and process: The DWS individuals interviewed in this study pointed to a lack of awareness on the guidelines and therefore lack of awareness on the classification process. One interviewed municipal representative said in his interview that there is a need for a standard to check sludge quality against, whereas the guidelines provide precisely that standard.

1.3.2.4 Limited skills and capacity

The 2022 Green Drop report states that strengthening technical skills and operational capacity with regards to sludge management should be a key focus for future improvements. Capacity shortages in terms of laboratory skills, technical knowledge, and time/attention were mentioned by study participants. With a limited number of staff and limited budgets, municipalities and water services providers must make decisions about what to focus on. The representative from Tshwane spoke specifically about a lack of capacity in the internal laboratory to classify the sludge. He described how there was previously someone within the municipality who had the technical knowledge to do microbial analysis, but when she retired, the skills were not properly transferred and also some of the analysis equipment stopped working.

1.3.3 Ideas to improve sludge management

Participants in this study suggested that municipalities should share ideas with one another to contribute to increased skills and capacity within the sector. The DWS participants suggested that efforts being done throughout the country should be showcased to encourage learning.

> *I would say let us talk together and cross [pollinate] on the successes as well as challenges that you experience in sludge management… I think South Africa can work together and be a better place.*
>
> – Municipal representative

The DWS plays a critical role in supporting WSAs to fulfil their obligations. DWS representatives interviewed in this study confirmed this key role, and interviewed municipal representatives agree. One municipality mentioned specific support that DWS was providing to them in terms of identifying beneficiation opportunities and laboratories for classification. Increasing skills and capacity, particularly at the smaller WSAs, will require this practical ongoing support from DWS.

The following additional ideas were discussed by participants in this study to improve WW sludge management in South Africa:

- **Investigate private partnerships**: This was mentioned by several participants, including those that currently have partnerships with private companies and those that do not. This recommendation involves identifying individuals/businesses with an interest in sludge beneficiation, investigating partnerships that are mutually beneficial, and understanding the implications of the PFMA and MFMA for these types of partnerships. The municipal/water service provider representatives in this study acknowledge that a private partnership must benefit both parties.
- **Procurement arrangements**: The strategy of a long-term contract approved on the basis of funds flowing to the municipality (as opposed to away) seems to have worked well in terms of supporting a private partnership in one case. This strategy should be investigated in relation to the MFMA and then shared with other municipalities as a strategy for supporting private sector engagement in sludge beneficiation. As described by one private company, the arrangement they have works within the legislation and supports *both* parties, which is advantageous. The representative from another WSP also noted that this issue of sludge management requires special arrangements or consideration from a procurement point of view.
- **Improve sludge planning tools:** The Green Drop points to a lack of planning around sludge management. One participant suggested that a template for a sludge management strategy should be developed, and one representative said that sludge management should be planned for from the very early stages of wastewater treatment design. DWS also spoke about improving existing planning tools, such as Water Services Development Plans (WSDPs) to cover this topic.
- **Production of saleable product:** Municipal representatives, particularly those where sludge is being beneficiated by a private company, recognise the potential to generate income by selling beneficiated sludge. Income generated can be used to offset the cost of sludge management.

2 Status Quo: Faecal Sludge Management in South Africa

2.1 Understanding Faecal Sludge Management

2.1.1 Definition and classification

Faecal sludge is defined as human excreta (faeces and urine), water, anal cleansing materials, menstrual hygiene products, and sometimes solid waste that accumulates in on-site sanitation systems and is not transported through sewers (DWS, 2023b). Given that the National Sanitation Policy (2016) acknowledges on-site sanitation as an acceptable solution for municipal sanitation services, faecal sludge will continue to be produced across South Africa for years to come. Faecal Sludge Management (FSM) encompasses activities to *safely manage* faecal sludge from the place where it is produced to the location where it is eventually disposed of or beneficiated. FSM activities are encompassed in the FSM Service Chain, which includes containment, emptying, transport, treatment, and disposal/beneficial use (DWS, 2023b).

Faecal sludge is produced on a household or neighbourhood scale (for communal toilets), and therefore its properties vary widely. Faecal sludge characteristics are influenced by, inter alia:

- Sanitation technology used (e.g., dry vs. wet systems)
- Containment type (e.g., sealed, or permeable) and size
- Household practices (e.g., anal cleansing, trash disposal)
- Environmental factors (e.g., soil, water table, climate)

Therefore, it is difficult to classify faecal sludge. A study by Strande et al. (2018) proposed a method for estimating quantities and qualities of faecal sludge by considering averages over a centralised or semi-centralised scale, rather than at the level of single containment. The publication states that faecal sludge ranges in terms of quantities and quality; thus, context-specific estimates are required as opposed generalisations. Similar constituents are considered when characterising faecal sludge and wastewater sludge, including solids, organics, pH, and nutrients (e.g., nitrogen, phosphorus). In general, faecal sludge is less likely to be contaminated with pollutants like heavy metals originating from industry, but there is a risk of emerging contaminants (e.g., pharmaceuticals). Furthermore, faecal sludge that is contained on site undergoes biological stabilisation (Bakare, 2014).

2.1.2 Regulatory Framework for Faecal Sludge Management

The regulatory context for FSM in South Africa is described in detail in the *National Faecal Sludge Management Strategy* (DWS, 2023b). Overall, FSM in South Africa is governed by the following key policies (DWS, 2023b):

1. Section 24 of the Constitution of the Republic of South Africa (Act 108 of 1996), which affords everyone the right to an “environment that is not harmful to their health or well-being” and an environment that is protected of present and future generations
2. The Water Services Act (Act 108 of 1997), which gives Water Services Authorities (WSAs) the duty to ensure access to water services, including sanitation

3. National Sanitation Policy (2016), which sets the target for sanitation services that contribute to public health and are "hygienic, equitable, sustainable, and efficient for all people." This policy defines sanitation services across the entire sanitation service chain.

Provision of sanitation services is regulated at the national level through the Department of Water and Sanitation. Other national departments also play regulatory roles related to the different activities along the FSM service chain. Water Services Authorities (WSAs) have the primary responsibility for service delivery. This is done through legislation, planning, and delivery of infrastructure, which includes servicing that infrastructure.

In 2023, the DWS signed the *National Faecal Sludge Management Strategy,* which presents an important step forward to increasing the active management of faecal sludge, which is generated by approximately 36% of the South African population (Jack et al., 2020). The FSM Strategy provides a 10-year roadmap to safely manage faecal sludge along the entire service chain, including containment, emptying, transport, treatment, and reuse or disposal (DWS, 2023a). The strategy also introduces key roles for WSAs to play in planning for and implementing FSM. This suggests that in the coming years, interest should grow around strategies for cost-effective faecal sludge management.

2.2 Current Faecal Sludge Management Practices in South Africa

The *Status Quo Report* produced as a supplement to the *National Faecal Sludge Management Strategy* points to a lack of data about FSM in South Africa (National Faecal Sludge Management Strategy: Status Quo of FSM in South Africa Report, 2021). Efforts have been made to compile data, resulting in production of Shit Flow Diagrams (SFDs) for 10 municipalities; however, according to the status quo report, "there is no clear data on the status of FSM outside those 10 municipalities." In the Polokwane case study conducted as part of the FSM Strategy work, it was found that there are no systems in place to collect most of the data required about the "extent to which excreta generated from on-site and off-site sanitation technologies is effectively managed within each part of the service chain" (National Faecal Sludge Management Strategy: Status Quo of FSM in South Africa Report, 2021).

2.2.1 Estimated Quantities of FS being generated

In the absence of data on the faecal sludge quantities, estimates based on assumptions must be made, based on the sanitation systems being used across the country. The DWS Water Services Knowledge System publishes data on household access to toilets, and the information as of April 2023 is shown in Table 2. This data is based on the 2011 Census and is modelled to determine access to sanitation services. While it differs slightly from the 2022 census data, this data set is used in this report, particularly because it separates flush toilets connected to the sewerage system from those connected to septic tanks.

Faecal sludge is produced by on-site systems with containment that stores human waste for some time. This could be assumed to include septic tanks (3%), VIPs (14%), and pit latrines without ventilation (8%). Most households with septic tanks are private sanitation users who call vacuum tankers to empty their septic tank as needed. Most of this sludge is processed through nearby WWTPs. Based on previous work by Bakare (2014) sludge accumulation in VIPs and pit latrines can be estimated

at 50 ℓ/person/year. This translates to approximately 757 000 m^3 faecal sludge produced per year, most of which is simply left in-situ after the toilets are full.

Table 2: Household access to toilets (DWS, 2023c)

Toilet Type	No. households	% of total	Population
Flush toilet (connected to sewerage system)	12 613 539	64%	37 085 074
Flush toilet (with septic tank)	515 683	3%	1 590 733
Chemical toilet	1 304 768	7%	4 195 938
Pit latrine with ventilation (VIP)	2 805 724	14%	9 897 516
Pit latrine without ventilation	1 561 945	8%	5 254 772
Bucket latrine	577 360	3%	625 265
No sanitation	208 745	1%	1 984 820
TOTAL	19 587 764		60 634 118

In 2020, Jack et al. published a report detailing efforts to establish a nationwide excreta flow estimate for South Africa, which would capture how much of the population's faecal matter is safely managed. Working with eight municipalities in South Africa, the researchers produced Shit Flow Diagrams (SFDs), which are helpful in planning for faecal sludge management efforts when kept up to date. The team sourced data from a variety of sources but found that the data available was insufficient and that workshops and meetings were important for collecting accurate data. A key lesson from the report is that no municipality in South Africa is 100% sewered. This means that all South African municipalities have some amount of faecal sludge to deal with. While the General Household Survey captures the types of sanitation systems used by households, there is no reporting system in place for faecal sludge management progress.

2.2.2 Current faecal sludge management in South Africa

Much like wastewater sludge management, faecal sludge management is currently under-emphasised in the sanitation sector. Until the *FSM Strategy* was published, the focus remained largely on infrastructure construction rather than operations and maintenance, to gradually reduce the sanitation services backlog. As a result, very little is being done on a large scale to safely manage faecal sludge that is removed from on-site sanitation systems. In fact, most faecal sludge remains in on-site containment systems and is never emptied. Based on the information gathered through this study and previous work done, the following categories of FSM approaches are assumed to be practiced to some extent in South African municipalities:

1. Precast concrete structures are used under the assumption that when the pits are full, the top structures will be moved. According to the Status Quo Report, this approach was standardised about a decade ago, and many of these are filling up.
2. Faecal sludge is emptied from on-site sanitation systems and disposed of at the headworks of WWTPs, as mentioned by 2 participants in this study.
3. Faecal sludge is emptied from on-site sanitation systems and disposed of on-site through burial, which is the main approach taken in one metro municipality from this study.
4. Faecal sludge is emptied and transported to treatment facilities, though this remains an approach reserved for research and pilot-scale purposes at the moment, with no full-scale systems in place.

At present, FSM remains a field where case studies of isolated efforts are the only source of data and evidence. The sections below provide further details on each of the four approaches described above, including references to specific case studies where possible. This topic of faecal sludge management requires further investigation, and this will be done in the next phase of the research, with particular focus on filling in data gaps in the current case studies and identifying additional case studies for inclusion.

2.2.2.1 Precast concrete structures for relocation

Neethling et al. (2023) published a case study from one district municipality, highlighting progress with its backlog elimination programme, which began in 2010 and focused on the construction of VIP toilets. The case study states that movable structures (i.e., precast concrete structures) were used based on the idea that once the pit filled up, it could be closed, and the structure moved to a newly dug pit. A further assumption was that the responsibility to move the top structure would fall on the household, as the toilet was their property and responsibility. From the municipality's perspective, this would reduce maintenance costs. However, at the time of being interviewed, the person was not aware of any toilets that had been moved in such a way. Through personal communication in November 2023, a representative from one of the main suppliers of precast concrete structures in South Africa confirmed that they had supplied moving tools and provided training to several municipalities but had not yet heard of any work to move installed top structures.

2.2.2.2 Emptying of FS and disposal at WWTP headworks

Faecal sludge is very different from domestic wastewater, as it is more concentrated and drier, particularly when it is removed from dry sanitation systems (e.g., VIPs). Where a treatment plan has spare capacity, it is possible to effectively dampen the shock loads and accommodate faecal sludge through the WWT process. However, if it is not effectively managed, disposal of FS into the WWT process can cause problems.

One WSP confirmed in an interview that faecal sludge is disposed of at the headworks to WWTPs throughout the city. A recently advertised tender by this WSP called for desludging services for VIPs and conservancy/septic tanks using vacuum tankers or honeysuckers. Presumably, faecal sludge emptied under this contract will be sent to WWTPs, suggesting that this practice will continue. According to the Sludge Manager, this practice does not seem to have influenced the WWT process, likely because the treatment plants are relatively large. However, as the WWTPs get closer to full design capacity, a different solution will be required to avoid overloading the treatment.

A representative from one local municipality identified disposal of faecal sludge at treatment plant headworks as one of the largest challenges regarding sludge management. In areas around town, sludge from VIPs and septic tanks is emptied using honeysuckers, and typically, the sludge is taken to one of the 3 treatment plants. One treatment plant has a design capacity of 8 Mℓ/day and was at 113% capacity during the 2021 Green Drop Audit. Adding faecal sludge to a small, already overloaded plant, will likely have drastic effects. Some of the impacts were described by the municipal representative, who said that the primary clarifiers get blocked regularly due to the addition of FS. He also noted that the additional faecal sludge appears to be causing their clarifiers to become anaerobic, which causes odours and is a nuisance.

2.2.2.3 FS Emptied and disposed of on site

Deep row entrenchment (DRE, burial in trenches) of faecal sludge is highlighted as a safe disposal method in the National FSM Strategy. If properly implemented, DRE effectively contains faecal sludge, reducing environmental contamination risks and enabling the ongoing use of on-site sanitation facilities. In a metro municipality in 2015, a tender was advertised for the manual emptying of 50,000 urine diverting dry toilets (UDDTs), and a majority (38,000) were to have the faecal sludge safely buried on site, with a tree planted in the sludge. By implementing on-site burial at households with enough space to do so, the municipality saved on the cost of transporting sludge off-site. This tender and the pricing of it are discussed in Case Study 11. A report prepared by Khanyisa Projects analysing the contract for emptying found that the average cost of emptying with disposal on site was between R800 and R900 per UDDT, or approximately R1,340 per UDDT in 2024 Rands. This cost includes overhead, management, and health and safety, along with the actual cost for emptying and disposal. Assuming the emptied volume of sludge per UDDT is approximately 0.8m^3, this comes to R1,675/m^3.

In 2023, the metro advertised another tender for emptying of on-site toilets over a period of 36 months. This contract appears to be less specific than the 2015 one, as it states that emptying will be done “as and when” required. According to the municipality’s public tender documents, 5 contractors were awarded contracts for this work. As no designated faecal sludge treatment plant is available, it is assumed that most of that faecal sludge will be buried on site or delivered to WWTPs.

Another case study about on-site disposal is based on private emptiers engaged in emptying VIPs and septic tanks in the Pietermaritzburg area (Case Study 10). This business uses manual or semi-mechanised (Pitvaq) emptying, depending on the nature of the pit contents. The most common method used for disposal is DRE, wherein the company digs a trench and buries the removed sludge in it, backfilling with 300mm soil. A site depot was established for the team at a cost of R154,489 in 2021 (R183,754 if adjusted to 2024). In 2021, the advertised cost of emptying 1m^3 of faecal sludge and burying it in a trench on-site was R1,500. Adjusted to 2024 prices, this is approximately R1,784/m^3, similar to the estimated cost from the contract mentioned above. It is important to note that this business has not been able to generate enough work solely from emptying on-site sanitation systems, and therefore supplements this work with other construction work.

2.2.2.4 FS Emptied and transported to treatment facilities

Currently, there are no designated faecal sludge treatment plants (FSTPs) in South Africa, except for at the pilot or demonstration scale. The same contract in the metro municipality from 2015 specified that FS from 12,000 UDDTs was to be transported to a WWTP, where a pilot treatment facility for FS was located. The treatment facility used black soldier fly larvae to process the FS, producing several useful by-products. This approach had two key barriers:

1. Transporting sludge off-site is costly, never mind the cost of the treatment system itself
2. Beneficiation of FS is not effective unless there is a market for the products

Transportation of sludge is costly as demonstrated above with regards to WW sludge. For this reason, if economics are a driving force behind decision making, transport of sludge should be limited or avoided altogether. As described above, the average cost of emptying and on-site disposal was approximately R1,340 per site (adjusted to 2024). Using a similar approach, the average cost of

emptying and transport off-site was approximately R1,620 per site. This figure does not include the cost of further treatment of the sludge once it is delivered to the BSF plant, suggesting that income generation from sludge beneficiation efforts is critical to ensuring a cost-effective solution.

Case study 9 presents another pilot-scale FS emptying and treatment approach. In 2018, 100 Amalooloo MyLoo dry sanitation (urine diversion) toilets were installed in a district municipality. The municipality asked about the operations and maintenance (O&M) of these units, and Amalooloo agreed to partner with them and fund an O&M pilot project for those 100 units. This included the collection of dried excreta from the units, transport to an O&M centre in the community, processing of the excreta, and production of a soil conditioner. While this project has been fully funded by the private company, the experiences provide a useful example of emptying and beneficiation at a community scale in South Africa.

The O&M Centre employs 3 individuals who service all households and run the beneficiation process. Faecal sludge is removed from the MyLoo toilets approximately quarterly, and because it is relatively dry, emptying is done manually using spades and rakes. Faecal sludge is placed into bin bags and transported to the O&M Centre in a wheelbarrow. At the O&M Centre, the faecal sludge is further dried in a steel bin which is heated by the sun to 50-55 degrees Celsius. When the product reaches 4% moisture content, it is shredded, sieved, and packaged to be used as a soil conditioner. At present, the packaged material is given away to the community for free. The material is analysed for stability, inorganic contaminants, and nutrient and organic content.

The running costs for this operation are currently R18 512 per month, or R2 221 per household for the year. The service provider suggests that this could be scaled up to 1000 households without additional capital investment or personnel costs. The case study estimates that running the operation at this scale would cost approximately R255 per household per annum, or R21.25 per month. This could potentially be covered by charging a fee to the households, further beneficiating and selling the product, and/or government subsidy. Further detail can be found in Case Study 9 (Annexure I).

2.3 Discussion of FS Management in South Africa

As FSM starts to be implemented at scale, it can be assumed that many of the obstacles described in the WW sludge section would also apply. However, at this stage, the primary barrier to effective FSM is a lack of responsibilities and awareness around FSM. Until this barrier is overcome, progress will not be made and therefore, barriers to success will not be identifiable. This gap was acknowledged by interviewed DWS representatives who were involved in the development of the FSM Strategy. Though South Africans have been using on-site sanitation systems for a long time, one municipal representative stated that “it’s only now that faecal sludge is coming to the fore. It’s been neglected.” When asked about where responsibility for FSM should live within the municipality, he was unsure.

Since WSAs are given the primary responsibility in the Strategy for ensuring FSM services are delivered, it is critical to identify specifically who the responsibility falls on within the municipal structure. When asked which municipal structures would support the management of faecal sludge, the DWS officials interviewed first responded saying, “That’s a good question,” and then shared their

ideas around how FSM would fit within existing structures. Below is a summary of the initial thoughts from the DWS officials:

1. Containment is the responsibility of the infrastructure development unit, or PMU.
2. Emptying, treatment, and disposal/use of faecal sludge would fall under the wastewater management unit.

Adding responsibility for faecal sludge to the wastewater management unit will require considerable capacity building and even increased personnel resources, as it has not been handled by these units in the past. The representative also recommended that faecal sludge disposal/use should have specific people allocated to it, in a similar way that one metro has a designated Sludge Manager.

Expanding FSM throughout South Africa will require continued effort and focus on research and demonstration of practical solutions. Once the ball starts moving towards implementing FSM, many of the recommendations presented above around WW sludge management will be applicable.

3 Overview of costs of sludge management options

The following sections provide an overview of the costs of wastewater and faecal sludge management based on data from the case studies. These sections are available as stand-alone documents as well, which provide additional information about why sludge should be managed and the costs thereof. In addition, each resource is accompanied by an Excel spreadsheet that enables high-level cost comparisons between options.

3.1 Wastewater sludge management costs

This section presents an overview of costs for wastewater sludge management, based on the findings from the various case studies.

3.1.1 Options for managing wastewater sludge

The general options for managing wastewater sludge are summarised in Volume 1 of the *Sludge Guidelines* and include:

1. Agricultural use at agronomic rates (Volume 2)
2. On-site or off-site disposal (Volume 3)
    a. On-site (monofil, waste piles, lagoons)
    b. Dedicated land disposal
    c. Co-disposal in general landfill
    d. Co-disposal in hazardous landfill
3. Beneficial use (other than agricultural use at agronomic rates) (Volume 4)
    a. Once-off high rate sludge application
    b. Continuous high-rate application for edible or industrial crops
    c. General landfill cover material
    d. Hazardous landfill cover material
4. Thermal treatment (Volume 5)
5. Commercial products (Volume 5)
    a. Fertiliser products
    b. Other commercial products (e.g., bricks)

The selected option for managing wastewater sludge will depend primarily on the sludge classification in terms of microbiological, stability, and pollutant classification. In addition to considering sludge quality, the choice of sludge disposal or beneficial use will depend on land availability, costs, demand for beneficiated products, and the waste hierarchy. According to the waste hierarchy, disposal should be the last resort, and options for recycling and beneficial use should be prioritised. This is in line with the move towards wastewater sludge as a resource, rather than a liability.

3.1.2 What do we know about the costs for wastewater sludge management?

The cost of disposing or beneficially using sludge produced in wastewater (WW) treatment plants depends on several different factors. In this study, 6 different case studies provided data on the costs of WW sludge disposal. The case studies and data provided are described below.

Table 3: Summary of case studies with cost data on WW sludge disposal/beneficial use

Study no.	Approach description	Compliance	Transport	Treatment	Disposal/ Beneficial Use	Data provided
1a	Agricultural application of waste activated sludge in sugarcane fields in line with Volume 2 of the sludge guidelines	✓	✓		✓	Contractor rates per cubic metre for management (incl. classification), transport, and disposal
1b	Agricultural application of digested sludge in sugarcane fields in line with Volume 2 of the sludge guidelines	✓	✓		✓	Contractor rates per cubic metre for management (incl. classification), transport, and disposal
2	Disposal of sludge in hazardous landfill		✓	✓	✓	Contractor rates per cubic metre from contract
3a	Transport of digested sludge to farms an average of 50km away		✓			Rates per cubic metre for transport – costs exclude management tasks done by the WSA and application
3b	Composting of sludge, with product collected by farmers			✓		Treatment cost only for composting, reported by WSP
3c	Composting of sludge, with product delivered to farmers		✓	✓		Treatment + transport costs, reported by WSP
4	Production of commercial product by private partner					No cost to the municipality – all costs (and income) borne by the private party
6	Continuous high-rate application of sludge with industrial crops					No cost data provided – but costs are borne by the private party except for compliance
7	Transport of dried sludge from small WWTPs to central site for further drying and land application/ treatment		✓			Transport costs only (transport in 10-ton trucks)
8	Transport and application of dried sludge in agriculture	✓	✓			Municipality's costs for classification Contractor's rate for transport, inclusive of all work necessary to comply with guidelines

The case studies described above generally present five different approaches to wastewater sludge management, namely:

1. Agricultural application: Transporting sludge from the WWTP to farms for land application as per the *Sludge Guidelines.*
2. Solar drying/composting and delivery to farms: Treating sludge from the WWTP further through a solar drying and composting process in order to produce an A1a product, as per the *Sludge Guidelines*. The present situation is that sludge is delivered to farms, rather than being sold, as supply exceeds demand. For comparison purposes, the option of composted sludge being collected by farmers is also presented below.

3. Continuous high-rate application of sludge for industrial crops: In this arrangement, digested sludge is pumped directly to sludge disposal lands where turf grass is grown. The turf grass operation is run by a private company that pays a fee to use the municipal land, and they keep all income generated through the sale of turf grass. The WSA owns the infrastructure and maintains it. They also cover all necessary monitoring including, e.g., sludge classification, soil monitoring, and groundwater monitoring. The actual costs for these were not provided to the researchers.
4. Production of a commercial product by a private company: In this arrangement, sludge from the WWTP is given (or sold) to a private company for further treatment and beneficiation. In this case, the private company pays a fee to the municipality (e.g., "buying" the sludge or land rental fee). The costs of further treatment, beneficiation, marketing, and packaging all fall on the private company, and no further costs are incurred by the municipality.
5. Hazardous landfill disposal: Transporting sludge from the WWTP to a hazardous landfill for safe disposal. The cost includes the gate fee, treatment to immobilise heavy metals, and disposal in trenches. This is one of few options for sludge with a "c" pollutant classification, as per the *Sludge* Guidelines (see Table 11 for more options).

The costs for these 5 approaches are summarised in Figure 5, highlighting the *cost to the municipality/Water Services Provider (WSP)*. These costs exclude "compliance" costs related to, inter alia, sludge classification. The costs indicate that partnerships with private companies with an interest in sludge beneficiation can lead to considerable savings. The most cost-effective option outside of this is the application of sludge in agricultural land, if sufficient land is available and close enough. The specific reported costs for the different aspects of the sludge service chain are summarised in the sections below.

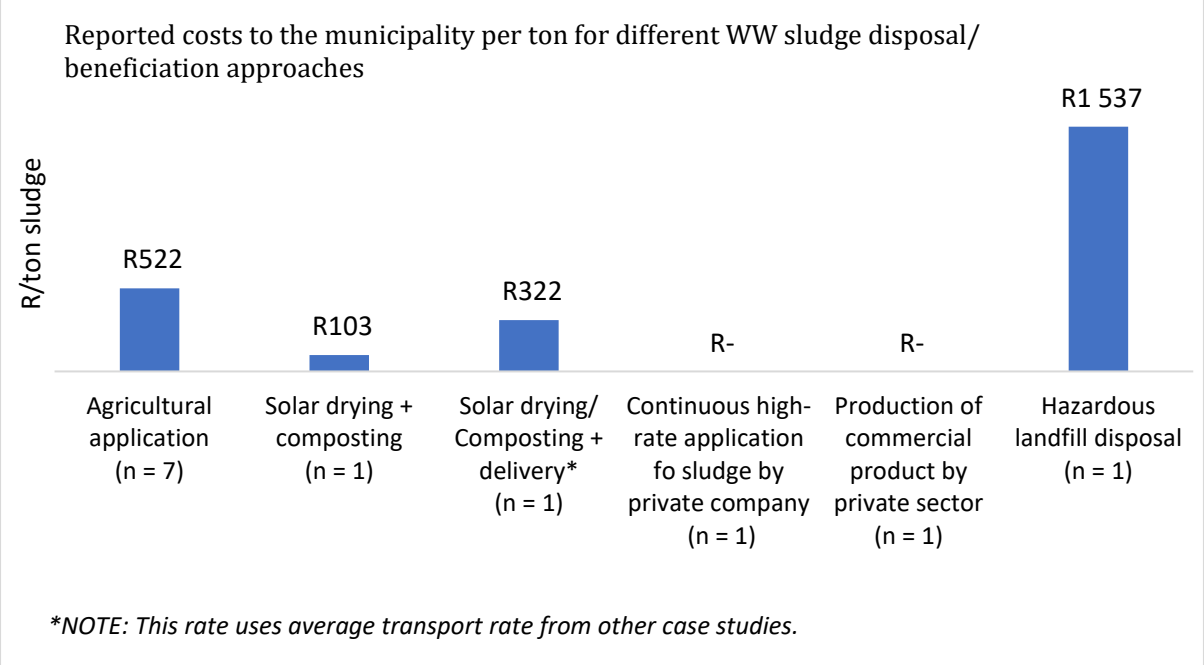


Figure 5: Reported cost of WW sludge management options (R/ton sludge processed) for different approaches across case studies (costs adjusted to May 2024 rates, excl. compliance)

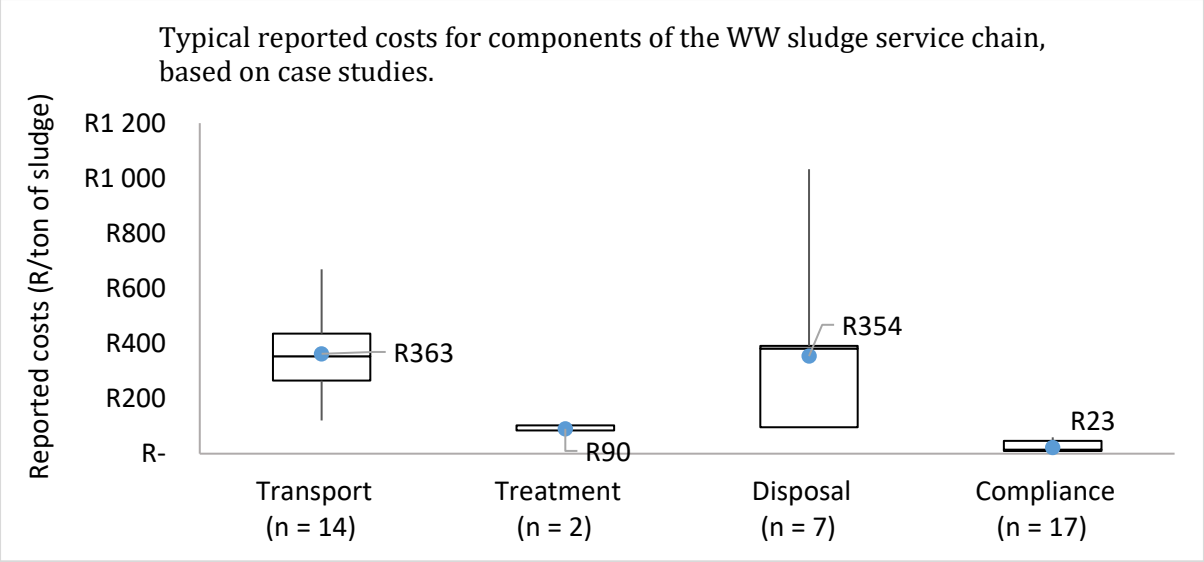


Figure 6: Average costs of sludge disposal/beneficiation, reported in case studies

Table 4: Cost ranges from case studies for different aspects of sludge disposal/ beneficiation

	Typical range (R/ton)	Median (R/ton)	Average (R/ton)
Transport	R 246 – R 421	R 336	R 350 (± R138)
Treatment	R 61 – R 103	R 103	R 89 (± R24)
Disposal	R 89 – R 1 033	R 382	R 349 (± R335)
Compliance	R 0.45 – R 59	R 14	R 23 (± R22)
OVERALL	**R 0.45 – R 1 514**	**R 426**	**R 470 (± R354)**

The different aspects of the sludge management service chain are discussed in detail below. This excludes the conventional treatment of WW sludge at WWTPs, which was excluded from this study. Breaking the process into these distinct parts assists with considering different combinations of approaches outside of the ones covered by this study.

3.1.2.1 Transport

Sludge may be transported for different reasons, including to a centralised treatment/ beneficiation facility, for application in agriculture, or disposal in a landfill. In this study, 14 data points were provided for transport of sludge[1]. The average rate for transport of sludge is R336 per ton, with a range from R112 to R669 per ton. The main factors that impact the cost of transporting sludge are distance and size of vehicle.

Distance

The distances from WWTP to destination in this study ranged from 20km to 74km, and the cost per ton over distance ranged from R2.23/ton/km to R20.33/ton/km, with an average of R7.63/ton/km.

[1] Note that some case studies provided several different rates for transport.

The wide range highlights the fact that there was not a strong correlation between distance and cost. The data provided suggests that at distances greater than 50km, the rate per ton for transport would likely increase.

Size of vehicle

Various vehicles were used to transport sludge in the case studies, including 7m^3 skips, 10-ton dump trucks, 18m^3 side tippers, and 30 m^3 side tippers. Larger vehicles, while heavier on fuel, will also make transport more efficient, reducing the number of trips to a minimum. This is consistent with decreasing rates for transport as larger vehicles were used.

What can make transport more efficient?

The best way to reduce the cost of transport is to reduce the amount of sludge being transported. By reducing the weight and volume of sludge, the total cost will decrease, though the volumetric rate for transport will remain the same. Volume and weight reduction is primarily done by drying sludge.

> *Three truckloads of 30 tonnes of wet sludge will be reduced to 1 truckload after you've dried it… when we transport…we are trying to avoid transporting more [wet than dry]… [transporting 80% water is] not feasible [or] profitable for the company.*
>
> – Sludge Manager at a WSP for a Metro Municipality

3.1.2.2 Advanced treatment

Advanced treatment refers to treatment beyond typical WWTP processes (e.g., anaerobic digestion, dewatering, drying). This may include composting, heat treatment, addition of chemicals, extended drying, or other processes. The benefits of treatment include:

- Reduction in sludge volume and weight
- Improvements to final product

This is typically done if the aim is to produce a product that can be safely used by the public and even sold for a profit (i.e., an A1a product), but it may also be done to make sludge safer for disposal. In this study, three case studies included treatment of sludge beyond the general WWT process:

1. Addition of lime before disposal in a hazardous landfill, as per Volume 3 of the *Sludge Guidelines*. This applies to sludge in pollutant class b and c to immobilise contaminants. (Case Study 2)
2. Solar drying and composting of digested sludge to produce an A1a product (without addition of a bulking agent) which is ideally collected by farmers but is occasionally delivered to them if sludge begins to pile up. This is done by the Water Services Provider (WSP) of a metro municipality, which has a dedicated "Sludge Manager" who can oversee the research and development of this process. (Case study 3)
3. Extended drying and granulation of sludge, followed by blending with commercial fertiliser to meet farmers' needs. This is done by a private business that pays the municipality for the dry sludge it receives from them. The unique arrangement, which does not cost the municipality anything, is based on a 15-year contract which was competitively adjudicated. (Case study 4)

Costs to the municipality/WSP for the above three processes are provided below.

Table 5: Reported costs for further treatment of WW sludge

Description	Cost to municipality (R/ton)	Case study ref.
Lime addition for landfill disposal	R 61	2
Solar drying and composting without bulking agent	R 103	3
Extended drying, granulation, and blending with commercial fertiliser	R 0*	4

In this case, the private company pays the municipality for the sludge supplied and there is **no cost to the municipality.*

While the arrangement in Case Study 4 leads to no income for the municipality from the fertiliser, it also incurs no costs, while limiting the risk to the municipality. The private business is motivated to maintain their processes and produce a product that is authorised and saleable, taking on the burden of compliance with the sludge guidelines as well as agricultural legislation.

3.1.2.3 Disposal

WW sludge disposal in this case covers both the discarding of WW sludge and application in agriculture, in line with the *Sludge Guidelines*. The cost of WW sludge disposal is primarily determined by the method used to dispose of sludge, which may require extensive labour or specific machinery. The safe method of sludge disposal is also determined by the sludge classification and characteristics. In this study, three instances of WW sludge disposal were included, with costs ranging from R89/ton up to R1 033/ton. The three instances are summarised below.

Table 6: Reported costs of WW sludge disposal from 3 case studies

Description	Cost to municipality (R/ton)	Case study ref.	Note(s) on costs
Application of waste activated sludge to sugarcane fields	R382	1	The instability of WAS requires that it be incorporated into the soil, rather than applied on top. This ensures vector control and requires special equipment and timeous land application.
Application of digested sludge to sugarcane fields	R89	1	Due to better stability class than WAS, sludge can be applied and spread on the surface, making the process simpler.
Disposal in hazardous landfill	R1 033	2	Costs include gate fees as well as the cost of trenching and burying the sludge.

Disposal in a hazardous landfill is limited by legislation and not sustainable due to finite space in landfills. As shown above, it also comes with a high cost primarily due to gate fees. Disposal in

agricultural fields or commercial forests is both cheaper and provides some benefit to the environment, provided the sludge does not have high levels of industrial pollution.

3.1.2.4 Compliance

Compliance costs, not included in the overall costs above, vary based on the selected sludge disposal/beneficial use method and the dry tons of sludge produced per year. Only one case study provided costs and frequency of sludge classification, whereas the others did provide specific detail. Therefore, the researchers have used the *Sludge Guidelines* along with cost estimates to determine estimated costs for compliance. The compliance and monitoring requirements for each approach are presented in Table 7, based on the relevant volume in the *Sludge Guidelines*. The costs of these activities are approximated below.

Table 7: Monitoring requirements for different sludge disposal/beneficial use approaches

Option	Guidelines Volume	Sludge	Soil	GW	Surface Water	SANS[2]
Application in agriculture	2	Y	R	N	N	N
Commercial products	5	Y	N	N	N	Y
Continuous high-rate application	4	Y	Y	Y	Y	N
Landfill disposal	3	Y	N	N	N	N

Y = Yes, required; R = recommended; N = Not required

The costs of compliance activities were estimated based on rates sourced from South African labs providing these services. The costs utilised in the estimates are shown below.

Table 8: Reported costs for monitoring

Monitoring	Description	Total cost[3]
Sludge classification	3 samples, as per *Sludge Guidelines*	R12 000
Soil monitoring	3 samples, nutrients, metals, and soil pH	R2 310
Water monitoring (surface or ground)	2 samples, chemistry, microbiology	R3 000

The frequency of required monitoring for each of the above is described in the relevant volume of the *Sludge Guidelines*. Importantly, the frequency of sludge classification depends on the dry tons of sludge produced each year. Using the above costs and the requirements provided in the *Sludge Guidelines*, the cost for compliance in the case studies included ranged from R0.45/ton to R59/ton, with an average of R23/ton.

[2] SANS classification is based on the specific commercial product being produced. Determination of these requirements and costs is outside the scope of this report.

[3] These cost estimates are based on quotes provided by suppliers. Note the suppliers' names have been kept confidential.

Table 9 shows the estimated compliance costs in rands per dry ton of sludge for the different options presented here. For most approaches, the cost per dry ton differs based on the quantity of sludge handled, because the monitoring frequency required in the *Sludge Guidelines* depends on the dry tons of sludge.

Agricultural application at agronomic rates requires considerable additional work to ensure compliance with the guidelines. Case study 1, which covered this approach in detail, reported rates for "management" ranging from R41 per cubic metre to R165 per cubic metre or R38/ton to R153/ton, respectively. In addition to sludge classification costs, these rates included identification of appropriate farms, liaison with farmers, and ensuring compliance during the sludge application process.

Table 9: Approximate compliance costs (R/dry ton sludge) for sludge disposal/beneficial use options, based on the *Sludge Guidelines*

Sludge quantity	Agricultural application	Commercial product	High-rate continuous application	Landfill disposal
<365 dt/yr	R88.68	R293.21	R2 481.25	R83.33
365 – 1 825 dt/yr	R68.09	R293.21	R227.38	R66.67
1 825 - 16 500 dt/yr	R18.40	R293.21	R31.23	R17.50
>16 500 dt/yr	R5.78	R293.21	R11.49	R5.00

3.1.3 How can one budget for wastewater sludge management?

How does one start to budget for sludge management, given the varied costs and the different approaches taken? This question is difficult to answer, especially given the reality that no two treatment plants are the same. Influent quality, wastewater and sludge treatment processes, operation, and climate all influence the quantity and quality of sludge that needs to be handled and therefore the cost of managing it.

Ideally, the end-use of sludge should be selected up front, based on economic and environmental analysis and assessment of the demand for beneficiated sludge products. In this case, sludge treatment would be designed based on the desired end-use. However, the reality in existing South African WWTPs is that there is a need to urgently find a way to manage the sludge that is already being produced.

Budgeting for sludge disposal or beneficial use firstly requires an understanding which options are possible and permissible within the *Sludge Guidelines*. So, the first step is classification.

1. **Classify the sludge:** If this has not been done yet, comprehensive sludge characterisation should be carried out on three samples from *every stream* of sludge that requires disposal. One estimate from a laboratory indicated that this would cost approximately R15 000 per sludge stream. Refer to Volume 1 of the *Sludge Guidelines* for more detail.

Based on the microbial, stability, and pollutant classification, determine the which options are possible.

2. **Identify possible options for sludge disposal**: Table 11 and Table 12 summarise the options presented in the *Sludge Guidelines* and whether they are possible/permissible based on the sludge classification.
3. **Determine the approximate cost for different options**: Data from this study has been used to produce general estimates for the cost of different approaches to sludge disposal/beneficial use. While the above section presents costs per ton of sludge, the budgeting figures in Table 10 below provide a cost per megalitre of wastewater treated, as this can be more useful for budgeting, particularly if sludge production is not well understood. The estimates assume typical sludge production of 1.7 m^3 sludge per Mℓ WW treated[4]. The costs will change based on the actual sludge production, which depends on several factors including influent characteristics and treatment processes. These costs highlight that enhancing sludge drying/dewatering can decrease costs. The next section of this report presents a tool that can provide more detailed estimates for the different methods.

Table 10: Typical sludge disposal/beneficiation costs for different approaches, assuming different dryness levels of sludge (costs based on data provided in this study)

Disposal Options with cost data	Typical sludge disposal/beneficiation cost (R/Mℓ WW treated)		
	4% TS	20% TS	40% TS
Agricultural application of digested sludge	N/A	R 1 220	R 610
Solar Drying and Composting (delivered)	N/A	R 720	R 360
Solar Drying and Composting (collected)	N/A	R 300	R 150
High-rate continuous application on industrial crops (PPP)	R 4.30	R 0.90	R 0.50
Production of commercial agriculture product (PPP)	N/A	R 2.00	R 1.00
Hazardous landfill disposal	N/A	R 2 730	R 1 370

Investments upstream in sludge treatment facilities can decrease disposal costs. And they can open the door to more downstream disposal/beneficial use options.

4. **Consider ways to improve sludge quality**: As shown in the sludge classification and options tables, changing the sludge classification can open new opportunities for sludge disposal or beneficiation. Microbiological and stability classification can be improved through various treatment methods:
    a. Improve anaerobic digester operation to improve stability
    b. Solar drying and/or composting to improve both

    Pollutant classification is more difficult to improve. If there are challenges with heavy metals in sludge, implement source control for wastewater coming into the WWTP by preventing illegal discharge by industries and stormwater ingress. Sludge treatment methods to remove metals are generally not cost-effective. If heavy metals are high, consider beneficiation technologies that produce products not used in agriculture.

[4] Source: von Sperling, M. (2007). *Biological Wastewater Treatment Series (Volume 1). Wastewater Characteristics, Treatment and Disposal.* Table 5.2, pp. 250.

3.1.3.1 A tool for estimating sludge disposal/beneficiation costs

The "WW Sludge Options" MS excel spreadsheet has been prepared to assist with budgeting and comparison of different options. Specifically, the following options are included in the spreadsheet, as these were covered by case studies in this project:

1. Agricultural application of sludge at agronomic rates
2. Solar drying and composting (delivered or collected from the WWTP)
3. High-rate continuous application on industrial crops (partnership with private company)
4. Production of commercial agricultural product (partnership with private company)
5. Hazardous landfill disposal

The user is prompted to enter the following information:

- Wastewater treated (Mℓ/day) [required]
- Sludge characteristics:
    - Classification [optional]
    - % total solids [required]
    - Production (m^3/day) [optional]

Enter data about your WWTP and sludge production:

WW treated (ML/day)	50
Sludge characteristics	
Classification	B2a
%TS	20%
m^3/day (actual)	80

As noted above, certain characteristics are required for the calculations and others are optional. The image above shows an example of data entered. If the quantity of sludge produced is not known, a range is suggested.

Based on the above, the tool calculates a range of cubic metres of sludge produced each day based on guidance from von Sperling (2007). This includes a "low" sludge production, "mid" or average sludge production, and "high" sludge production. If the actual sludge production was entered above, this is also included. Based on the percentage total solids (TS), the dry tons of sludge per year are calculated, which is important for determining the monitoring/compliance requirements. The sample output is shown below.

Estimated sludge production	m^3/day	dry tons per year
Low production	74.2	5 418
Mid production	85.9	6 273
High production	97.7	7 129
Actual	80.0	5 840

Based on the data entered and the calculated sludge quantities, the five different disposal options are summarised. This includes an assessment of whether the option is applicable based on the classification and a range of costs for transport, treatment, disposal, and compliance/ management. Again, costs are presented in units of rands per megalitre of wastewater treated, to support budgeting. The sample output is shown in Figure 7.

In addition to the summary table, two additional figures are generated, including one showing R/Mℓ treated for each sludge production level, and one showing an annual cost estimate for each.

Table 11: Sludge classification and appropriateness for approaches in Volume 2 and 3 of the *Sludge Guidelines*

Classification	Agricultural use at agronomic rates (Volume 2)	On-site or off-site disposal (Volume 3)			
		On-site (monofill, waste piles, lagoons)	Dedicated land disposal (DLD)	Co-disposal in general landfill	Co-disposal in hazardous landfill
A1a	Yes	Qualified no	Qualified no	Qualified no	Qualified no
A2a	Qualified yes	Qualified no	Qualified no	Qualified no	Qualified no
A3a	No	Qualified no	Qualified no	Qualified no	Qualified no
A1b	Qualified yes	Maybe	Maybe	Maybe	Maybe
A2b	Qualified yes	No	No	No	Qualified yes
A3b	No	Qualified no	Qualified no	Qualified no	Qualified no
A1c	No	No	No	No	Qualified yes
A2c	No	No	No	No	Qualified yes
A3c	No	No	No	No	Qualified no
B1a	Qualified yes	Qualified no	Qualified no	Qualified no	Qualified no
B1b	Qualified yes	No	No	No	Qualified yes
B1c	No	No	No	No	Qualified yes
B2a	Qualified yes	Maybe	Maybe	Maybe	Maybe
B2b	Qualified yes	No	No	No	Qualified yes
B2c	No	No	No	No	Maybe
B3a	No	Qualified no	Qualified no	Qualified no	Qualified no
B3b	No	Qualified no	Qualified no	Qualified no	Qualified no
B3c	No	Qualified no	Qualified no	Qualified no	Qualified no
C1a	Qualified yes	Qualified no	Qualified no	Qualified no	Qualified no
C1b	Qualified yes	Maybe	Maybe	Maybe	Yes
C1c	No	No	No	No	Qualified yes
C2a	Qualified yes	Qualified no	Qualified no	Qualified no	Qualified no
C2b	Qualified yes	No	No	No	Qualified yes
C2c	No	No	No	No	Qualified yes
C3a	No	Qualified no	Qualified no	Qualified no	Qualified no
C3b	No	No	No	No	Qualified yes
C3c	No	No	No	No	Qualified yes

Table 12: Sludge classification and appropriateness for approaches in Volume 4 and 5 of the *Sludge Guidelines*

Classification	Beneficial use (other than agricultural use at agronomic rates) (Volume 4)					Commercial products (Volume 5)		
	Once-off high rate sludge application	Continuous high-rate application - Edible crops	Continuous high-rate application - Industrial crops	General landfill cover material	Hazardous landfill cover material	Thermal treatment methods	Fertiliser products	Other commercial products
A1a	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
A2a	Qualified yes	Qualified yes	Qualified yes	Qualified yes	Qualified yes	No	Yes	Yes
A3a	No	No	No	No	Qualified yes	No	Yes	Qualified yes
A1b	Qualified yes	Qualified yes	Qualified yes	Qualified yes	Qualified yes	No	No	Yes
A2b	Qualified yes	Qualified yes	Qualified yes	Qualified yes	Qualified yes	No	No	Yes
A3b	No	No	No	No	Qualified yes	No	No	Qualified yes
A1c	Qualified yes	No	Qualified yes	Qualified yes	Qualified yes	No	No	Yes
A2c	Qualified yes	No	Qualified yes	Qualified yes	Qualified yes	No	No	Yes
A3c	No	No	No	No	Qualified yes	No	No	Qualified yes
B1a	Qualified yes	Qualified yes	Qualified yes	Qualified yes	Qualified yes	Qualified no	Yes	Yes
B1b	Qualified yes	Qualified yes	Qualified yes	Qualified yes	Qualified yes	Qualified no	No	Yes
B1c	Qualified yes	No	Qualified yes	Qualified yes	Qualified yes	Qualified no	No	Yes
B2a	Qualified yes	Qualified yes	Qualified yes	Qualified yes	Qualified yes	Qualified no	Yes	Yes
B2b	Qualified yes	Qualified yes	Qualified yes	Qualified yes	Qualified yes	Qualified no	No	Yes
B2c	Qualified yes	No	Qualified yes	Qualified yes	Qualified yes	Qualified no	No	Yes
B3a	No	No	No	No	No	Qualified no	Yes	Qualified yes
B3b	No	No	No	No	No	Qualified no	No	Qualified yes
B3c	No	No	No	No	No	Qualified no	No	Qualified yes
C1a	Qualified yes	No	Qualified yes	No	Qualified yes	Maybe	Yes	Yes
C1b	Qualified yes	No	Qualified yes	No	Qualified yes	Maybe	No	Yes
C1c	Qualified yes	No	Qualified yes	No	Qualified yes	Maybe	No	Yes
C2a	Qualified yes	No	Qualified yes	No	Qualified yes	Qualified yes	Yes	Yes
C2b	Qualified yes	No	Qualified yes	No	Qualified yes	Qualified yes	No	Yes
C2c	Qualified yes	No	Qualified yes	No	Qualified yes	Qualified yes	No	Yes
C3a	No	No	No	No	No	Yes	Yes	Qualified yes
C3b	No	No	No	No	No	Qualified yes	No	Qualified yes
C3c	No	No	No	No	No	Qualified yes	No	Qualified yes

SUMMARY OF OPTIONS

	Agricultural application of digested sludge	Solar Drying and Composting	High rate continuous application on industrial crops (PPP)	Production of commercial agriculture product (PPP)	Hazardous landfill disposal
Description	Application of dewatered sludge at agronomic rates, assuming distance of 50km or less	Treatment done by municipality to achieve an A1a product. Low-end assumes product collected by farmers. Does not consider a scenario where the product is sold, and does not include cost of classifying and registering product with Department of Agriculture.	Pumping digested sludge to field for application and production of industrial crops. Assumes costs are covered fully by fee/rental paid by private company to municipality. Only works with high MC sludge that can be pumped.	Complete outsourcing of commercial product production to a private company, who pays a small fee for receiving and beneficiating the dried/dewatered sludged from the municipality.	Transport and disposal of sludge in hazardous landfill, including treatment with lime to immobilise pollutants and trenching for disposal. Assume transport <50km.
Guidelines volume	2	5	4	5	3
Permitted /possible	Qualified yes	Yes	Qualified yes	Yes	Qualified yes
Sludge treatment (typ)	- Anaerobic digestion - Thickening - Dewatering / drying	- Anaerobic digestion - Thickening - Dewatering / drying	Anaerobic digestion (no dewatering)	- Anaerobic digestion - Thickening - Dewatering / drying	- Anaerobic digestion - Thickening - Dewatering / drying

Estimated costs (R/ML WW treated) (range)												
Transport	R 540	R 720	R -	R 430	R -	R -	R -	R -	R 540	R 720
Treatment	R -	R -	R 160	R 220	R -	R -	R -	R -	R 90	R 130
Disposal	R 360	R 490	R -	R -	R -	R -	R -	R -	R 1 650	R 2 180
Compliance / Management	R 80	R 110	R 90	R 130	R 140	R 200	R 90	R 130	R -	R 10
Total	**R 990**	**R 1 310**	**R 250**	**R 770**	**R 140**	**R 200**	**R 90**	**R 130**	**R 2 300**	**R 3 040**

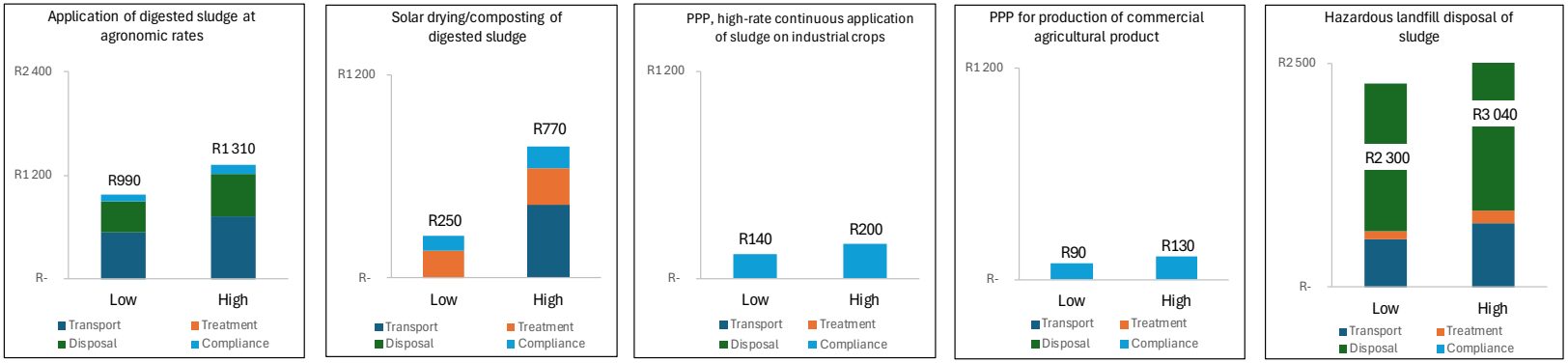


Figure 7: Example output from "WW Sludge Options" spreadsheet

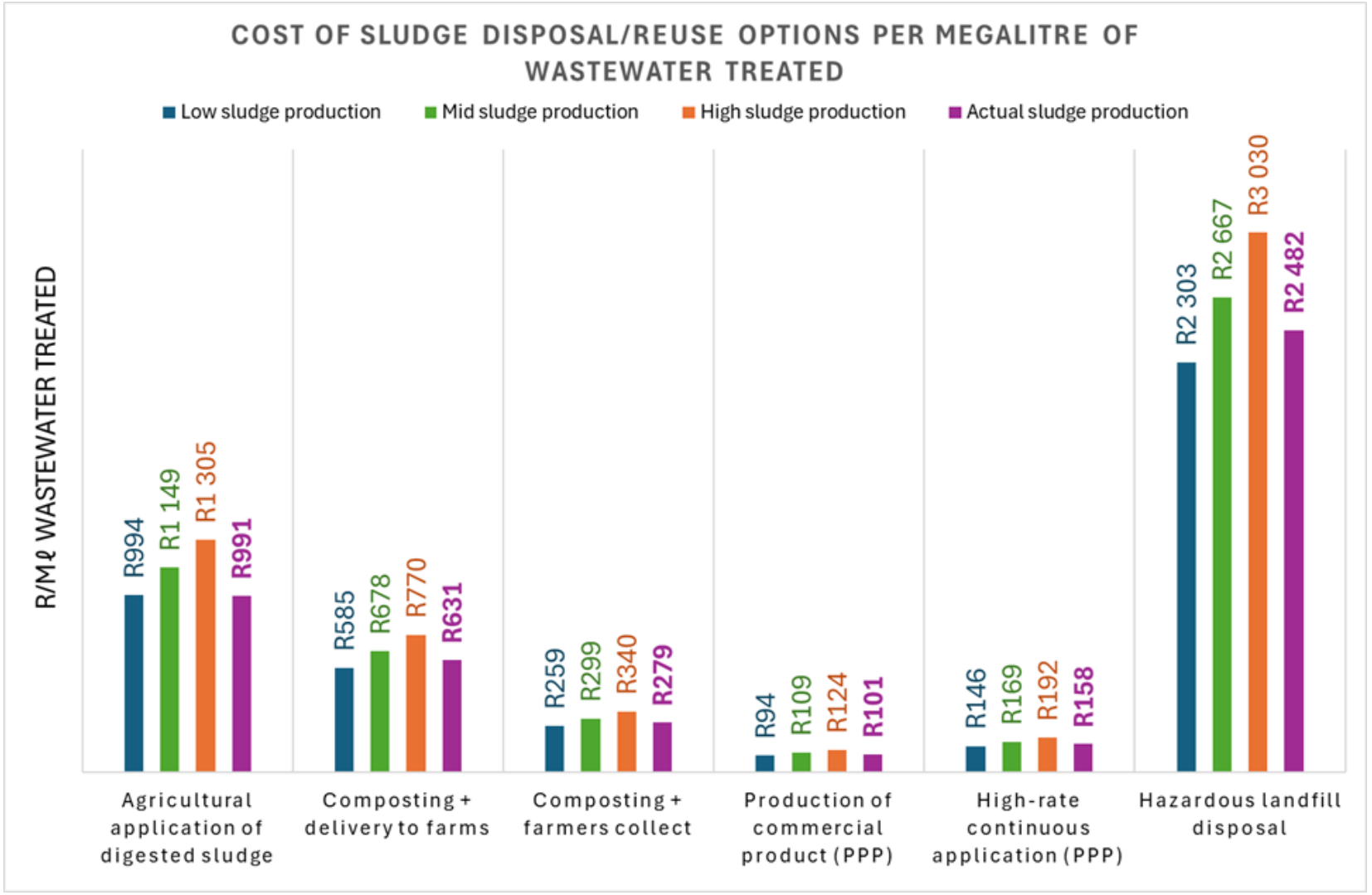


Figure 8: Estimated costs per megalitre WW treated for various options

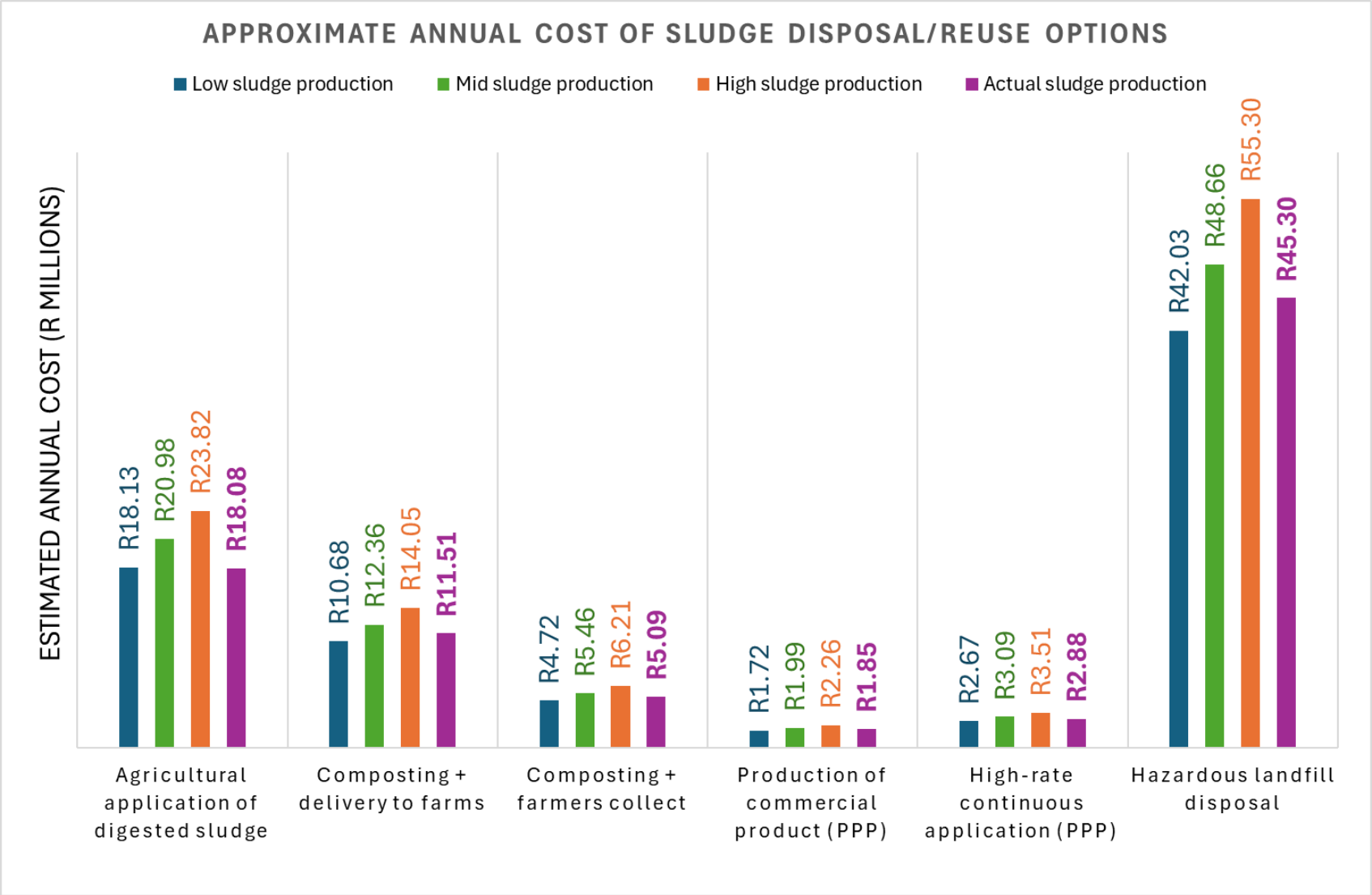


Figure 9: Approximate annual cost of different options (costs in 'R millions)

3.2 Faecal sludge management costs

This section presents an overview of costs for faecal sludge management, based on the findings from the various case studies.

3.2.1 Options for managing faecal sludge

Other publications have detailed technology options for different parts of the faecal sludge management service chain[5]. Below is a brief description of the general options available, to set the stage for conducting cost comparisons for the complete service chain.

Containment includes the user interface (toilet) and the containment unit which stores the faecal sludge. In South Africa, the following user interfaces are typically used:

- Dry toilet (e.g., VIP pedestals)
- Dry, urine-diverting toilet
- Cistern-flush toilets
- Pour flush toilets (no cistern included)

The above user interfaces can be used with different containment units. Different containment unit options are described below.

Table 13: Typical containment options for onsite sanitation systems

Containment Option	Notes on context/use
Lined pit with open joints (most VIP toilets have this construction)	• Most used option in South Africa • Allows liquid to soak away into the soil, leading to lower sludge accumulation • Appropriate where groundwater contamination risk is low (refer to the DWS Groundwater Protocol for further information) • Single pits are typical, but double pits can be used to extend the life of the toilet. In this case, one pit is in use while the other one rests, allowing the sludge to decompose and dry out.
Single sealed pit or vault	• Typically used with urine diverting toilets • Appropriate option for areas with a high groundwater contamination risk • Sealed containments typically fill up faster, as liquid cannot soak away • Single pits are typical, but double pits can be used to extend the life of the toilet. In this case, one pit is in use while the other one rests, allowing the sludge to decompose and dry out.
Septic tank with soakaway	• Septic tanks should have at least 2 chambers. • Soakaway allows supernatant to drain into the ground, extending the emptying interval. • Appropriate where groundwater contamination risk is low (refer to the DWS Groundwater Protocol for further information)

[5] See the *Compendium of Sanitation Systems and Technologies* (Tilley et al., 2016), which can be accessed here: Compendium-Sanitation-Systems-and-Technologies.pdf (iwa-network.org)

Containment Option	Notes on context/use
Conservancy tank/sealed tank with no soakaway	• Appropriate option for areas with a high groundwater contamination risk • Require very frequent emptying, as all water and excreta must be emptied and transported to a WWTW
Container toilets	• Refers to chemical toilets, container toilets, and other containment systems utilising a small (<50 litre) sealed tank to collect human excreta • Must be emptied extremely frequently (i.e., multiple times per week) depending on the number of users • Produce fresh excreta which may favour certain treatment processes, but also the volume of sludge to handle is much higher because no decomposition or drying take place • Appropriate option for areas with a high groundwater contamination risk

Table 14: Typical emptying options for onsite sanitation systems

Emptying Option	Notes on context/use
Fully mechanised	• Most commonly vacuum tankers • Works well with containment systems that have wet, pumpable sludge (e.g., septic tank systems) • If sludge is dry, water will need to be added and mixed in to allow the sludge to flow • Can face difficulty with sludge that has a large amount of foreign material
Semi-mechanised	• Includes technologies for which some aspects are mechanised and others are human-powered. Many new, innovative technologies fall into this category (e.g., the Pitvaq, which is made in South Africa) • Typically designed specifically for households that are difficult for a vacuum tanker to reach, for example, in densely populated, steep, and/or informal areas • Typically lower cost than a vacuum tanker and therefore provide opportunities for small businesses with limited capital • Works well with containment systems that have wet, pumpable sludge (e.g., septic tank systems) • For pumping systems, if sludge is very dry, water will need to be added and mixed in to allow the sludge to flow • Can face difficulty with sludge that has a large amount of foreign material
Manual	• Typically, long-handled spades and shovels • Appropriate for dry sludge and sludge with excessive foreign material

Table 15: Typical transport options for onsite sanitation systems

Transport Option	Notes on context/use
Vacuum tanker	If a vacuum tanker is used for emptying, the faecal sludge is pumped to the tank on the truck. Thus, the tanker functions as emptying and transport technology.
Bakkie or other small vehicles (e.g., tuk tuk, tractor/trailer)	Other vehicles can be used to transport faecal sludge, as long as the sludge is placed in bins with tight-fitting lids or another type of sealed container.

Table 16: Typical treatment options for faecal sludge

Treatment Option	Notes on context/use
Faecal sludge treatment plant	• Designed specifically to handle faecal sludge • Just like WWTW, FSTPs should be designed based on the specific quantity and characteristics of the faecal sludge to be treated • Typical treatment processes used in FSTPs include, inter alia, anaerobic digestion, drying beds, composting, and constructed wetlands (to treat liquid fraction)
Co-treatment in WWTP	• If the WWTP has spare capacity, FS can potentially be co-treated • For liquid faecal sludges (e.g., those from container toilets), the FS is typically discharged at the headworks of the WWTP after initial screening of the FS to remove foreign material • For dryer sludge, there may be options for adding it to the sludge treatment stream, again following screening to remove foreign material. Dry sludge from systems like VIP toilets should typically not be added at the WWTP headworks, because it is entirely different from wastewater and can inhibit and even damage the WWT process
Faecal sludge treatment units	• Innovative technologies are in development which treat faecal sludge within a single unit. These could understood as similar to package wastewater treatment plants, but for faecal sludge. • The technologies use different processes to treat faecal sludge and vary in terms of required energy input and final output from the process.

Table 17: Typical disposal and end-use options for faecal sludge

Disposal/End-Use Option	Notes on context/use
Deep row entrenchment	• Burial of faecal sludge in pits/trenches and covering with at least 300mm soil to prevent pollution and exposure • Can be done safely onsite if the site has low groundwater contamination risk and is appropriate for soakaway and/or lined pits with open joints. Can also be done at a designated site which is appropriate for burial. • Buried sludge can support trees/plants and thus contribute to the circular economy

Disposal/End-Use Option	Notes on context/use
Agricultural products	• Faecal sludge contains organic matter and nutrients that can be helpful for farming and agriculture • Faecal sludge that is treated to remove pathogens can provide agricultural products such as compost, soil amendment, and fertiliser. This depends on the specific treatment processes used.
Energy	• Organic matter in faecal sludge also means that it can become an energy source in the form of, e.g., biogas or briquettes
Building materials	• It is also possible to produce bricks/blocks out of treated faecal sludge. This process is still at the research stage and has reached a commercial level.

The appropriate technologies for each stage above will depend on several factors including, inter alia, water availability, sanitation practices, faecal sludge characteristics, site characteristics such as groundwater table and soil type, and demand for products. These can be considered at each stage of the service chain to design a complete system that is appropriate for a given area and community.

3.2.2 What do we know about the costs of faecal sludge management?

Because FSM services have not been provided systematically across most of South Africa, very little is known about the actual costs to provide this service. This study included a total of 5 case studies focusing on the management of sludge from onsite sanitation systems. Within some case studies, multiple different scenarios were relevant, leading to a total of 8 data points. These are summarised below, including a description of the data received.

Table 18: Summary of case studies with cost data on faecal sludge management

Study no.	Approach description	Containment	Emptying	Transport	Treatment	Disposal/ Beneficial Use	Data provided
9	Urine diverting dehydration toilets (UDDT) emptied 2x per year, faecal sludge delivered to a treatment facility to produce a soil conditioner.	✓	✓	✓	✓		Actual costs from company doing emptying and treatment. Product given away for free.
10a	VIP toilets emptied manually or with Pitvaq, sludge disposed of safely on site through deep row entrenchment (DRE).		✓			✓	Rates for emptying and disposal
10b	VIP toilets emptied manually or with Pitvaq, sludge transported to farm where composting takes place.		✓	✓			Rates for emptying and transport (excludes treatment cost)
11a	UDDT toilets emptied manually and sludge disposed of through DRE, including a tree planted.	✓	✓			✓	Rates for emptying and disposal, including health and safety, and fruit trees

Study no.	Approach description	Containment	Emptying	Transport	Treatment	Disposal/ Beneficial Use	Data provided
11b	UDDT toilets emptied manually and sludge disposed of through DRE, excluding tree.	✓	✓			✓	Rates for emptying and disposal, including health and safety
12a	UDDT toilets emptied manually, sludge transported to black soldier fly (BSF) treatment (income generated from protein and oil)	✓	✓	✓	✓	✓	Contract rates for emptying, plus OPEX for treatment and projected income.
12b	UDDT toilets emptied manually, sludge transported to black soldier fly (BSF) treatment (no income generated)	✓	✓	✓	✓		Contract rates for emptying, plus OPEX for treatment and projected income.
13	Container toilets in a Metro, emptied 4x per week with sludge delivered to the WWTP headworks.	✓	✓	✓			Only cost of emptying and transport provided, plus cost for janitorial services

The costs of the above approaches are summarised below, showing the cost per household served per year.

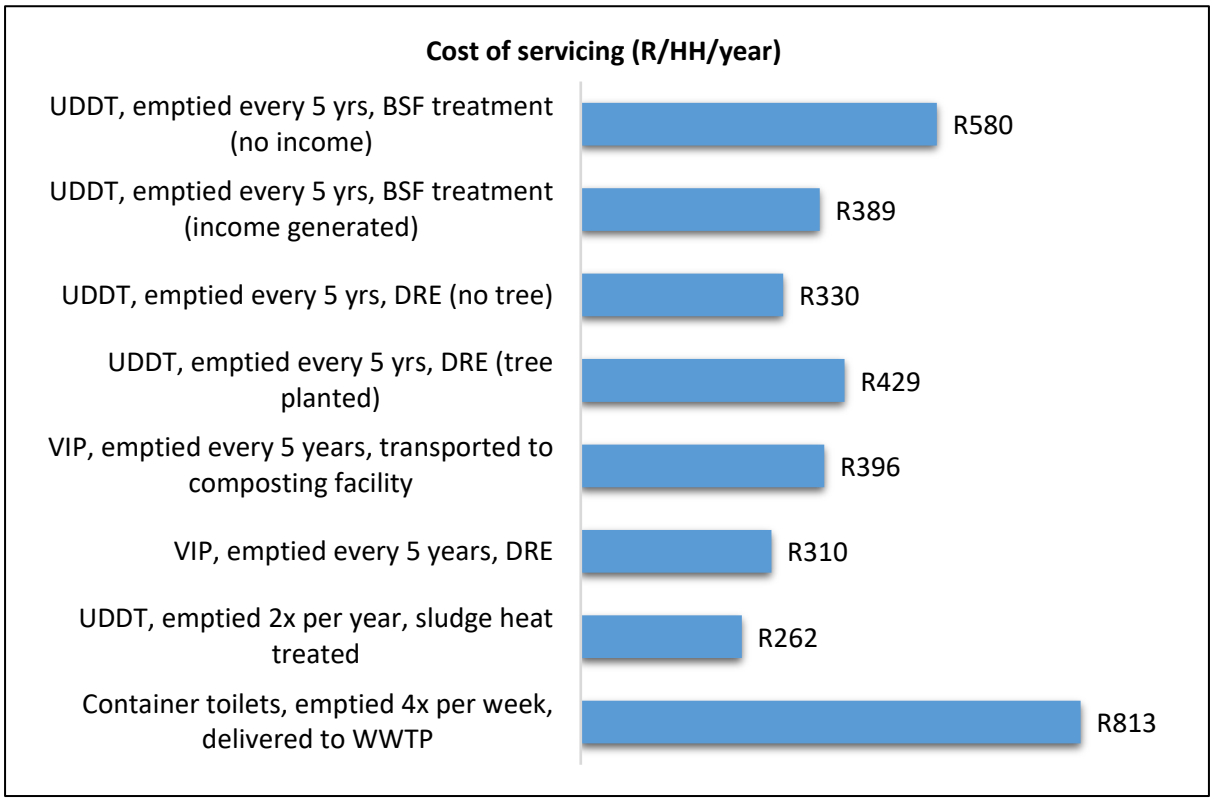


Figure 10: Costs for different FSM solutions per household, averaged per year, reported in case studies (R/HH/yr)

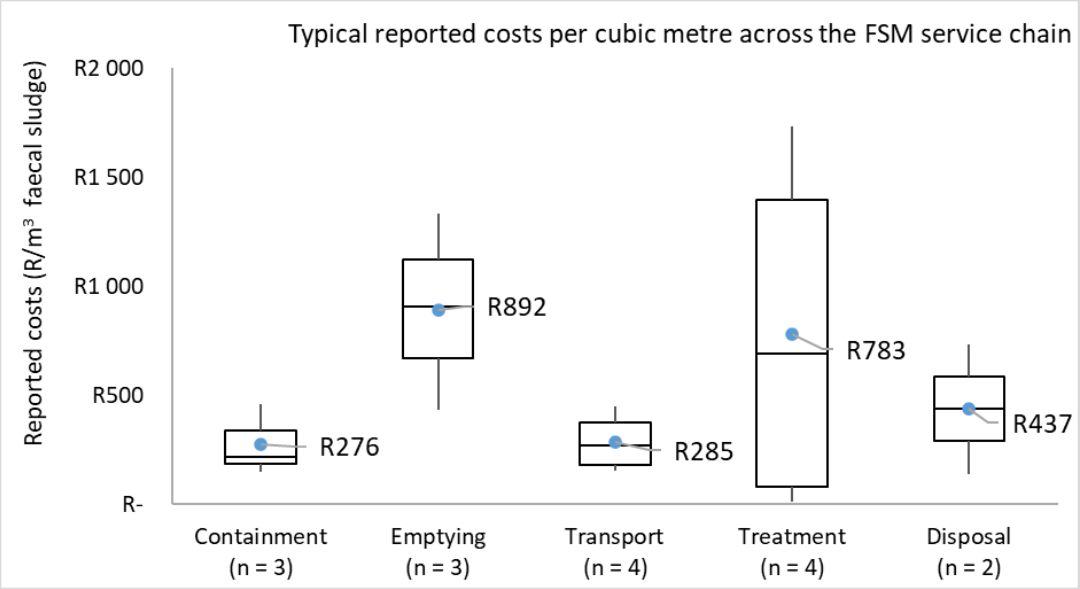


Figure 11: Typical reported costs for various aspects of the FSM service chain

Table 19: Cost ranges for different aspects of FSM, based on case study data

	Range (R/m³)	Median (R/m³)	Average (R/m³)
Containment (n = 3)	R 151 – R 460	R 218	R 276
Emptying (n = 3)	R 433 – R 1 336	R 907	R 892
Transport (n = 4)	R 152 – R 449	R 269	R 285
Treatment (n = 4)	R 11 – R 1 734	R 697	R 785
Disposal (n = 2)	R 141 – R 733	R 437	R 437
Reuse cost (n = 1)		R 475	R 475
Income (n = 1)		R 907	R 907
TOTAL (n = 8)	**R 822 – R 2 573**	**R 1 762**	**R 1 771 (± R578)**

3.2.2.1 Containment

Containment is the first part of the sanitation service chain, relating to the toilet and storage of faecal sludge on site before emptying. Various activities relating to containment were described in the case studies, including janitorial services for communal toilets, household education, and fixing aspects of containment (e.g., panels/access hatches). The reported costs were normalised per m³ of faecal sludge, and these are presented in Table 20.

Table 20: Reported "containment" costs for on-site sanitation systems

Description	Reported rate (R/m³)	Case study ref.
Household education and management	R 151	9
Re-attachment of back panels to urine-diverting dehydrating toilets	R 218	11/12
Janitorial services for container toilets	R 460	13

3.2.2.2 Emptying

Costs of emptying were provided in 3 different case studies. Two of them involve manual emptying of urine diverting dehydration toilets (UDDTs), while the other is for manual or semi-mechanised emptying of VIP toilets. The reported costs per cubic metre are presented in Table 21. The reported costs range from R433 to R1 336 per cubic metre. The lowest cost reported was for a municipal contract for emptying 50 000 UDDTs, and this likely points to the economies of scale in comparison to the other two rates from much smaller-scale operations.

Table 21: Reported emptying costs for on-site sanitation systems

Description	Reported rate (R/m^3)	Case study	Note(s)
Manual emptying of UDDTs	R 907	9	Cost to service provider
Manual / semi-mechanised emptying of VIP toilets	R 1 336	10	Rate charged to households
Manual emptying of UDDTs	R 433	11/12	Municipal contract rate

3.2.2.3 Transport

Transport of faecal sludge was provided in 4 case studies. The average rate for transport of faecal sludge was R285 per cubic metre, with a range from R152 to R449 per cubic metre. Considering transport distance, the average cost is R18.94/m^3/km. Again, the two lowest cost options per kilometre are the options with the largest scale operation.

Table 22: Reported transport rates for faecal sludge

Description	Reported rate (R/m^3)	Distance (avg.)	R/m^3/km	Case study
Tuk tuk transport of dried sludge to processing facility	R 152	4	R 38.10	9
Bakkie with sealed bins for faecal sludge on back	R 449	25	R 17.95	10
Bakkie with sealed bins for faecal sludge on back	R 189	20	R 9.43	12
Vacuum tanker transport of chemical toilet sludge to WWTP	R 350	34	R 10.29	13

3.2.2.4 Treatment

Treatment costs vary widely depending on the actual treatment process utilised. The costs presented below exclude capital costs and only represent operational expenses. The faecal sludge treatment costs provided in this study are presented in Table 23.

Table 23: Reported costs for faecal sludge treatment

Description	Cost (R/m^3)	Case study	Notes
Solar heat drying in a stainless-steel bin to produce soil conditioner	R1 283	9	Includes cost of land rental for treatment facility, running costs, and workers' salaries
Treatment in Black Soldier Fly treatment facility	R1 734	12	Total operational expenses
Treatment of container toilet waste in WWTP	R 12	13	Production cost from WWTP assumed, as the sludge is added at the WWTP headworks (Green Drop 2022).

3.2.2.5 Disposal

Disposal on site was reported in two case studies, and both involved on-site disposal at the household level. In both cases, faecal sludge was buried on site through deep row entrenchment (DRE), which simply involves burying sludge in a trench or hole and covering it with soil. The reported rates for DRE are presented in Table 24. The average cost for disposal from these two case studies is R437 per cubic metre of faecal sludge.

Table 24: Reported rates of faecal sludge disposal

Description	Reported rate (R/m^3)	Case study	Note(s) on costs
Burial of VIP sludge at household	R 141	10	Deep row entrenchment (DRE)
Burial of UDDT sludge at household	R 733	11	Deep row entrenchment (DRE)

3.2.2.6 Reuse

Reuse of faecal sludge can come with costs and potentially income. Two cases provided costs/income for faecal sludge reuse. These are described below. In addition, Case Study 9 includes the beneficiation of faecal sludge to a soil conditioner, but the product is given away for free to the community and so there is no income received.

- Planting a fruit tree on buried sludge can allow a household to reap benefits from buried sludge. Case study 11 included DRE and planting of a fruit tree at a cost of R475/m^3.
- The Black Soldier Fly (BSF) treatment used in Case Study 12 produces two products with potential for income generation, namely, protein and oil, both of which can be used in animal feeds. Assuming there is a market for these products, the potential income generation from these products is R907/m^3. This can offset the operational expenses for the treatment process.

3.2.3 How can one budget for faecal sludge management?

How does one start to budget for faecal sludge management, especially when no systems are in place and the limited cost information available is so variable? This is difficult to answer, because the

appropriate options will be based on the specific context, and also the cost of the options will vary based on specific factors. Ideally, the full sanitation service chain for FSM services is planned from the beginning, including toilet type, emptying, transport, treatment, and disposal/reuse. Treatment systems would be designed based on the desired disposal or reuse option. The reality in South Africa is that sanitation coverage is wide, and many communities are using on-site sanitation systems, but no plan is in place for the rest of the service chain. Thus, the starting point in most cases will be the existing sanitation systems.

The following steps can start to illuminate which options are possible and how to start setting aside budget for FSM:

1. **Know what systems exist that produce faecal sludge and where they are located**: This will require data collection in communities served by on-site sanitation systems. The type(s) of information that should be collected include:
    a. Toilet and containment type
    b. Condition of the toilet and containment
    c. Fullness of the containment, and characteristics of the faecal sludge if feasible
    d. Estimate the faecal sludge to be handled each year, based on approximate sludge accumulation rates, population, and containment sizes
    e. Access characteristics including, e.g., space, road access, distance to key landmarks such as WWTP
2. **Determine possible options for FSM based on the assessment**: Assess each stage of the service chain to identify which option(s) may be appropriate:
    a. Emptying and transport: Is the sludge dry and diggable or wet and pumpable? What equipment do you or contractors already have available?
    b. Treatment: Does the WWTP have spare capacity to co-treat faecal sludge? Is there unused land or facilities at the WWTP that can be used to treat or dispose of FS? Is the WWTP too far from the households with on-site systems? Is land available that could be used for a designated faecal sludge treatment facility?
    c. Reuse: Is there demand for faecal sludge by products? Is there a private partner who is interested in beneficiating the sludge?
    d. Disposal: How big are individual plots, and is there sufficient space for on-site deep row entrenchment? If so, is this appropriate in terms of the DWS groundwater protocol? Is there land available to establish a designated disposal/sludge burial site? Is there demand or opportunity for beneficiation by planting trees over buried sludge?
3. **Compare the approximate costs of the options**: The provided costs for options in this study have been used as the basis for comparing different options for FSM, and costs have been converted to approximate cost per household, to assist with calculating an actual budget amount. The approximate costs for options included in this study are summarised in Table 25.

Table 25: Approximate cost of FSM options presented in this study (R/HH/yr)

Description	Approximate cost (R/household/yr)	Case study ref.
UDDT, emptied 2x per year, sludge heat treated	R 262	9
VIP, emptied every 5 years, DRE	R 310	10a
VIP, emptied every 5 years, transport off site	R 396	10b
UDDT, emptied every 5 yrs, DRE (tree planted)	R 429	11a
UDDT, emptied every 5 yrs, DRE (no tree)	R 330	11b
UDDT, emptied every 5 yrs, BSF treatment (income generated)	R 389	12a
UDDT, emptied every 5 yrs, BSF treatment (no income)	R 580	12b
Container toilets, emptied 4x per week, delivered to WWTP	R 813	13

4. **Implement a user-education campaign to improve sludge quality:** One aspect that impacts downstream treatment, whether in a WWTP or designated treatment facility, is foreign material in faecal sludge. Many households use their on-site toilets to dispose of solid waste and other items, which generally must be removed before treatment and beneficiation. Investing in a user-education campaign can lead to lowering costs of FSM, both in terms of extending the life of on-site containment systems and reducing the cost of treatment.

3.2.3.1 A tool for estimating FSM costs

The "FSM options" MS Excel spreadsheet has been prepared to assist with budgeting and comparison of different options based on the type of on-site toilet(s). Specifically, the following toilet types are considered:

- Container/ Chemical toilets
- VIP (open joint)
- Plain pit (open joint)
- Urine diverting toilets (sealed containment)
- Composting toilets (sealed containment)
- Flush with septic tank to soakaway
- Flush with conservancy tank (sealed) (no greywater)
- Flush with conservancy tank (sealed) (incl. greywater)

For each of the above toilet types, two different options are considered. These are shown in Table 26, along with the assumed average sludge accumulation rate.

Table 26: Options included in Faecal Sludge Management options spreadsheet

Description	Avg sludge accumulation rate used (ℓ/person/yr)	Option 1	Option 2
Container/chemical toilets with mechanised emptying	550	Transport to and treatment in WWTP	Transport to and treatment in FSTP
Dry toilets with open joints (e.g., VIPs) with manual emptying	40	On-site burial	Transport to and treatment in FSTP

Description	Avg sludge accumulation rate used (ℓ/person/yr)	Option 1	Option 2
Dry toilets with sealed containment (e.g., UDDTs) with manual emptying	50	On-site burial	Transport to and treatment in FSTP
Septic tanks with soakaway, with mechanised emptying	30	Transport to and treatment in WWTP	Transport to and treatment in FSTP
Sealed conservancy tanks (blackwater only) with mechanised emptying	5475 (incl. water due to sealed containment)	Transport to and treatment in WWTP	Transport to and treatment in FSTP
Sealed conservancy tanks (black and greywater) with mechanised emptying	25 550 (incl. water due to sealed containment)	Transport to and treatment in WWTP	Transport to and treatment in FSTP

The user is prompted to enter the following information about the community:

1. No. households
2. Type of toilets (technology and communal/household)
3. Typical containment volume in cubic metres
4. Number of households per toilet
5. Average household size

Enter data about the community

No. Households	500
Sanitation characteristics	
Communal/household toilets	Household
Toilet type	VIP (open joint)
Typical containment volume (m^3)	1.5
No. households per toilet (avg)	1
Average household size (no. people)	5

Based on the selected toilet type, containment size, and number of households/people, the approximate volume of faecal sludge generated each year is calculated, along with the required emptying frequency and volume to be removed during emptying. Three scenarios are included, namely, average sludge accumulation, high sludge accumulation, and excessive sludge accumulation due to high trash/foreign material content.

	Approx. m^3 sludge/ yr	Required Emptying frequency		V removed each emptying period (m^3)
Average sludge accumulation	100.0	6.0	Years	600
High sludge accumulation	150.0	4.0	Years	600
Excessive trash	200.0	3.0	Years	600

Based on the above calculations and toilet type, the approximate budgets for options 1 and 2 are calculated. The final outputs are shown in the figures below.

SUMMARY OF OPTIONS

	OPTION 1	OPTION 2
Description	Dry toilets with open joints (e.g., VIPs) with manual emptying and on-site burial	Dry toilets with open joints (e.g., VIPs) with manual emptying and transport to faecal sludge treatment plant
Emptying description	Manual emptying with shovels	Manual emptying with shovels
Transport description	None	Sealed drums on bakkie/other transport
Treatment description	None	Treatment in an FSTP (costs based on reported operational costs from
Reuse description	Not included, though planting fruit tree over sludge is possible	Depends on treatment (cost not included here)
Disposal description	FS buried in a trench on site, covered with 300mm soil	Depends on treatment (cost not included here)
Notes/considerations	- Open joints allow liquid to drain into the surrounding soil - DWS Groundwater Protocol should be consulted to confirm that this option is appropriate - If the site is suitable for this sanitation system, it is suitable for sludge burial - Planting a fruit tree is advised to ensure beneficial use - Costs exclude health and safety supports, e.g., tools and equipment, worker depot	- Open joints allow liquid to drain into the surrounding soil - DWS Groundwater Protocol should be consulted to confirm that this option is appropriate - FSTP capital cost not included - FSTP should be designed to treat faecal sludge from dry on-site systems
Suggested budget and emptying cycle	Approximately R797150 every 4 Years	Approximately R726020 every 4 Years

	R/HH/yr		Total budget/yr	Total budget per emptying cycle	R/HH/yr		Total budget/yr	Total budget per emptying cycle
	Average	High			Average	High		
Emptying	R179	R268	R133 770	R535 060	R179	R268	R133 770	R535 060
Transport	R0	R0	R0	R0	R57	R86	R42 750	R170 990
Treatment	R0	R0	R0	R0	R7	R10	R5 000	R19 970
Reuse	R0	R0	R0	R0	R0	R0	R0	R0
Disposal	R88	R132	R65 530	R262 090	R0	R0	R0	R0
Total	**R267**	**R400**	**R199 300**	**R797 150**	**R243**	**R364**	**R181 520**	**R726 020**

Figure 12: Comparison of options (example) output from FSM Options spreadsheet

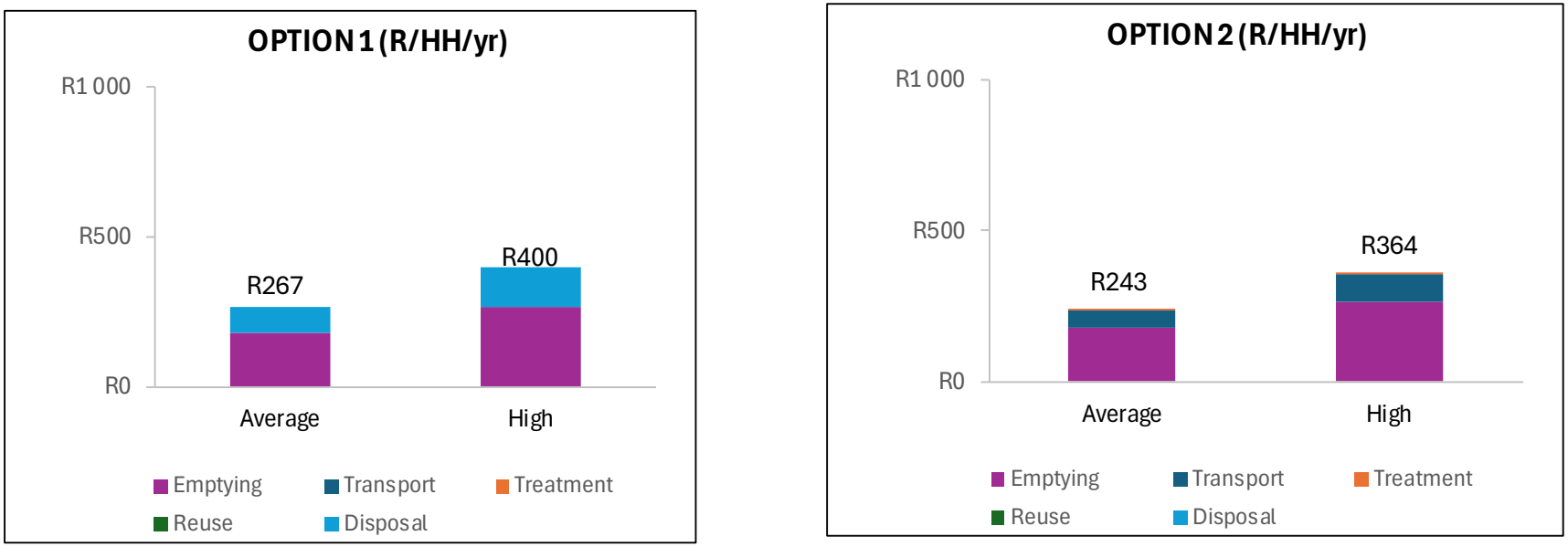


Figure 13: Example output showing estimated cost per household per year for options 1 and 2 described in example above

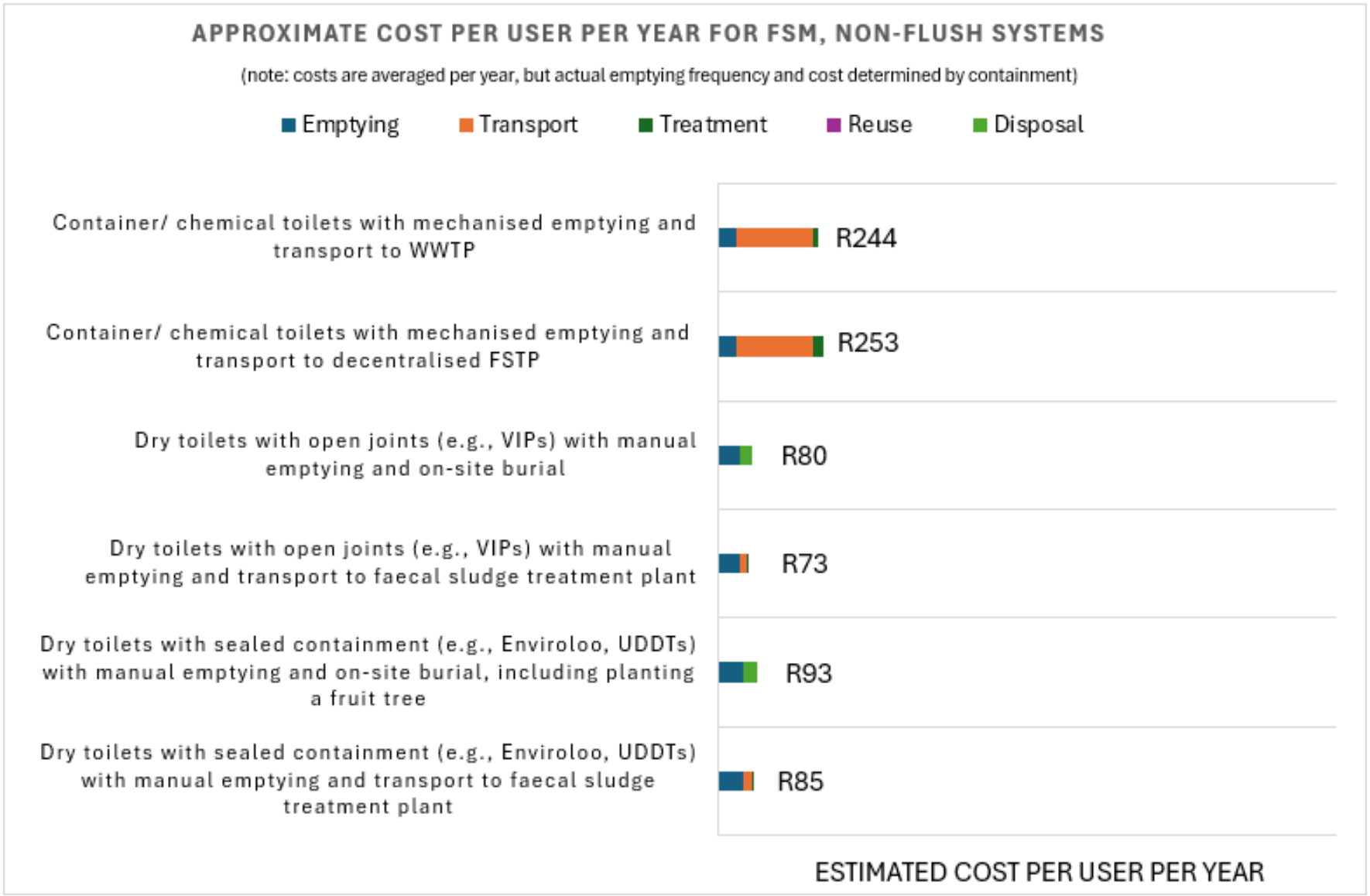


Figure 14: Estimated cost per user per year, for non-flush toilets

4 Conclusions

Two briefs have been prepared as part of this research to provide an overview of how best to improve sludge management in South Africa. These can be found in Annexures N and O and are also available as standalone documents. This section of the report summarises the primary recommendations.

4.1 Opportunities for cost-effective sludge management in municipalities

Based on the findings of this research, the following three opportunities were identified to improve the cost-effectiveness of sludge management:

1. **Reduce transportation distance and cost:** Transportation is the main cost-determinant for sludge disposal. Therefore, it is worthwhile to focus efforts on reducing the need for transportation of sludge.
2. **Reduce volume/weight and/or improve the quality of sludge generated:** Reducing the weight/volume of sludge will reduce the amount that must be managed and therefore the costs. This links directly to number 1 by reducing the quantity of sludge that must be transported. Improving sludge quality can also make sludge management simpler and open up more opportunities, allowing municipalities more decision-making power to select the most cost-effective option.
3. **Transfer some costs to private sector through a mutually beneficial partnership:** This research highlighted several cases of municipalities partnering with a business centred on beneficiation of sludge. These arrangements meant that some of the cost of managing the sludge were transferred to the business, who in turn produced a product that they could market and sell. This ensures that the municipality can focus on their core business of providing services while still taking advantage of the demand for beneficiated sludge.

Specific recommendations for pursuing these 3 strategies for wastewater and faecal sludges are described below.

Reduce transportation distance and cost	
Wastewater sludge	- Identify disposal locations closer to where the sludge is generated - If land is available within the WWTP, consider on-site deep row entrenchment (DRE) as a simple, cost-effective option. This may be an especially effective way to deal with stockpiled sludge. - Invite potential sludge users (e.g., farmers) to collect sludge from your WWTP. This is especially attractive if the quality/classification of the sludge produced is good (e.g., A1a).
Faecal sludge	- If space allows and the sites are suitable for typical open-joint on-site sanitation (e.g., VIP toilets), household-scale deep row entrenchment (DRE) eliminates the need to transport sludge off-site. - Establish decentralised, designated disposal or treatment facilities near households with on-site sanitation. WWTPs are often far from where faecal sludge is generated, requiring long transportation distances. Designated facilities should be located closer to where the faecal sludge is generated.

Reduce volume/weight and/or improve the quality of sludge generated	
Wastewater sludge	- Optimise sludge treatment in the existing WWT process, including ensuring that anaerobic digesters are operating correctly and producing an adequately stabilised sludge. - Invest in sludge drying. Solar drying beds provide a low-cost and simple solution for this, provided sufficient space is available. Belt presses require more capital investment, but they can be used in areas where space is a limitation. - Provide further sludge treatment to improve the sludge classification. A1a sludge is easier to manage and has fewer restrictions in terms of agricultural application. By producing a higher quality sludge, the municipality will open up additional opportunities for safe sludge disposal, which can empower them to select based on cost-effectiveness. A higher quality sludge is also more likely to be willingly collected by sludge users, reducing the cost to the municipality.
Faecal sludge	- Consider on-site sanitation units that provide some level of treatment before emptying and transport are required. This might include biological degradation, enhanced drying, or removal of liquids in the on-site containment unit. Examples include urine-diverting toilets that separate solids and liquids, toilets that dehydrate the waste, and some composting toilets. - Designated faecal sludge treatment plants can be established close to the areas where faecal sludge is generated. Treatment processes in these plants should focus on improving sludge quality and reducing sludge quantity. This might include digestion, solar drying, and composting, among others.

Transfer some costs to the private sector through a mutually beneficial partnership	
Wastewater sludge	- Identify potential public-private partnerships. In such partnerships, the private partner has an interest in the sludge produced in the WWT process to beneficiate it and generate saleable products. This can reduce cost to the municipality, as the cost of treating sludge beyond the WWT process falls on the private partner. Furthermore, the cost of transporting the beneficiated product then gets transferred to the end-user, as that cost is included in the price of the product. This arrangement requires some creativity in the procurement process but can likely be justified to reduce costs to the municipality.
Faecal sludge	- Similar to wastewater sludge, identifying potential users of faecal sludge can help municipalities to transfer some of the costs to the private sector. While such solutions may not generate income for the municipality, they are likely to reduce the cost to the municipality of providing services on the entire sanitation service chain.

4.2 Opportunities to support sludge management

This research has highlighted the following recommendations for how the Department of Water and Sanitation can support municipalities in sludge management:

- **Improve awareness and understanding of the public-private partnership process**: South Africa has a framework for pursuing public-private partnerships through the official procurement process, but the municipalities in this study were generally reticent to pursue this route. There is a need for awareness raising and capacity building among municipalities on how to go about establishing partnerships with the private sector while complying with the Municipal Finance Management Act (MFMA).
- **Build awareness among the private sector on opportunities in wastewater sludge beneficiation**. A small number of companies are doing this, and they have emphasised the fact that demand for their products is high. There is a market for other businesses in this space, and expanding the pool of private companies can assist with overcoming procurement challenges (e.g., only one company submitting a proposal) and making circular economy solutions accessible throughout the country. DWS can assist with this advocacy process by using its platform to share research, development, and projects in this space.
- **Develop planning tools and templates for wastewater and sludge management**: Planning for wastewater and faecal sludge management is limited across the country. One research participant requested a template for a sludge management strategy, and others said that sludge management should come through in Water Services Development Plans (WSDPs). In addition, model by-laws or standard technical specifications can assist. Lastly, standard data collection methods for FSM can help to generate information about on-site sanitation systems, which is currently lacking.
- **Support the development and testing of designated sludge treatment and beneficiation facilities**: This applies to both wastewater and faecal sludges. Wastewater sludge beneficiation facilities are being built in one metro municipality, and these should be studied and the information shared with other municipalities. For faecal sludge treatment, the first FSTP must be constructed, and the municipality should be capacitated to manage it. Once the first faecal sludge treatment plant is built in South Africa, it will open the door to more by demonstrating the technical, legislative, financial, and operational needs of the facility. A simple, low-tech solution should be implemented so that it can be replicated elsewhere.
- **Consider establishing minimum requirements for personnel focused on sludge management**: One case study in this research had a designated Sludge Manager with a core focus on the treatment, disposal, and beneficiation of wastewater sludge. This ensures that sludge management is not neglected. This should potentially be implemented across municipalities, both for wastewater sludge and faecal sludge.

Finally, this research has highlighted the need to share practical lessons learned by municipalities to build capacity around sludge management. While researchers can summarise and disseminate information, municipalities implementing practical solutions have more relevant information to share with their colleagues. This study provided one platform to consolidate experiences and views from different municipalities, and additional platforms are needed to encourage learning.

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ANNEXURE A: CASE STUDY 1

Case study 1 –Application of wastewater sludge in sugarcane farms (retrospective)

This case study covers the application of wastewater sludge in sugarcane fields outside of a large metro. This was done over several contracts which covered both stockpiled sludge and sludge produced on a daily basis.

Project description

This metro municipality had large stockpiles (approximately 80 000m^3) to deal with and sought proposals for innovative beneficiation projects, but one tenderer suggested a simpler, more cost-effective approach. Expressions of interest were invited for dealing with large stockpiles, with a keen interest in pelletisation as well as producing a fertiliser product enhanced with nitrates and phosphates. One consultant submitted an Expression of Interest which suggested that a simpler and quicker route would be to follow the WW *Sludge Guidelines* to apply sludge to farmland. Following this, a tender was advertised for this approach, removing stockpiles from 3 treatment works and applying the sludge to sugarcane farms. This was followed by 3 more contracts of a similar nature, including contracts for the daily offtake of sludge produced at the treatment works. The scope of works included all tasks required for doing this in compliance with the sludge guidelines, namely:

1. Identifying farmers to accept sludge
2. Identifying suitable fields, including distance from water sources and permissible tons per hectare
3. Loading vehicles on site
4. Transporting sludge to farms
5. Offloading sludge at farms and applying the sludge as per the sludge guidelines

Municipality Type	Metro
Organisation(s) involved	Municipality, Service Provider, Farmers
Type(s) of sludge processed	Sewage sludge
Other waste streams processed?	None
Description of technology and process	WW sludge was collected by the contractor and delivered to sugarcane farms. This included several different types of sludge (i.e., WAS, digested, dried, stockpiled). Memorandums of Agreement were signed with farmers, and sludge was applied and then monitored based on Volume 2 of the *Sludge Guidelines*.
Description of end use/disposal	Sludge applied in sugarcane fields. Digested and dried sludge was applied on the ground and waste activated sludge was injected into the subsoil due to high moisture content.
Volumes of sludge processed per day (m^3/day)	In 2014 and 2017, average of approximately 36 m^3/day from WWTPs having sludge taken off site on an ongoing basis. A sludge stockpile at one WWTP of 570m^3 was removed in 3 days.

Transport distance to processing facility	n/a
Transport distance to end-use	50km on average
Date when project was initiated	2009
Date when project ended	2015

Including each step under the tenderer's scope ensured control over the process from start to finish. It also required municipal contracts managers and tenderers to understand the sludge guidelines in depth. The Bill of Quantities split the rate of sludge disposal into three parts, namely: transport, application, and management. The management fee encompassed the requirements for identifying farmers and suitable sites as well as analysing the sludge every month to determine the classification.



Figure 15: Example of skip vehicle to transport sludge



Figure 16: Example of side tipper used to transport sludge collected in silos on WWTP site



Figure 17: Example of roll-on tank

The contractor's responsibilities, as stated in the Tender Document were:

- *Finding farmers to accept application of sludge on to their land*
- *Meeting with farmers directly, checking that the land where sludge is to be applied is suitable, and securing a signed contract from each farmer using the format in Appendix B to [the] tender document*
- *Transport of sludge from the WWTW to the farmers' land*
- *Ensuring proper application of sludge to land*
- *Ensuring farmers comply with any restrictions imposed*
- *All reporting and compliance issues*
- *Ensuring adherence to DWAF sludge disposal guidelines and other relevant legislation throughout the process.*

For digested sludge, the contractor described the sludge application process as follows:

1. Tip sludge onto "drop zone"
2. TLB loads a Keenan Oribital Spreader
3. Large tractor pulls orbital spreader to apply sludge at the designated rate



Figure 18: Orbital spreader in use (photo supplied by Oricol)

This requires the contractor to have special equipment, including sludge transport vehicles, a TLB and spreading equipment. In the case of this contract, there was some sharing of equipment with one of

the farmers, but for the most part, the contractor owned the necessary equipment. This suggests that the start-up costs for doing this work are high. It also means that efficiency of the operation is key, as keeping the equipment busy all the time is more cost-effective.

For waste activated sludge (WAS), a different approach was taken, as the sludge was wet and had to be incorporated into the soil, rather than spread on the surface. This was important to avoid nuisances. The contractor developed a machine for incorporating sludge into soil using off-the-shelf equipment. This technology rips open furrows, drops sludge into the furrows, and then covers the sludge with soil.



Figure 19: WAS sludge applicator showing furrow and sludge application (supplied by Oricol)

Data collected

The following data was collected to complete this case study:

- An interview with Municipal Engineer
- An interview with Technical Manager from the sludge disposal contractor
- Documents from municipality: tender document, sludge management report (internal), contract pricing document, sludge classification report and data
- Documents from contractor: offtake data for 2 months, proposal document

Motivation

This approach to sludge disposal was chosen for several reasons. It began as a way to swiftly deal with stockpiles of sludge while also complying with the *Sludge Guidelines*. The quotes below speak further to the motivation.

Dealing with stockpiles

We managed it in terms of stockpiles. We had contracts for…removing sludge to agriculture. (Interview with municipal engineer)

Sludge was piling up and [we] needed to get it out. (Interview with municipal engineer)

Comply with Sludge Guidelines

Ensuring adherence to DWAF sludge disposal guidelines and other relevant legislation throughout the process. (Tender document)

Sludge Classification

Sludge classification was part of the contract and was done by the contractor on a monthly basis. The largest concern for this method was the pollutant class (heavy metals), but only a few samples had elevated levels of metals. This was typically quickly resolved and did not impact the operations.

Regular testing (depending on volumes generated) is required to assess nutrient content, heavy metal contamination as well as pathogen levels and stability. (Contractor proposal)

Costs

The costs below are based on a daily offtake report from 2014, adjusted to 2024 prices[6]. These are the tenderer's rates, and thus represent the cost to the municipality. For waste activated sludge (WAS), the average cost for sludge disposal was R813 per cubic metre, compared to an average of R474 per cubic metre for digested sludge. This difference is primarily due to the higher costs associated with application of WAS, which was ploughed into the ground as described above, rather than applied on the surface. Further information about factors impacting the cost of sludge disposal is provided below.

The breakdown of the rate for sludge disposal at 4 different WWTPs is presented in Figure 6, and Figure 7 shows the cost of sludge disposal per cubic metre of wastewater treated. The cost of sludge disposal at Verulam far exceeds the other 3, which is likely due to higher sludge production at that treatment plant. In 2013, one WWTP was only operating at 45% capacity, which could explain the higher sludge production compared to wastewater treated.

[6] Price adjustments done using https://inflationcalc.co.za which calculates based on data from Stats SA.

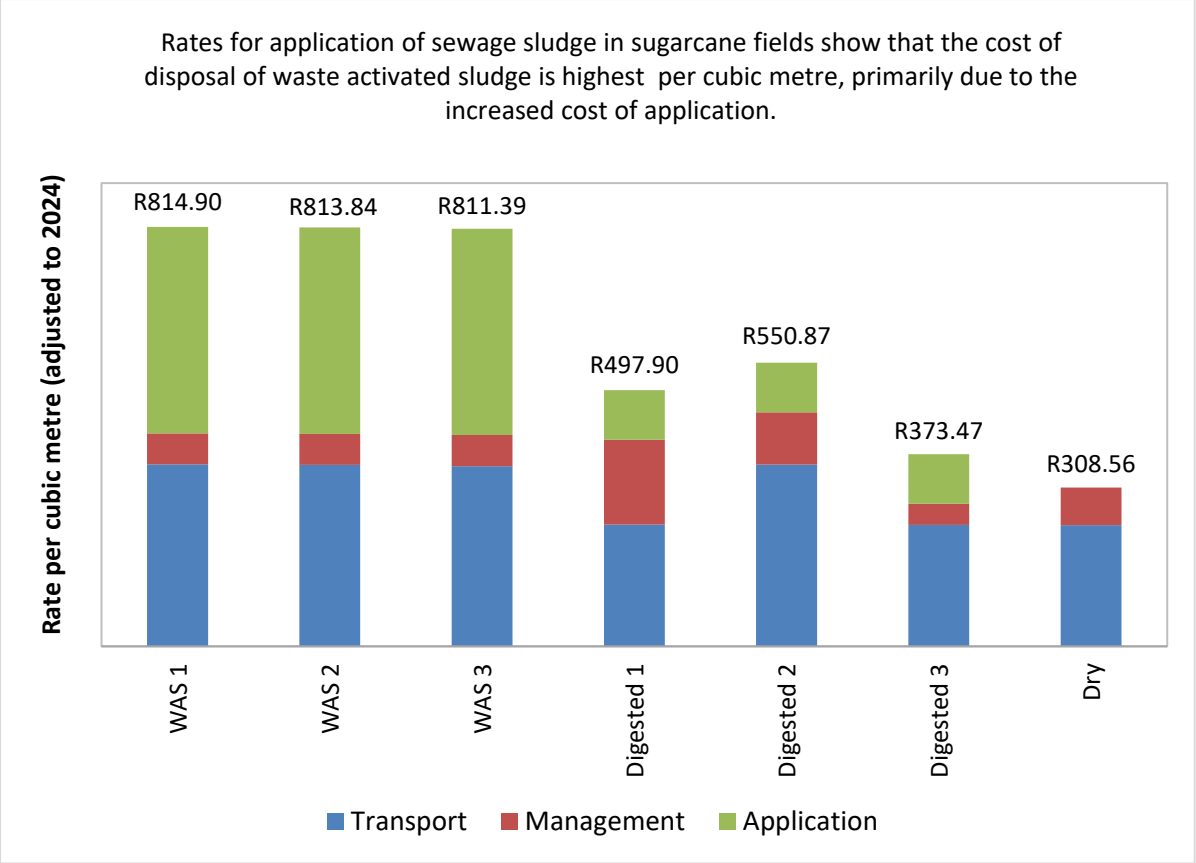


Figure 20: Rate per cubic metre of sludge for each treatment plant and type of sludge, broken down for transport, management, and application

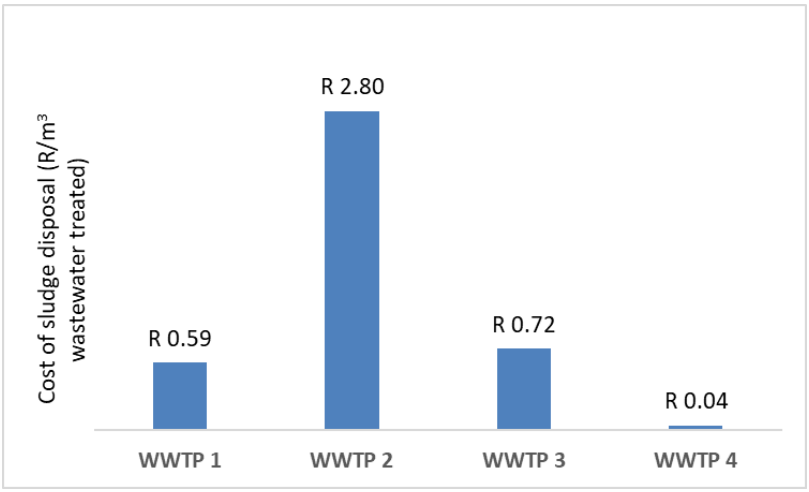


Figure 21: Cost of sludge disposal per cubic metre of wastewater treated at 4 treatment plants

Transport costs

The contractor noted that the distance to a farm has an impact on the cost of transport, as expected. To simplify the contract, a single rate per cubic metre for each treatment works and sludge type was used, but this opened the contractor up to some risk if he could not find farms within a range of 50km.

> *…We had to put a stick in the sand, and say, we are going to find enough farmers within…a 50-kilometre radius… that we don't have to go further than that… If we do go further than*

that, then...we've got to suck it up, but then again…we would find some farmers a little bit closer…and it would all shake out in the mix. (Interview with contractor)

Implications of inefficiency

The contractor highlighted that the type of sludge storage facility at the treatment works determined the type of transport used and, therefore, the costs of transport. While large silos at the WWTP made it simple to offload large volumes of sludge into large side tippers, treatment plants without sufficient storage would be given a skip to discharge to. Skips could carry a smaller volume; thus, transport was less efficient.

… some of the works have…big silos… 100 cubic metre silos where we could…just dump 30 to 34 cubic metres of sludge into the big side tippers, and then it [is delivered to the farm] and then that would do three loads in a day… and then other ones…because of the discharge area, we had to put skips under there… six cubic metre bins, which were more expensive, because now you're moving smaller parcels around with less efficient vehicles. (Interview with Contractor)

Management costs

The contract included a management fee per cubic metre, which would cover all necessary tasks related to identifying farmers and ensuring compliance with the Sludge Guidelines.

A management fee, which involved…going out there, finding the farmers, engaging with the farmers, analysis of the sludge, because we had to analyse the sludge every month to make sure what class of sludge it was… (Interview with Contractor)

Sludge classification impacts the costs

The management fee described above includes the necessary classification of sludge. In the proposal, the contractor highlighted the potential impact of varied sludge classifications on the cost of sludge disposal. Due to the different methods of dealing with sludges of different pollutant classes, the contractor noted a key assumption in pricing that pollutant class "a" would be dealt with.

This document has been compiled on the understanding that the sludge removed from the various works will be rated as pollutant class "a" sludges. Should this classification be downgraded during the ongoing monitoring of the material being removed, requirements for compliance with the sludge guidelines would change and there would be a ***significant change to the management costs associated with reusing the material****.* (Contractor proposal)

Application costs

The proposal also included a rate for application per cubic metre. The contractor highlighted that including application of sludge in the contract was critical to ensuring that sludge application is done correctly, as per the Guidelines.

Oricol's Proposal includes the cost of land application of the sludge. This is crucial to the success of the project. In some cases, Oricol relied on farmers to apply sludge themselves

and in every case we had to go to the farm and apply it ourselves. (Contractor proposal for contract renewal)

Higher costs for applying wet sludge that must be incorporated into the soil

The higher cost of WAS compared to digested sludge was discussed in the contractor's proposal, emphasising the need for a different sludge application method. This is due to the unstable nature of WAS making it more vulnerable to causing nuisance.

Handling of the Waste Activated Sludge added to the complexity of this project which had to be very carefully managed in order to comply with the guidelines and not to cause nuisances to neighbours / farm owners etc. (Contractor proposal)

WAS is the most problematic sludge stream to be used in agriculture as it has to be incorporated into the soil on the day that it is delivered to the farm. This is in order to comply with the sludge guidelines which stipulates this requirement to prevent nuisances such as flies and odours from developing as WAS is a lot less stable than Digested Sludge. (Contractor proposal)

Benefits and challenges

The benefits and challenges with this approach are summarised below, based both on feedback from the interviewed individuals and the researcher's assessment.

Benefits:

1. **Compliance with guidelines:** The contract and contractor's methodology focused on compliance with the Sludge Guidelines. The contractor was responsible for compliance from start to finish in terms of "where it's getting applied, to what crops, how close to rivers or streams," and other key aspects. This is in contrast to approaches where farmers are asked to collect and spread sludge themselves.
2. **Product safety:** Applying sludge to sugarcane fields reduced the risk of human exposure to pathogens, because harvested sugarcane is processed before human consumption. In general, the sludge transported in this contract was low in pollutant levels, which is important to the safety and compliance of this approach.
3. **Positive reception by farmers:** Farmers were generally positive about receiving the sludge, especially since it did not come with any extra costs to them. The benefits for farmers outweighed the potential nuisances of sludge for most farmers. The contractor did not face a shortage of acceptable sites. According to the contractor, the sludge was "a cheap source of nutrients [for] the farmer…it would help with build-up of organic material and… help the farmer… with… input costs."
4. **Competent contractor** with skills and experience related to logistics and waste management. These skills proved critical in ensuring an efficient operation, particularly because it involved several different WWTPs, sludge types, and farms. While this was the first project completed by the contract that involved sewage sludge, their background skills proved invaluable. In addition, according to the contractor, their involvement over several years allowed them to constantly improve their processes, demonstrating the value of ongoing sludge disposal

efforts to ensure contractors have the necessary capacity. “It's all about logistics, and we had to look at how we're loading it, what's the turnaround time, how many bins we put on site…”

5. **Contractor providing the necessary equipment:** The contractor described the different equipment needed for transporting and spreading the sludge, which was organised by them rather than expecting farmers to provide it themselves. This was a cost-efficient way to do it, while also ensuring appropriate procedures. “It makes more sense for one contractor to own all the equipment…which makes the application costs more affordable. It would be very expensive for several farmers to each invest in this equipment…”
6. **Relationships with farmers**: The proposal by the contractor emphasised that those managing the spreading of sludge were also tasked with identifying farmers and deciding where and how sludge would be applied. The proposal stated, “The success or failure of this type of project will hinge on developing relationships with farmers who take the material.” This aspect of the approach should not be underestimated.

Drawbacks/challenges:

1. **Sludge with heavy metals:** While the approach worked well for sludge that met the pollutant level requirements, the municipality noted that they had some treatment plants receiving industrial wastewater, which led to heightened levels of heavy metals in the sludge. In these instances, sludge was disposed of in landfills as part of a separate contract.
2. **Complexity of the operation:** The operation was complex in that it involved multiple treatment works, types of sludge, and transport and application methods. This emphasises the need for a competent contractor to manage this work.
3. **Potential for nuisance:** A few reports were received of nuisance at or near farms where sludge was applied, and a few farmers did not want the sludge because they were worried about nuisance. This included sludge spills during the application process that led to sludge getting onto tyres and then being tracked onto roads. This was remedied by protocols for cleaning vehicles and equipment before leaving site. These issues did not seem to hamper the efforts, as there were plenty of farms in the area that were happy to receive sludge.
4. **Supply chain challenges**: While the municipal engineer did not elaborate, he did mention that there is a need for long-term supply chain models, e.g., public-private partnerships or longer-term contracts. This comment was partly in relation to the fact that these contracts had to be redone every 3 years and ultimately ended due to the lengthy process required. While sludge production did not stop, the contract for continuous removal of the sludge did, which left the municipality with another challenge to overcome. From the contractor’s point of view, longer-term contracts would be more ideal, as it gives the contractor time to build up capital to pay for the equipment required, and it also allows them to build relationships with farmers and improve the process.

Opportunities

This approach is a relatively simple method for dealing with both sludge stockpiles and daily production. WWTPs that have large stockpiles could pursue this route, provided there is sufficient agriculture of the right kind within an approximately 50km range of the WWTP and provided that the sludge is not polluted with industrial waste. The contractor for this project noted that removing large

stockpiles over a set contract period was much simpler than daily offtake, because the quantities are predictable, and the schedule can be optimised for efficiency.

This approach can work well with crops that:

- Are highly processed after harvesting before human consumption, e.g., sugarcane, sunflowers
- Have the main crop growing well above ground, e.g., maize
- Are not for human consumption, e.g., timber

Where large agricultural lands are available near WW sludge sources, the ongoing removal and disposal of sludge can be implemented. The most important aspect of this approach is that the municipality and the contractor understand and take ownership of the specific requirements laid out in the Sludge Guidelines.

ANNEXURE B: CASE STUDY 2

Case study 2 – Disposal of wastewater sludge in landfill (retrospective)

Project description

Digested dewatered sludge from one WWTW in this metro municipality was disposed of at a hazardous landfill for several years between approximately 2014 and 2021. This was done because of elevated levels of heavy metals in sludge disqualifying it from any other safe disposal methods. This method is covered by Volume 3 of the *Sludge Guidelines*, which states that disposal in landfills requires a Waste Permit. Since this work was done, liquid wastes have been banned from landfills based on the *National Norms and Standards for Disposal of Waste to Landfill* (2013) from the *NEMWA* (2008). Liquid waste includes waste with a moisture content of >40%. The sludge in this case is dry enough to not be considered "liquid waste" and it would therefore still be allowed for disposal in landfill.

Table 27: Overview of Case Study 2

Project title	Landfill disposal of digested dewatered sludge
Municipality Type	Metro
Organisation(s) involved	Municipality, transportation contractor
Type(s) of sludge processed	WW
Description of technology and process	Digested dewatered sludge is removed from the WWTW and transported to the landfill. It is treated with lime to immobilise pollutants and then buried in trenches.
Description of end use/disposal	Landfill disposal
Volumes of sludge processed per day (m^3/day)	31 m^3/day (2014 data)
Transport distance to processing facility	n/a
Transport distance to end-use	20 km
Date when project was initiated	2014
Date when project ended	2021

Data collected

This case study is based on:

- An interview with a WW Engineer from the municipality
- A contract pricing document for landfill disposal (2014)
- An internal report on sludge management in the municipality (2023)
- A sludge classification report by a consultant (2019)

Motivation

Sludge was taken to landfill only if it had a poor classification in terms of pollutants (heavy metals). The sludge classification report from 2019 highlighted elevated levels of chromium, lead and nickel primarily in sludge from this WWTP. Due to the elevated levels, sludge from drying beds and belt press

both had a pollutant classification of "c", which makes it inappropriate for any sludge disposal methods besides landfill application. The sludge classification report from 2019 also assigns a stability classification of "3", due to inadequate stabilisation through anaerobic digestion. While stability classification can be improved though further treatment, pollutant classification is difficult to improve as it is dependent on characteristics of the wastewater coming into the WWTP.

> *If… metals are coming out too high, [and] the pollutant load is not complying, we used to take it to landfill site.* (WW Engineer)

Costs

The costs of sludge removal and disposal in landfill were adjusted from the municipality's own estimate from April 2014. Two cost estimates were provided based on two different skip sizes (7 m^3 and 11 m^3), providing some insight into the impact of larger transport vehicles on costs. Costs have been adjusted to 2024 prices and are summarised below[7].

Table 28: Cost estimates for disposal of WW sludge in landfill[8]

Item	7m^3 skip		11m^3 skip	
	R/m^3	R/ton	R/m^3	R/ton
Transport	R439.02	R406.51	R254.17	R234.14
Disposal	R1 115.40	R1 032.77	R1 115.40	R1 027.53
Treatment	R65.55	R60.69	R44.40	R34.96
Bin Rental	R0.62	R0.57	R0.54	R0.50
TOTAL	**R1 620.58**	**R1 500.54**	**R1 414.51**	**R1 297.13**

The costs above demonstrate that transport in a larger skip is more efficient and therefore lower in cost overall. The transport cost ranges from R12/ton/km to R20/ton/km, based on a 20-km distance. The costs also highlight that disposal is the most expensive aspect of this option, which is also demonstrated in Figure 1 below. Disposal costs include gate fees and disposal in a trench.

[7] Price adjustments done using https://inflationcalc.co.za which calculates based on data from Stats SA.
[8] R/ton rates were provided in the cost estimate and were adjusted to R/m^3 assuming a density of 1080 kg/m^3 (von Sperling, 2007)

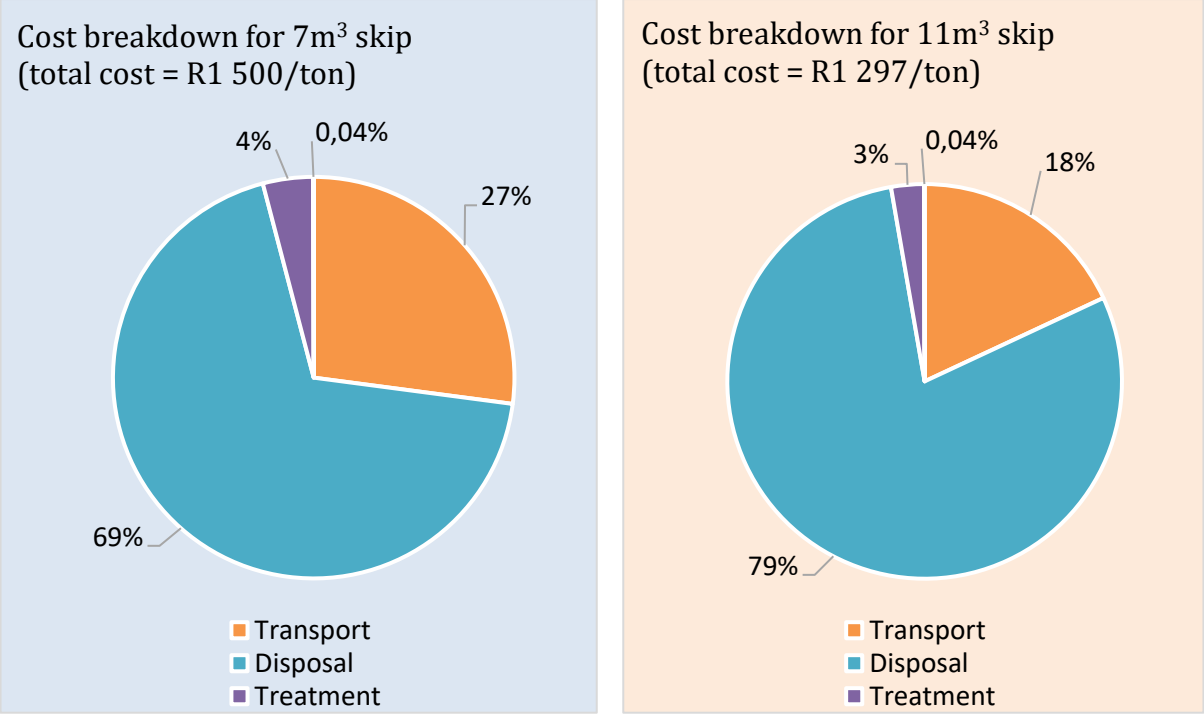


Figure 22: Comparison of breakdown of costs for disposal of WW sludge in hazardous landfills

Benefits and challenges

The benefits and challenges with this approach are summarised below, based both on feedback from the interviewed individuals and the researcher's assessment.

Benefits:

1. **Safe way to deal with polluted sludge**: This option complies with the *Sludge Guidelines* and utilises existing facilities to reduce the cost. By disposing of the sludge in the hazardous landfill, pollutants are kept out of the environment, assuming the landfill operates appropriately.

Drawbacks/challenges:

1. **High cost of disposal:** The disposal costs in this case study are excessive due to the gate fees and need to dispose of sludge in trenches.
2. **No beneficiation of sludge:** When sludge is disposed of in landfills, no benefits from the organic or nutrient content of sludge can be realised. Disposal is the lowest priority in the waste management hierarchy, but in this case, it was the only practical option based on the sludge classification.
3. **Limited landfill space:** As landfill space is finite, this is an option that cannot continue indefinitely. The fact that the landfill in this case study was only 20km from the WWTP allowed transport costs to remain low. However, if this landfill were decommissioned, travel distance, and therefore cost, would increase.

Was there another option?

The above approach was taken due to the need to comply with the *Sludge Guidelines*. As shown above, disposal in a hazardous landfill comes with considerable costs, and there are a few other options to

deal with this sludge type as per Volume 3 of the *Sludge Guidelines*. Volume 3 provides guidance for the following disposal locations, in addition to landfill:

- Mono-fill
- Waste piles
- Lagoons
- Dedicated land disposal

Volume 3 specifies that sludge with a pollutant classification "c" can *only* be disposed of in a hazardous landfill site or in another "engineered, lined facility with stringent requirements." A mono-fill (i.e., a land disposal site for one type of waste) could have been constructed to receive the sludge. According to Volume 3, the following areas are not permissible for sludge disposal:

- Areas within the 1 in 100-year flood line
- Unstable areas
- Areas with steep gradients
- Areas of groundwater recharges and/or highly permeable soils
- Areas upwind of a residential area in the prevailing wind direction(s)
- Natural habitat of endangered species
- Less than 400m from surface water/borehole
- Less than 5m from top of aquifer

In this case, the WWTW is adjacent to a river, and there is not a suitable location within the WWTW where land disposal would be permissible. If the site were appropriate, the mono-fill would have several requirements, including:

1. It would need to be lined, due to the pollutant class
2. Vector attraction reduction would still be required, as was done in this case by adding lime
3. Sludge would need to have at least 20% solids
4. Runoff collection mechanisms would be required
5. Leachate would need to be collected and recycled to the WWTP headworks
6. Surface water and groundwater would need to be protected
7. Regular monitoring of methane gas
8. No edible crops to be planted
9. Restrictions on access by the public and grazing animals

Extensive regular monitoring would also be required, including sludge classification, groundwater, surface water, soil, and methane.

ANNEXURE C: CASE STUDY 3

Case study 3 – Agricultural application and sludge composting (Metro)

The water services provider (WSP) for this metro manages the 6 WWTWs within city, where a few different sludge disposal methods are utilised. Most sludge is digested and then delivered to farms for agricultural application as per the *Sludge Guidelines* (Volume 2). A portion of the digested sludge is solar dried and composted to produce A1a sludge which is given away to farmers.

Project description

This case study presents three distinct approaches taken to handle digested/dewatered sludge from the 6 WWTPs, which are summarised in Table 1.

Table 29: Sludge disposal/reuse options utilised in Case Study 3, including volumes processed in 2022/2023

Description	Volume of sludge processed in 2022/2023
Transport of digested/dewatered sludge to farms between 0-100 km away	81 983 m^3
Solar drying and composting of digested/dewatered sludge, collected by farmers	7 874 m^3
Solar drying and composting of digested/dewatered sludge, delivered to farms	2 860 m^3

Table 30: Summary of Case Study 3

Project title	Agricultural application and composting of WW sludge
Municipality Type	Metro
Organisation(s) involved	WSP, farmers
Type(s) of sludge processed	WW sludge
Description of technology and process	WW sludge is treated in digesters and mechanically dewatered. A portion of the sludge is then further treated through solar drying and composting to increase solids content and improve stability, ultimately improving the sludge classification.
Description of end use/disposal	Most of the sludge (digested and dewatered) is delivered to farms and applied as per the guidance in the Sludge Guidelines. The sludge that is dried and composted is mostly collected by farmers, as it meets the A1a classification. However, excess sludge is delivered to farmers by the municipality.
Volumes of sludge processed per day (m^3/day)	In the 2022/2023 financial year, approximately 92 717 m^3 digested/dewatered sludge was produced (~254 m^3/day)
Transport distance to processing facility	n/a
Transport distance to end-use	Between 25-100 km

Approximate population served	6 826 667[9]
Date when project was initiated	2009
Date when project ended	Ongoing

In general, this metro aims to utilise a single sludge disposal approach across all 6 WWTPs in order to simplify and optimise processes. This is supported by a Sludge Manager who plans for sludge disposal from all WWTPs, rather than just focusing on a single treatment plant. Historically and at present, the most common approach was to deliver digested and dewatered sludge to farms in the surrounding areas and apply it in line with the *Sludge Guidelines*. According to a report published in 2010, this was considered an "interim solution, since sludge off-loaded on farmland [was] not always ploughed into the soil by the farmer, as required by the *Sludge Guidelines*" (Boyd et al., 2010). However, over a decade later, this approach is still being used for approximately 74% of sludge produced.

To lower the costs of disposal, working within the *Sludge Guidelines*, the metro has also been engaged in trials of solar drying to increase solids content from 18% to 45% and composting to improve stability (Boyd et al., 2010). These trials, which were documented in 2010, are still ongoing and have not yet reached full scale operation. Photographs of the solar drying and composting process are shown below in Figure 1 to Figure 3.



Figure 23: Solar drying of sludge with mechanical turner (Boyd et al., 2010)

[9] Population equivalent based on total wastewater treated reported in the Green Drop 2022 report (942). The estimate assumes typical consumption of 230ℓ/cap/day and wastewater production is 60% of consumption (Green Drop Report, 2022).



Figure 24: Composting sludge without a bulking agent (Boyd et al., 2010)



Figure 25: Final product (Boyd et al., 2010)

According to data provided by the WSP, they are currently producing only approximately 18% of the sludge volume that they would expect to produce if their WWTPs were operating effectively. According to the Green Drop report 2022, the green drop score for this municipality dropped from 86% in 2013 to 73% in 2022. The primary items highlighted for improving functionality included the primary and secondary settling tanks, which are key to producing sludge, and belt presses, which are key for drying sludge. Furthermore, the Sludge Manager highlighted the need for upgrades to digesters to achieve better stability.

Data collected

The following primary and secondary data was consulted to prepare this case study:

- A group interview with 3x representatives from the WSP
- A municipal questionnaire completed by the Sludge Manager
- Rates for sludge transport supplied by the Sludge Manager
- A published paper from 2010 about the composting process

Motivation

The primary motivation within the metro is to ensure cost-effectiveness and comply with the *Sludge Guidelines*. The 2010 report detailed the changes made to the approach to sludge disposal in direct response to the publishing of the 2006 *Sludge Guidelines* (Boyd et al., 2010). Ultimately, the continued development of the drying/composting operation aims to produce A1a sludge that can be safely taken by farmers or even sold as a soil enhancement, in order to reduce the operational cost.

> *Our ultimate goal is to attain the status of A1a which is saleable product. And then as soon as we get to that level, we'll register it with the Department of Agriculture.* – Sludge Manager

In addition to contributing to a better sludge classification, the solar drying process can reduce the cost of transport by reducing the total tons of sludge/compost produced and transported off site.

> *Because three truckloads of 30 tonnes of wet sludge will be reduced to 1 truckload after you've dried it… it reduces the volume because again… we are trying to [transport] more dry than wet…*– Sludge Manager

Sludge Classification

Sludge is classified by the WSP's internal laboratory. According to the Sludge Manager, every "batch" of sludge taken off site is classified. While Volume 5 of the *Sludge Guidelines* requires classification of every batch of sludge given away or sold for public use, Volume 2 requires sludge classification monthly for agricultural application, depending on the dry tons of sludge produced. While the dried/composted sludge should meet A1a classification, no information was shared about the classification of the sludge that is applied in agriculture.

While this municipality is the laboratory's biggest "customer", the laboratory is also able to classify sludge from other municipalities, for a fee.

Costs

In 2009, the cost of solar drying/composting was R270 per dry ton. Adjusted to 2024 prices, this is approximately R570/dry ton. Assuming digested/dewatered sludge has a dry solids percentage of 17%, the cost is approximately R97/ton of digested sludge treated.

Contract rates for transportation of sludge were supplied by the municipality and reported as rands per cubic metre for varying distances. Ranging from 0km to 100km, the cost of sludge transport over a 50 km distance was R106.24/m^3, or R2.12/m^3/km. This rate is for *transport only* and does not include the costs for management of the agricultural application of sludge, e.g., identifying farmers and appropriate sites and monitoring the application of sludge on land. These tasks fall under the Sludge Manager's responsibilities, and it is therefore difficult to estimate the cost. The cost of ploughing the sludge into the land is borne by the farmers, but the municipality must monitor to ensure this happens in line with the *Sludge Guidelines*. These internal costs were summarised by the Sludge Manager:

> *Before we start, before we get into a contract agreement with the farmer, we do a survey of the land in terms of suitability, the slope, and if there's a borehole, the aquifer must be [more than 5m deep] and… the distance [to households] must be 200 meters… after doing*

that…we enter into an agreement with them and then after we sign the agreement based on the size of the land, we'll determine the number of loads that the farmer will get. And then as and when we deliver or dispose to that land, we're doing constant monitoring in terms of handling, because they must plough it in as and when they receive it unless they have the suitable place for storage. – Sludge Manager

Ideally, A1a sludge produced through composting would be collected by farmers, thus eliminating the cost of transport to the municipality. However, due to space limitations, when composted sludge begins to pile up, the municipality delivers it to farmers and does not charge for the delivery cost.

The reported costs per dry ton[10] for each of the 3 options are presented in Figure 4. The results highlight that the cost per *dry ton* for transport to farms is slightly higher than the cost of solar drying and composting. The cost per *dry ton* when dried/composted sludge must be transported to farms is slightly higher than the cost of transporting digested/dewatered sludge, but as shown, the cost of transport of dried/composted sludge is only R219/dry ton, compared to R579/dry ton for transporting sludge that is not treated further. This is because the drying process reduces moisture in the sludge from approximately 83% to 55%, thus reducing the total tonnage by 3.7 tons per dry ton of sludge processed.

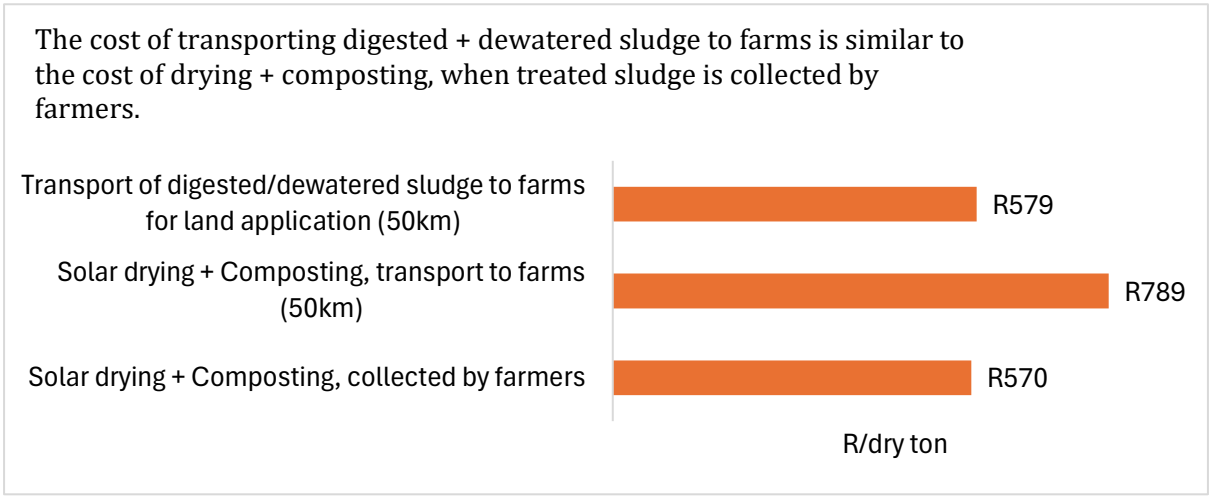


Figure 26: Reported costs (R/ton) for different approaches to sludge treatment and/or disposal

While considering the cost per dry ton is helpful for comparison, it is also useful to consider the cost per ton of digested/dewatered sludge (i.e., sludge coming out of the WWTP, before additional treatment) for the different approaches. The commonly used option of transporting sludge to farms for disposal costs approximately R98 per ton of sludge transported. By comparison, solar drying and composting the sludge costs approximately R97 per ton of sludge. If the dried, composted sludge must be transported, the total cost comes to approximately R134 per ton of sludge. This again highlights the impact of drying sludge on the cost of *transport*, due to reduced weight.

Given the hidden costs for management of the agricultural application of sludge not shown in the figure below, solar drying/composting seems to be the best and most cost-effective option for the metro to pursue. This is supported by the fact that an A1a product is produced, which requires less

[10] Cost per dry ton is the cost per ton of *dry solids* in the sludge, *not* the cost per ton of *dried sludge*.

monitoring and management, even if the product must be transported to farms. This also does not consider potential income generation from sale of an A1a product, but this could further improve the cost-effectiveness.

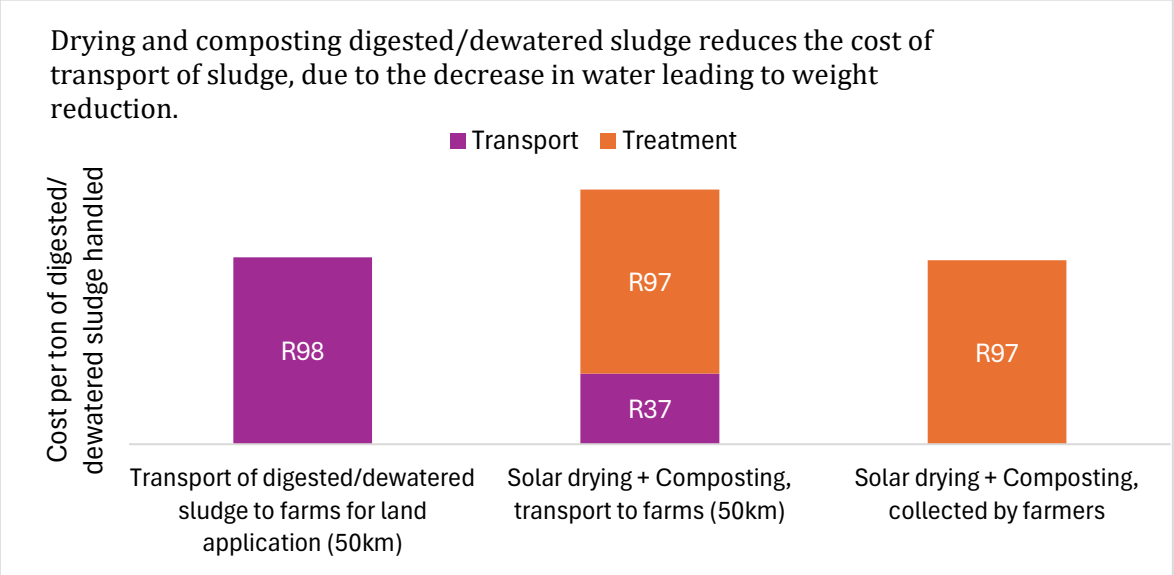


Figure 27: Costs of 3 options per ton of digested/dewatered sludge, broken down by transport and treatment costs

Benefits and drawbacks

The benefits and drawbacks are summarised below for transporting digested/dewatered sludge to farms for land application and providing further treatment through solar drying and composting.

This metro was the only municipality in this study that employed an individual dedicated to sludge management. The Sludge Manager in this case can identify needs with regards to sludge treatment and disposal and focus on research and development of new solutions. He also emphasised that they aim to coordinate efforts around sludge treatment and disposal/reuse across the municipality, which can simplify the process and ensure the technical expertise within the municipality is best utilised.

Transport to farms

Benefits:

1. **Beneficial use of sludge**: Sludge enriches the farmlands by adding organic matter and nutrients.

Drawbacks/challenges:

1. **Costs fluctuate based on distance travelled:** Transport rates increase as distance increases. Thus, when closer farms reach capacity in terms of sludge application, the cost of transport increases as the municipality must move to farms that are further away.
2. **Limited control over sludge application:** Sludge application (ploughing into fields) is the responsibility of the farmers receiving sludge. The municipality must monitor this closely since in the past farmers have not always complied with this requirement.
3. **Reliance on a Sludge Manager:** The Sludge Manager plays a pivotal role in identifying and liaising with farmers and ensuring that sites are suitable for agricultural application. Without

this expertise within the municipality, the cost of this option would increase, as *someone* must fulfil this role to ensure compliance with the guidelines.

Solar drying/composting

Benefits:

1. **Production of an A1a product:** The treatment process allows production of an A1a product, which does not have restrictions in use and can be sold or given away to the public. This reduces the management costs and the risks of non-compliance with regards to use of the sludge in agriculture.
2. **Potential for income generation:** The A1a product can be registered with the Department of Agriculture and sold. Rates from 11 sources online indicate that the average cost of compost is R767 per cubic metre, which points to a potential to offset costs of sludge treatment. This is, however, dependent on the packaging of the product and demand for the product. Furthermore, other options which increase the value of the product may have more income generation potential.
3. **Reduction in water content:** The drying process increases solids content to approximately 45%, which in turn reduces the total weight of sludge. This impacts the cost of transport of sludge if it must be taken off site. It is more efficient to transport sludge with a higher solids content.
4. **No need for external inputs:** The treatment process does not require electricity or additives. While some equipment is required, the low cost of consumables makes this a cost-effective option.

Drawbacks/challenges:

1. **Affected by climatic factors:** Solar drying is vulnerable to the changes in weather, including cold weather during winter and wet weather during summer.
2. **Demand not keeping up with supply:** At present, the most cost-effective way to handle the dried/composted sludge is for farmers to collect it from the WWTPs. However, the metro must still deliver some of this sludge to the farms to keep it from piling up. This brings into question the potential for income generation if the A1a product were marketed and sold.

Opportunities

The metro's interest in beneficiating the sludge itself is motivated by identifying a cost-effective method for safely handling sludge. In the interview with the Sludge Manager, he said they had not considered options for partnering with private companies to simplify and improve the beneficiation of sludge. Given that the sludge drying and composting operation has been at a pilot scale for over a decade now, it may be worthwhile to consider private partnerships like the one from Case Study 4. In that case, sludge from drying beds is given to a company that beneficiates it. The sludge is dried further and pelletised before being mixed with nutrient fertilisers to meet farmers' precise fertiliser needs. This model generates some income for the municipality while placing the risk and business motivation solely on the private company, so that the municipality can continue to focus on its core business. There is a good opportunity for this type of approach, especially given that the metro already has solar drying facilities in place. The metro can generate income this way either by selling the dried sludge to the company or charging a fee for rental of municipal land.

ANNEXURE D: CASE STUDY 4

Case study 4 – Partnership with company to turn WW sludge into a saleable fertiliser product

[The company] is employed by the municipality under a 15-year contract period which will expire…in 2027… We charge them [for the sewage sludge] as an income for the municipality. We dry the sludge. We give them a dry product. They will granulate it and then they will enrich it according to the site-specific requirements of the farmers. And it is a registered agricultural product, so they comply with all the regulating requirements…We're looking at the possibility to extend it, but it is currently not approved.

- WWT Manager, municipality

Project description

This metro municipality has 16 wastewater treatment plants serving a population 3.28 million people. The combined design capacity of these treatment plants is 600 Mℓ/day. According to the 2022 Green Drop report, the average Green Drop score for these treatment plants was 60%, ranging from 29% to 98%. Sludge management in this municipality varies, with most plants drying and stockpiling digested sludge, while some treatment plants have arrangements with private parties that take the sludge for their own use. At two of the treatment plants, the municipality has an arrangement with a company specialising in beneficiation of sewage sludge. This case study presents an overview of this partnership.

The company utilises dewatered sewage sludge to produce a fertiliser, which is enhanced by the organic matter in the sewage sludge and blended with nutrients to meet specific farms' fertiliser needs. Dewatered sewage sludge is received from the municipality and then undergoes a process of further drying, granulation, and then blending with chemical fertiliser. While the processing of sludge to dried granules takes place on site at the given WWTW, blending takes place at specific blending facilities that are located closer to the farms that purchase the fertiliser.

While the company has operations at two treatment plants, they currently only receive 6 dry tons of sludge per day from one of the treatment plants. This is far below the potential capacity of 70 dry tons per day. This can partly be explained by the fact that the specific treatment plant is currently using only 50% of design capacity of 54.5Mℓ/day. With a Green Drop score of 69%, this plant is also not certified in terms of Green Drop criteria, which suggests that the treatment process is not operating optimally, and this can influence sludge production. According to the company representative, this plant also has the option to apply digested sludge on sacrificial land, which may divert some from the beneficiation process.

This project has been in operation since 2012, and the company has a 15-year contract to conduct the work. The project originally went out on a 2-stage tender process. Typically, service contracts are only awarded on 3-year bases, due to restrictions in the Municipal Finance Management Act (MFMA). However, in this case, no funds are paid by the municipality to the contractor, which makes this limitation fall away, according to the municipality. Rather, an arrangement is made for the contractor to pay the municipality either for the sludge itself or through monthly rent for the land.

Table 31: Summary of WW sludge beneficiation project

Project title	Partnership with company to turn WW sludge into fertiliser
Municipality type	Metro
Organisation(s) involved	Municipality, company/contractor
Type(s) of sludge processed	Wastewater treatment sludge (dewatered)
Other waste streams processed?	Chicken manure (as needed)
Description of technology and process	WWTW sludge is mechanically dewatered and then handed over to the company that operates on site. The company dries the sludge further, puts it in windrows for composting and stabilisation, and then further dries it. The dried product is then moved to the granulation and disinfection plant. The granulated product is screened and coated and then sent to the blending facility. The granulated product is blended with commercial fertiliser to the specific needs of the farm.
Description of end use/disposal	Farmers purchase the blended product
Volumes of sludge processed per day (m^3/day)	30-40m^3 per day (6 dry tons per day)
Transport distance to processing facility	None
Transport distance to end-use	Varies – granulated product is transported to blending facilities, and then it's transported to the farm. Transport is paid for by the customers.
Date when project was initiated	2012
Date when project ended	Current contract expires 2027

Data collected

This case study included two interviews, one with the Acting Director for Wastewater Treatment Works for the municipality, and one with the Managing Director of the agriculture company. In addition, the researchers reviewed other videos and documentation on this project.

Motivation

For the municipality, this approach allows them to be compliant with the regulators and be more environmentally friendly. "If we could supply more dried sludge…and extend the contract with approval from our internal processes…it will benefit in disposing the sludge in a more environmentally friendly way accepted by the regulators."

For the company, their interest in sludge beneficiation is rooted in the agricultural benefits and business opportunities. While compost is an option for beneficiation, it is a low-value product. To make a business beneficiating sludge, they produce a product that is acceptable in the agriculture

industry and usable with their existing equipment. By mixing conventional chemical fertiliser with the organic sludge product, they can produce fertiliser that meets farmers' exact needs based on their soil. The inclusion of organic material from sludge improves the longer-term benefits of the fertiliser.

> *You won't believe the results we've achieved from the agricultural side with the product.* – Managing Director

Sludge Classification

The sludge is not currently classified by the municipality, as they lack "capacity and capability" to classify the sludge. According to the Wastewater Manager, the person who used to do microbial analysis for sludge classification retired, and "the training and skills [were not] properly transferred to the incoming microbiologist." Furthermore, the instrument used for chemical analysis is not currently in operation. The partnership with the company is beneficial in this regard, because the company *must* classify the product in order to sell it. Thus, they take on this burden.

Before the company engages any sewage treatment plant, they conduct a full chemical analysis of the sludge to determine if anything in the sludge will limit the use of sludge in agriculture. If the chemical content is good (i.e., metals), then they can proceed. Agriman conducts chemical analysis on a 6-monthly basis and pathogen analysis on a monthly basis, in order to ensure that the treated product maintains an A1a classification. Sludge samples are sent to various labs, including NviroTek, Bemlab, and ERWAT laboratory.

Costs

The cost to the municipality for this approach was only the construction of solar drying beds, which assist with sludge treatment. Beyond that, the municipality bears no cost for the beneficiation and disposal of their sludge. The fact that the company processes the sludge at the WWTWs means that there is no transportation cost to the municipality for this solution. Rather, the cost of transporting the end product to end use is included in the cost of fertiliser, paid by their customers.

> *It's not an expense, and for that reason it…went out for a longer than three-year term and it was allowed as soon as there is an expense, you need to go out on public participation and also get approval from National Treasury.* – Acting Director, WWT

Benefits and drawbacks

The benefits around this solution include:

1. **Beneficiation of sludge:** Through this project, wastewater treatment sludge is transformed from a hazardous waste into a resource that is in demand, licensed, and safe to use. This enhanced fertiliser product is in such high demand that they are currently importing granulated treated sludge from Namibia to keep up.
2. **No cost to the municipality**: In this arrangement, the municipality bears no cost for the beneficiation of the sludge, not even for classification. Setup of the operation required capital investment by the municipality in drying beds for the sludge, but in South Africa, many treatment plants already have drying beds on site. Furthermore, construction of drying beds

has benefits even if the beneficiation process ends, because solar drying reduces the weight of sludge to be transported. Thus, if the municipality reverts to transporting their sludge for off-site disposal or agricultural use, the weight of sludge to be transported, and therefore, the cost of transport, is reduced.

3. **Potential income for the municipality**: The municipality has an opportunity to earn some income from the private contractor by either charging for the sludge or charging rental for the use of municipal land.
4. **Creativity in the procurement process**: According to the municipality, because there are no funds flowing from the municipality to the contractor, the regulations in the MFMA around 3-year appointments falls away. This arrangement has allowed for a 15-year contract to be implemented, which means that the business has an opportunity to grow and benefit, as opposed to shorter-term contracts which will limit the ability of business to reach a point of sustainability.
5. **Stimulating the economy**: This solution takes a municipal "problem" and turns it into an opportunity for a private business to thrive. In addition to producing a product that supports the farming industry, the sludge beneficiation process provides stable employment for 7-9 people per treatment plant. The company is interested in developing a franchising model for this approach, in which local franchise holders could run the beneficiation plant and sell the organic granule product to the parent company. They would then provide the technical expertise in agriculture to blend the product and market it for sale to customers. Such a model would provide employment opportunities in the sludge management sector.

Drawbacks/challenges of this solution include:

1. **Business dependent on sludge production by WWTP**: The contractor is not receiving the full amount of sludge they would expect from the treatment plant. This is most likely due to challenges with the WWT process, including that one of the dewatering plants is not running. To ensure they have enough organic matter to process, the contractor must occasionally import material from other areas (e.g., sludge from other WWTPs or chicken manure). Low supply of sludge can harm the business side of things, which could discourage entrepreneurs from participating in the sector.
2. **Only applies to sludge without chemical contamination**: Use of sludge in agriculture requires the heavy metals to be low and therefore makes this solution inapplicable for treatment plants that handle industrial wastewater.
3. **Not applicable in small treatment plants:** Due to economies of scale, the contractor says that this solution would not make business sense for treatment plants treating less than 15 Mℓ/day. In the case of this municipality, 9 of the 16 plants meet this requirement, including the two where they are currently operating.
4. **Need for a drying surface:** The beneficiation process requires dried sludge, which requires municipalities to construct a drying surface, and this may prove to be a challenge where municipalities are struggling financially or where land availability is limited.
5. **Procurement:** While the municipality has found a way to work within the MFMA requirements and enter into a long-term agreement with the contractor, the contract has an end date in 2027. Thus, though the partnership has been beneficial to both parties, it is likely that the project will have to go out to tender again, ideally for another 15-year contract. While the long-term contract is beneficial for the business, it is still finite, which can limit the extent to

which the business can grow. Furthermore, though this municipality has gotten on board with this approach, according to the contractor, most other municipalities do not consider this option because it is unknown and requires people to “think outside the box” in terms of the procurement regulations.

Opportunities

According to the Acting WWT Manager, in addition to the two WWTWs where they currently operate, 10 treatment plants have sludge drying beds. This suggests that there is considerable opportunity within the municipality to expand the beneficiation approach at no additional cost to the municipality. Expanding their services will ensure sludge is handled in an environmentally friendly way while limiting the cost to the municipality.

ANNEXURE E: CASE STUDY 5

Case study 5 – Metro Municipality with a Standard Approach to Sludge Management and a Vision for a Sustainable Future

Project description

The metro municipality has 26 Wastewater Treatment Plants (WWTPs), including:

- 16 activated sludge
- 3 marine outfalls
- 1 trickling filter
- 2 pond systems
- 4 rotating bio contactors in outlying areas

Much of the metro's approach centres on using what is there and adapting it to work better. The marine outfalls do not produce sludge. Because these are in areas with high real estate costs, it is unlikely that the outfalls will be replaced. Sludge from pond systems is disposed of at one of the other WWTPs. Most of the sludge to be managed in the metro comes from the activated sludge plants.

At present, only one WWTP in the metro, the biggest one, has an anaerobic digester. All activated sludge plants are equipped with two belt presses: one for primary sludge and one for waste activated sludge. Primary sludge is dried to approximately 25% solids, and activated sludge is dried to approximately 16% solids.

The metro has a standard approach for all WWTPs that produce sludge. This includes dewatering on site, and then removal of dewatered sludge by service providers. This is done on a 3-year contract basis and managed by the operations unit within the wastewater department. Sludge is generally removed every day or every second day, to avoid nuisances on site. The contracts include transport, disposal at hazardous landfills for primary sludge, and disposal on agricultural land for waste activated sludge. The scope also includes larvicide and groundwater monitoring on sites where the sludge is disposed of.

> *[The contractors] change on a three yearly basis because of Municipal Finance Management Act, we can only contract for three years.*

Sludge disposed of in agriculture is not applied in fields growing crops for human consumption. Rather, sludge is applied to land producing animal fodder, primarily owned by dairy and beef farmers. To follow the *Sludge Guidelines* in terms of sludge application rates, the metro must rotate between various farms, and the selection of farms is done through a collaborative committee.

> *There's a committee that consists of the farmers and the city, where these things get discussed… By legislation, you can only apply so much [sludge] per hectare, [so] there needs to be a… rotation…it all depends on the classification of the sludge as well… The farmers would like to receive [sludge] all the time… because they like it. But it doesn't work that way.*

Table 32: Sludge disposal/reuse options utilised in Case Study 5, including volumes processed in 2022/2023

Description	Volume of sludge processed in 2022/2023
Landfill disposal of primary sludge	13 128 dry tons
Agricultural land application of waste activated sludge	32 244 dry tons
On-site disposal of digested sludge	10 236 dry tons

Table 33: Summary of Case Study 3

Municipality type	Metro
Organisation(s) involved	Municipality and contractors
Type(s) of sludge processed	WW sludge
Other waste streams processed?	None
Description of technology and process	Primary sludge and waste activated sludge are dried on belt presses at all WWTPs before final disposal
Description of end use/disposal	Primary sludge is disposed of in a hazardous landfill, and waste activated sludge is applied in agriculture as per the *Sludge Guidelines*. Farms receiving sludge produce crops for animal feed. Both disposal methods are done by contractors on 3-year contracts.
Amount of sludge processed per day	152 dry tons per day
Transport distance to processing facility	n/a
Transport distance to end-use	Unknown
Approximate population served	3,740,026
Date when project ended	Ongoing

Data collected

The following primary and secondary data was consulted to prepare this case study:

- Semi-structured interview with the Head of Development and Planning for Wastewater
- Municipal questionnaire filled in by the Head of Development and Planning for Wastewater
- *Sewage Sludge Status Quo Report 2020/21*, Western Cape Government (2021)

No cost data was provided by the participant, and this information was not shared by anyone else at the municipality.

Motivation

The municipality is largely motivated by environmental sustainability and cost effectiveness when considering their sludge management approach. Originally, the activated sludge WWTPs in the municipality functioned as extended aeration, without primary sedimentation and anaerobic digestion. To address the need for managing sludge effectively, each activated sludge plant was

equipped with two belt presses: one for primary sludge and one for waste activated sludge. This was seen as the more cost-effective solution, as it would have been expensive to install digesters at every WWTP.

The disposal of primary sludge in a hazardous landfill is done out of necessity, as the primary sludge is less stable and not applicable in agriculture. Disposal of waste activated sludge in agriculture is selected both due to its simplicity and the positive impact the sludge can have on farmlands. This is evidenced by farmers' engagement in the process and requesting for sludge to be disposed on their farms.

> *And the agricultural route is followed because…it is a fairly simple way of disposing of sludge. And also [our city has] very sandy soils. So, the soils actually have a great need for the sludge [as a] a soil conditioner and a fertilizer.* – Wastewater Manager

Sludge Classification

Sludge is classified internally by the scientific services branch. The classification of sludge varies from one plant to another and even from one season to the next. This variation can make planning for sludge disposal difficult. In general, this metro does not have big industrial loads in their WWTPs, so there is no issue with metal contamination. However, the stability and microbiological classifications vary. At present, they are not producing any A1a sludges.

Costs

No cost information was provided by the metro. However, in general, this approach comes with the following costs:

1. Sludge classification
2. Collection and transport of sludge by contractors
3. Gate fees at hazardous landfill (primary sludge)
4. Application of sludge
5. Monitoring (e.g., groundwater monitoring at sludge disposal sites)

Transportation of sludge was specifically mentioned by the participant as a cost-determining step. This applies to both the hazardous landfill and the agricultural fields, because the disposal sites are located on the outskirts of the city. The participant said that improving drying is key to keeping costs down, stating, "The drier we get it, the less water we truck around, so the cheaper it gets."

Benefits and drawbacks

The benefits and drawbacks are summarised below for landfill disposal and agricultural application. On-site disposal is also included, as this is done at one of the smaller treatment plants.

Landfill disposal

Benefits:

2. **Simple solution for primary sludge:** Because primary sludge is not sufficiently stabilised, the options for safe disposal are limited.

Drawbacks/challenges:

1. **Legislative limitations:** Restrictions on liquid and organic wastes in landfills will make this option unfeasible. In the province, the target is to divert 100% of organic waste from landfill by 2027.

   There's two pieces of legislation that affect us. One is the liquid ban to landfill. And our sludges, even though they are… [essentially] solid, are still classified as a liquid by that piece of legislation. And then the organic diversion from landfill and primary sludge [is] obviously organic…And even though we're only a drop in the ocean, it is still an organic. So, we will have to divert from landfill or at some stage the landfills will stop accepting.

2. **Transport cost:** As the landfill is on the outskirts of the city, transportation costs are high.
3. **Unsustainable:** The participant spoke about landfill disposal as an environmentally unsustainable method. When primary sludge is disposed of in a landfill, methane gas is produced, contributing to the metro's carbon footprint.

Agricultural disposal

Benefits:

1. **Demand for sludge:** Farmers like the sludge, because it improves the conditions of their sandy soils. The metro has a group of farmers who are actively engaged in a committee that decides where the sludge will be applied.
2. **Low-risk:** Sludge is only applied to land used to grow fodder for animals, not crops for human consumption. This reduces the risk of contamination and is one way to get around public perception challenges.
3. **Compliance with *Guidelines*:** Land application is done in line with the *Sludge Guidelines*, and this therefore provides a good example of following the requirements.

Drawbacks/challenges:

1. **High cost of transport:** Since farms are on the outskirts of the city, the transport cost can be high.
2. **Logistical challenges:** This includes the need to consistently rotate the site(s) where sludge is applied, due to the limitations on how much sludge can be applied per hectare. The metro has a good system for collaboration and consultation with farmers, but this is a hurdle to be aware of.
3. **Limitations on sludge application rates:** A report from 2021 indicated that the metro was slowly running out of suitable agricultural land for land application and that this could take place in 5-10 years. Improving the sludge classification can open up more options for land application, as sludge with a better classification (e.g., A1a) can be applied more liberally.

   And then ideally, we would want to dispose only A1a sludge onto land. And that would also open up a much bigger section of land for us because then we could dispose onto land that carries crops for human consumption.

On-site disposal

Benefits:

1. **Simple and cost effective**: No transportation off site, which keeps costs low.

Drawbacks/challenges:

1. **Not environmentally sustainable**: This approach does not realise any of the potential from sludge.
2. **Potentially won't be licensed again**: Stockpiling on site is not allowed, and the existing permit for doing this will likely not be renewed. This is therefore an unreliable approach to sludge management.
3. **Nuisance, such as vectors and odours**: On-site storage of sludge, particularly unstable sludge, has a risk of attracting vectors and producing odours.

Opportunities

> *In 2010, the branch decided that what we are currently doing, which is what we're still currently doing, should change… And we need a new approach to sewage sludge disposal because there was always a lot of focus on treated effluent quality, both provincially and nationally. And I think there is still a lot of focus on that rather than on the sludge, even though the sludge has a potential [to pollute]. So, [we considered how we could] change our sludge disposal options to be more…cost effective and more sustainable.*

The metro worked with consultants to conduct feasibility studies to understand the options for sludge beneficiation, settling on a recommendation for 3 regional Biosolids Beneficiation Facilities (BBFs), which include anaerobic digestion and combined heating and power generation. The report from 2021 highlighted that these facilities are intended to reduce sludge quantities, produce a beneficiated A1a product, and recover nutrients from sludge. In addition, these facilities would produce electricity.

> *[Our motivation for this upgrade is primarily] environmental sustainability. So, carbon footprint and doing the right thing. And recovering what we can from the sludge, because there is quite a bit that can be recovered.*

In addition to the environmental motivation, this approach must reduce the cost to the metro. Providing three regional facilities will allow the WWTPs clustered around these facilities to become "donor plants" to the BBFs. This will help minimise the transport distance to the facilities, thus reducing costs. Furthermore, by reducing the volume of sludge produced through treatment at the BBFs, the quantity of sludge travelling far distances to agricultural land will reduce.

> *The distance to the facilities is much less than we're currently trucking. And then the amount of sludge that comes out of the facilities after digestion is about 50% to 60% less.*

Costs can also be reduced by producing electricity at the BBFs. "[The] electricity can be used to offset our operational costs because we pay quite a lot for electricity. I think we're the second biggest user of electricity within the city, within the municipality, only outdone by street lighting."

The other main resource recovery that will take place is phosphorus, which is useful for agriculture. Phosphorus would be precipitated out as struvite, which will remain within the biosolids, providing a slow-release fertiliser for farmers.

The primary barrier to implementing these three BBFs is the high capital cost: "Each of these installations…is supposed to cost between one and one half billion rands, which is a good chunk of

money." For this reason, the plan is to phase these facilities in over time. While the first facility was meant to be operational in 2015, budget cuts and reprioritisation due to drought led to this project being delayed. At present, planning and financing for the first facility is underway. This demonstrates the challenges with limited budgets and sludge management competing with other critical services, such as water supply and wastewater treatment. Furthermore, changing administrations within the metro lead to changing priorities, making long-term planning challenging.

The metro is also interested in investigating opportunities for income generation through partnerships. "I mean…**we are mandated to process sludge**, so that is the main aim of it, [but ideally], it would be nice to get some return [for the money put in]". One consideration was to open up the final BBF to industry that disposes of high COD discharges, which would assist with increasing biogas and power output. Furthermore, there is interest in producing a saleable product, but the participant is aware that "South African municipalities, are [not] geared toward… the further processing, the packaging, [and] the marketing." This is where partnerships with private sector partners could be helpful.

A feasibility study on potential sludge beneficiation and income generation revealed that agriculture is the most promising option. The participant added, "If you can produce it in a format that the farmers like… such as little pellets that mimic the artificial fertilizer…" there is a better possibility for generating income. He mentioned private companies that do this, but also expressed barriers due to the Municipal Finance Management Act (MFMA), that even restricts their ability to consult with such companies for advice.

ANNEXURE F: CASE STUDY 6

Case study 6 – Application of digested sludge to produce turf grass

One water services provider (WSP) has operation and maintenance agreements with three different municipalities. These agreements include management of the sludge produced at 11 wastewater treatment plants (WWTPs). This case study discusses the approach at the largest of those treatment plants.

Project description

The WWTP is owned by the local municipality and operated by the WSP under a service agreement between the two. Sludge generated by the WWTP is irrigated onto land reserved for production of turf grass which is harvested and sold to the public. This approach falls under Volume 4 of the *Sludge Guidelines* and is known as continuous high-rate sludge application for production of industrial crops. Sludge is digested and thickened before being pumped to the turf grass land (a 100-ha site adjacent to the WWTP). This project began as a pilot project in 2005 as a partnership between the WSP and a private company. After the pilot period, the private company expressed an interest in continuing with this approach.

Table 34: Overview of Case Study 6

Project title	Application of sewage sludge for turf grass production
Municipality type	Local
Organisation(s) involved	WSP, private company
Type(s) of sludge processed	Digested sewage sludge
Description of technology and process	Sludge is digested and sent to a pond where a coagulant is added. Settled sludge is pumped to holding tanks from which it is used to irrigate turf grass.
Description of end use/disposal	The sludge is distributed over the turf grass using a centre pivot, providing nutrients, moisture, and organic matter for the turf grass.
Volumes of sludge processed per day (m^3/day)	1 000 m^3/day, applied over 100 ha
Transport distance to processing facility	n/a
Transport distance to end-use	n/a
Approximate population served	500 000
Date when project was initiated	2005
Date when project ended	ongoing



Figure 28: Turf grass field where digested sludge is applied using a centre pivot

Data collected

This case study is based on the following primary and secondary data:

- Interview with turf grass company and inspection
- Interview with Regional Manager of Operations at the WSP
- Published research paper by Cele (2020) about wastewater sludge management by the WSP

Motivation

This approach began as part of a 2005 research study investigating what happens when sludge is irrigated on turf grass lands. The study was done in collaboration with a university, the WRC, and others, including a private turf grass company. This work was inspired by other parts of the country that were doing similar work with their sludge, for example in Gauteng where sludge was being applied to land used to grow maize. The study was generally successful, and results suggested that the long-term impact of the sludge on the soil would be limited. Based on the success of the study, the company approached the WSP and expressed interest in continuing with the approach, demonstrating their interest from a business point of view. According to representatives at the turf grass company, the demand has grown over the subsequent years and they sell all the grass they grow.

Sludge Classification

Sludge classification is done by the WSP. No information was provided in terms of the frequency or cost of sludge classification. A sludge classification report from 2018 was provided by the WSP, but this report did not include full classification data for this specific WWTP. Pollutant classification data was reported by Cele (2020) and is shown in Table 2. Volume 4 of the *Sludge Guidelines* specifies the sludge classification frequency requirements based on dry tons of sludge disposed of each year. The recommended frequency is quarterly.

Based on the classification below, the sludge may be applied in a continuous high-rate application on turf grass land. Application of 1 000 m^3/day on a 100-ha area translates to approximately 158 dry

tons/ha.yr[11]. This is slightly higher than the maximum application rate of 120 tons/ha.yr specified in Volume 4 of the *Sludge Guidelines*.

Table 35: Pollutant concentrations in sludge (Cele, 2020)

Element	Concentration (mg/kg)	Pollutant class
Arsenic	9.24	a
Cadmium	4.13	a
Chromium	1 799.72	b
Copper	211.01	a
Lead	60.92	a
Mercury	2.68	a
Nickel	27.10	a
Zinc	764.09	a

Costs

Most of the operational costs for this solution are covered by a rental fee paid by the private company operating on the municipal land. This includes rental of municipal land and operation and maintenance of equipment. The capital costs for equipment used in sludge transfer to the site and land application are borne by the turf contractor, who owns the equipment.

The cost of compliance is not covered by the rental fee and is borne by the WSP. No details were provided on the frequency and costs of monitoring activities. Rates from other laboratories in the country have been used for guidance, along with the required frequency of monitoring from Volume 4 of the *Sludge Guidelines*. Cost estimates for the compliance and monitoring requirements are provided in Table 3, with an estimated total cost of R130 000 per year.

Table 36: Approximate costs to water services provider for compliance

Item	Assumed frequency (*Sludge Guidelines*)	Approximate cost to WSP
Soil sampling and analysis[12]	3x5 samples biannually	R23 100 /yr
Borehole sampling and analysis [13]	2 samples quarterly	R12 000 /yr
Surface water sampling and analysis[14]	4 samples monthly	R72 000 /yr
Sludge classification[15]	3 samples monthly	R144 000 /yr
TOTAL COMPLIANCE COST		**R251 100/yr (R0.69/m^3 sludge)**

Benefits and drawbacks

This approach presents an example of a partnership between government and the private sector. While limitations have been identified in terms of contracting and making the partnership official, there is considerable interest from the private sector in the income generation opportunities with sludge disposal. This is worth noting, as it provides WSPs an option for reducing costs by partnering with the private sector. Benefits and drawbacks of this approach are elaborated on below.

[11] Assuming density of 1080 kg/m^3 and moisture content of 4%.
[12] Estimated from published rates from Cedara laboratory.
[13] Estimated from a quotation from Talbot laboratory.
[14] Estimated from a quotation from Talbot laboratory.
[15] Note that sludge classification is done by the water service provider's own laboratory, but approximate costs from A.L. Abbott & Associates have been included here to provide a full picture.

Benefits:

7. **Low cost to the WSP:** The site is located next to the WWTP, so sludge does not need to be transported far. End use and disposal in this case are one in the same, which means that sludge byproducts do not require further transport either. The municipality pays for the necessary classification and monitoring. In addition, the municipality receives rental income from the company for the land.
8. **Mutual benefits for WSP and business:** The business has a vested interest in the sludge, which encourages them to find ways to support the WSP. For example, five years ago, the WSP asked if they could deliver sludge from other WWTPs to the site. Though they does not need the sludge, the company agreed to take it and find a way to use it. To try to maintain a positive working relationship and the benefit of leasing the land, the company finds additional ways to support the municipality.
9. **The partnership has allowed for additional opportunities:** In recent years, the company has agreed to participate in a composting project being championed by a university and the WSP. Their participation supports research and development, and the company sees this project as part of securing their turf business. Their aim to become "indispensable" leads to their cooperation in different initiatives on the site, which benefits the WSP and the broader research community.
10. **Compliance with guidelines:** This approach can be defined as "continuous high-rate application", as described in Volume 4 of the *WRC Sludge Guidelines*. The permissible application rate (PAR) should be determined based on the sludge characteristics and the soil characteristics. Where the PAR exceeds the maximum application rate (MAR), the MAR should apply, which is 120 tons dry sludge/ha.year. As shown above, the current application rate likely complies with the guidelines, but this should be confirmed based on the ongoing soil and sludge characterisation.

Every time you will be harvesting your turf grass, you harvest … a layer of soil…It's a combination of sludge and soil because you've been irrigating sludge [for] 6-7 months .... the …accumulation of sludge … is not that much" because some is removed each time grass is harvested. – Operational Manager, WSP

Drawbacks/challenges:

5. **Land application of sludge can be influenced by the weather/climate:** For most of the year the turf company has a shortage of sludge, but during very wet periods they have difficulty using the sludge (no irrigation being needed).
6. **Time required to establish a viable business:** The WSP representative and the private business representative both indicated that the time required to establish a viable business can be a limitation. For the business, establishing the market is the hardest part, and the current private partner is successful in part because they have had over a decade to build up their client base. Similarly, private businesses would have to invest in equipment at the start (e.g., tractors, office space), which would further limit the business viability over the short-term. In the typical procurement environment where contracts are limited to 3 years, this type of long-term arrangement is not possible, and this discourages private businesses from getting involved.

7. **Fluctuations in sludge quality:** Sludge quality can fluctuate based on industrial discharge into the WWTP as well as stormwater ingress into the system. This is particularly important with regards to the pollutant classification of sludge. If excessive heavy metals enter the treatment process and pollute the sludge, this option would no longer be viable based on the *Sludge Guidelines* limitation on class "c" sludge in continuous high-rate sludge application.
8. **Limitations on long-term contracts:** As mentioned above, 3-year contract terms are too short to encourage this sort of mutually beneficial partnership between the WSP and the private partner. In the absence of longer-term agreements, the lack of business opportunity leads to high rates charged to the WSP for sludge removal and disposal. While longer-term contracts are possible within the Municipal Finance Management Act (MFMA) with some extra effort (e.g., public participation process), the WSP in this study generally seemed hesitant to pursue this route. This appears to mainly be centred on concerns about being non-compliant with the MFMA. This may point to the need for further analysis of the MFMA and capacity building among WSPs around how to interpret the 3-year contract limitation and exceptions within it. Capacity building is also required for WSPs/WSAs to understand how to pursue official public-private partnerships successfully.
9. **Large land requirements:** Even though this approach applies sludge at high rates, there is still a land requirement. In this case, a large piece of open municipal land was available directly adjacent to the WWTP, but this will not be possible in every situation.

The quotes below provide further elaboration on the above points:

> *The minute we sign an agreement with those people, the very first month they have to pay us, you understand. And in that month, they may not have a product from the ground. They may have planted something, but they may not have a product. So… people see these and say, well, I'm in Gauteng, if I have to go and start this tender in KZN I have to mobilize the whole team, get equipment buy this and buy that… pay people and only be able to start really having a… product to sell to the market in a year. So, meanwhile I have to have establishment costs but a lot of people don't respond to the tender… Our processes are such that you exhaust everything and then prove that you've done it and opened it to the market before you can say I have to have special conditions. So, you first have to do it and prove there was no response from the market before you sign a contract with the only person that responded.* – Operational Manager, WSP

> *If it took [the company] 12 years to become fully established. If you were to find somebody else, it will take them that much time. Meanwhile, you can only contract with them for three or five years, depending.* - Operational Manager, WSP

> *There's not a big pool of contractors that do this.* – Operational Manager, WSP

Public Private Partnership Opportunity?

The one opportunity discussed with the partners was the potential for an official public private partnership (PPP). The WSP operational manager indicated that they are trying to pursue this path, but the requirements are extensive.

According to the National Treasury's *Public Private Partnership Manual*, a public private partnership is defined as a "commercial transaction between an institution and a private party" in which the private party:

a) "Performs an institutional function on behalf of the institution; and/or
b) Acquires the use of state property for its own commercial purposes; and
c) Assumes substantial financial, technical, and operational risks in connection with the performance of the institutional function and/or use of state property; and
d) Receives a benefit of performing the institutional function or from utilising the state property, either by way of:
    a. Consideration to by paid by the institution which derives from a revenue fund or, where the institution is a national government business enterprise or a provincial government business enterprise, from the revenues of such institution; or
    b. Charges or fees to be collected by the private party from users or customers of a service provided to them; or
    c. A combination of such consideration and such charges or fees"

The key tests for whether a public private partnership will be approved include:

- Affordability – can the institution afford it?
- Value-for-money
- Risk transfer – is sufficient technical, operational, and financial risk transferred to the private party?

The process of getting a public private partnership (PPP) approved includes these steps:

1. Inception
2. Feasibility Study (1 approval during this phase))
3. Procurement (3x approvals during this phase)
    a. Approval IIA: Procurement process designed is fair, equitable, transparent, and competitive
    b. Approval IIB: Preferred bidder selected, value-for-money report prepared
    c. Approval III: PPP agreement management plan
4. Project phase

The above highlights that while the PPP approach might be most appropriate here, it will still require a lengthy process, which includes procurement, before it can be approved. It will also likely require some adjustments to the approach, for example, some evidence of increased financial benefit to the WSP. In this case the sludge disposal costs the WSP nothing, which represents a substantial saving relative to other disposal options.

ANNEXURE G: CASE STUDY 7

Case study 7 – Transport of sludge from small treatment plants to a single disposal location

One water services provider (WSP) has operation and maintenance agreements with three different municipalities. These agreements include management of the sludge produced at 11 wastewater treatment plants (WWTPs). This case study discusses an emergency sludge management approach taken with several smaller wastewater treatment plants (WWTPs).

Project description

A Water Services Provider (WSP) has operation and maintenance (O&M) agreements with three different municipalities to operate and maintain WWTPs, which includes sludge management. In total, they manage 11 WWTPs, most of which are relatively small. Sludge from these WWTPs is dewatered or dried before being transported to a dedicated land disposal site adjacent to another WWTP. This was an interim solution in response to the changing NEMWA legislation, which restricts the disposal of sludge in landfills. The sludge is spread thinly at a disposal site for further drying before it is either added to a composting operation or applied to turf grass fields.

Table 37: Case Study 7 overview

Project title	Transport of sludge from small WWTWs to designated sludge disposal site
Municipality type	Local
Organisation(s) involved	WSP, turf grass company
Type(s) of sludge processed	Sewage sludge (various)
Description of technology and process	Sludge from 4 small treatment plants is transported to a designated sludge disposal site, where it is spread thinly on a 1-hectare block for drying.
Description of end use/disposal	The sludge is mixed with compost or applied to land where turf grass is grown on digested sludge.
Volumes of sludge processed per day (m^3/month)	Approximately 360 m^3/month from 4 of the WWTPs
Transport distance to processing facility	Varies from 30-75km
Transport distance to end-use	n/a
Date when project was initiated	Approximately 2018
Date when project ended	Ongoing

Data collected

The following data was collected to prepare this study:

- On-site interview and inspection with turf grass company operating on the municipal land
- Interview with Regional Manager of Operations for the Water Services Provider
- Cost information on sludge transport (supplied by WSP)
- Sludge classification data provided by the WSP

Motivation

Changing legislation meant that disposal of sludge to landfills was not permitted. Beyond the immediate need for an interim solution, the WSP wanted to find an affordable option, and this option utilises existing facilities at one of their WWTPs.

> *It's affordable and it doesn't break the law while we're doing it. And fortunately, there was a project that is ongoing, so we're not going to have an accumulation of… sludge at Darvill.*
> – Operations Manager, WSP

Sludge Classification

A comprehensive sludge classification report was prepared in 2018, which classified sludge from all WWTPs being managed by the WSP. The classifications of sludge from the four WWTPs included in the case study are presented in Table 2. According to the operations manager, there is no system currently in place for regular classification of sludge.

Table 38: Classification of sludge from 4 WWTPs (Bosch, 2018)[16]

Treatment plant	Classification
WWTP 1	C1c
WWTP 2	C2b/C3a (dry/wet)
WWTP 2	C2b
WWTP 4	C1b

Based on the classifications above, application of these sludges for production of industrial crops (e.g., turf grass) is permissible with some restrictions, except for WWTP 1, due to its pollutant classification of "c". The addition of the sludge to a composting process may be restricted, primarily due to pollutant classifications of "b" and "c". While drying and composting can improve microbial and stability classification, pollutant classification cannot be improved to a, because the pollutants will not be removed in the process. Thus, it will not be possible to produce an A1a product that can be classified and sold as compost. Any sludge with pollutant class c is *not permissible* for use in agriculture, and the *Sludge Guidelines* state that "source control should be implemented to improve the pollutant classification."

Costs

The costs supplied by the WSP include only the cost of transporting the sludge from these smaller WWTPs to the dedicated disposal site. These costs are shown in Table 3.

Table 39: Approximate costs for transporting sludge from small treatment plants to disposal site

Treatment Plant	Distance (km)	Estimated cost per month	Approximate tons/month	R/ton	R/m^3.km
WWTP 1	49	R 7 014	20	R 351	R 7.73
WWTP 2	32	R 123 274	250	R 493	R 16.64
WWTP 3	74	R 66 108	100	R 661	R 9.65
WWTP 4	44	R 8 416	20	R 421	R 10.33
Total		**R 204 811**			

[16] Bosch Projects (2018). *A Detailed Study on the Sludge Management Options*.

While the above adds some helpful data on the cost of transporting sludge, there is no information on the cost of the sludge disposal option. This is partly because this is seen as an interim solution by the WSP. This has meant that proper measures have not been put in place to comply with the *Sludge Guidelines*. The end use/disposal of the sludge is left up to the private company operating at the site (i.e., either turf grass application or composting). These two options require different measures in terms of monitoring, environmental health and safety and site design, but the costs associated with these are not available for this case study.

Benefits and drawbacks

As mentioned above, this approach is seen as interim to the WSP, but the benefits and drawbacks of this approach as a permanent solution are presented below.

Benefits:

1. **Centralised sludge management**: Because a WSP is tasked with managing several small WWTPs, this approach simplifies the process by bringing the sludge to one place. This can be more efficient in terms of staff requirements and expertise required.

Drawbacks/challenges:

1. **Inadequate monitoring**: This case study does not provide sufficient information on monitoring done, both in terms of regular sludge classification and monitoring of soil and water on site. This is partly because this is seen as an interim solution and therefore the measures described in the *Sludge Guidelines* have not been applied.
2. **Cost of sludge transport:** Transporting the sludge from these 4 WWTPs is costing the WSP over R200 000 per month. This translates to approximately R0.72 per m^3 of WW treated solely to transport the sludge. The actual cost would be higher if the final use or disposal methods and monitoring were included in the costs.

ANNEXURE H: CASE STUDY 8

Case study 8 – Disposal of WW Sludge in Agriculture

Project description

This local municipality operates seven wastewater treatment plants (WWTPs), with a combined total capacity of 18 Mℓ/day. All these treatment plants are activated sludge plants with no anaerobic digestion, ranging from 0.2 Mℓ/day to 5 Mℓ/day. Historically, most of the sludge from these plants has been stockpiled. In 2022, the municipality advertised a tender for removal of sludge from their two largest WWTPs, one with a capacity of 3.5 Mℓ/day and the other with a capacity of 5 Mℓ/day. Sludge is collected from the two treatment works and then disposed of for agriculture, as per the *Guidelines for Utilisation and Disposal of Wastewater Sludge* (hereafter referred to as the *Sludge Guidelines*) (Snyman et al., 2009).

The tender advertised in 2022 stated that the municipality has B1a sludge that needs to be dealt with in accordance with the *Sludge Guidelines* and requested solutions from potential bidders. According to an engineer from the municipality, they received a wide range of solutions, from agricultural application to disposal in landfill, and a wide range of prices from R1 million to R14 million. This contract was only initiated for 1 year, as it was a new project, and if it is successful, it will be re-advertised on a 3-year basis.

Table 40: Overview of sludge disposal for Case Study 8

Project title	Wastewater Sludge Disposal
Municipality	Local Municipality
Organisation(s) involved	Municipality and contractor
Type(s) of sludge processed	WW
Description of technology and process	At the smaller WWTP (3.5 Mℓ/day), sludge is mechanically dewatered. Dewatered sludge is collected by a contractor. At the larger of the two (5 Mℓ/day), sludge is stockpiled, and when the stockpile is big enough, the contractor is called to collect. This happens approximately quarterly.
Description of end use/ disposal	Sludge is applied to land for agricultural use. An interview was not undertaken with the contractor, but according to their website, organic waste streams that they process are delivered to composting facilities that beneficiate the waste.
Volumes of sludge processed per day (m^3/day)	15m^3/week dried sludge (at the smaller WWTP) Unknown for the other WWTP
Transport distance to processing facility	n/a
Transport distance to end-use	Varies
Date when project was initiated	November 2022
Date when project ended	July 2024

Data collected

An online interview was conducted with the Engineer for Wastewater Operations and Compliance at the municipality, and he supplied the following additional information for review:

1. WWTW design reports
2. Sludge classification results
3. Sludge removal tender documents

Motivation

The municipality is motivated primarily by effluent quality and maintaining a reputation of excellence, according to the Engineer. This translates to striving to achieve Green Drop status across their treatment plants, "Even though we've got very good feedback on the Green Drop, it's just not good enough for us because that's not where we want to be. We want to achieve higher than that." In 2021, 6 of the 7 WWTWs achieved a score above 80%, with one achieving Green Drop Status. The Green Drop assessment includes points for the adequacy of the sludge management at a WWTP, and this has motivated the municipality to improve the sludge management practices at their works.

Both treatment plants referenced in this project had recent upgrades to their sludge handling facilities. According to the engineer, they did not have "sufficient draw-off facilities" for sludge, and so sludge production was low. However, with the upgrades to the sludge stream side of treatment works, a solution was required for removal of the sludge. For this reason, the tender was advertised. According to the engineer, the tender is likely to be re-advertised at the end of the current contract for this same reason – complying with minimum requirements and achieving Green Drop status. In this way, the case study demonstrated the effectiveness of the Green Drop audit in encouraging municipalities to comply and improve their processes.

> *…because the green drop scoring chart gives points for sludge removal, it was one of the motivating factors for us to do it, because we're focusing on all the elements that we can score easy points.*

Sludge Classification

Sludge samples from all 7 treatment plants are sent to A.L. Abbott and Associates annually for classification or as needed for specific concerns. In general, the sludge classification B1a, though there are some occasional variations. There are generally no challenges with this process for the municipality.

The classification report for one of the WWTPs from 2023 indicates that the sludge has a classification of B1a. This classification means that the sludge is acceptable for agricultural application with some minor restrictions. The stability class indicates little risk of vectors, and the pollutant classification suggests no restrictions in terms of pollutant load on the soil. However, the microbial class "B" comes with the following restrictions, as described in the *Sludge Guidelines* Volume 2 (Snyman and Herselman, 2006):

- This should not be used on vegetables consumed raw.
- Crops with edible parts that *do not* touch the soil/sludge should only be harvested **30 days** after sludge application

- Crops with edible parts that *do* touch the soil/sludge should only be harvested 14 months after sludge application
- Crops with harvested parts below the soil surface where:
    - Sludge remains on the surface for 4 months or longer before incorporation into the soil must not be harvested until 20 months after sludge application
    - Sludge remains on the surface for *less than* 4 months before incorporation must not be harvested until 38 months after sludge application
- Access by animals to graze on the land should be restricted for at least 30 days after sludge application
- Access by humans to the land should be restricted for at least 30 days after sludge application

Achieving a higher microbial classification (A) would remove restrictions and even open opportunities for sale of the product. This could be done through processes that disinfect the sludge, for example, heating sludge to temperatures high enough to kill pathogens (e.g., composting).

Costs

The municipality pays a contractor to remove the sludge from the treatment works as and when required and manage it in accordance with the *Sludge Guidelines*. According to the municipal representative, they are currently paying approximately R7 000 each week, and the contractor's rate is R510 per ton. As reported above, the volume of sludge produced each week is 15m^3, thus the rate can be translated to R467 per cubic metre of sludge.

The cost of compliance is borne by the municipality. Based on the *Sludge Guidelines* Volume 2, they collect 3 samples of dewatered sludge each year for analysis and characterisation. According to invoices from the laboratory, the classification costs R1 900 each year for a single WWTP, which is only 0.5% of the total cost of sludge disposal reported.

Benefits and drawbacks

The primary benefits of this approach include:

1. **Sludge is dealt with in a way that is compliant with the WRC *Sludge Guidelines***. This requires the contractor to demonstrate an understanding of the *Sludge Guidelines* and an acceptable level of expertise to execute disposal appropriately. Effective disposal of sludge and compliance with monitoring requirements also earns the municipality bonus points on their Green Drop audit report.
2. **Sludge is utilised beneficially:** Though the tender as advertised did not specify beneficial reuse as a requirement, the selected tenderer is a company that strives for "zero organics to landfill", suggesting that the sludge they remove is reused in agriculture. Though the study did not uncover further details about what specifically is done with the removed sludge, this project does incorporate sludge reuse on some scale. It is notable that the tenderer that proposed sludge reuse in agriculture had the lowest total bid price, compared to contractors that proposed disposal in landfill. This speaks to the high cost of disposing sludge in landfills and suggests that the beneficial use option made the winning tender more competitive.

The primary drawbacks to this approach are:

1. **Cost to municipality:** According to the municipality, they are "open to any solution to get rid of [sludge] that is more cost effective to [them]."
2. **Need to balance demand vs. sludge generation**: One limitation to pursuing more cost-effective options is the small size of the treatment plants in this municipality. For a business to run effectively, a certain economy of scale will be required. Unless that can be met, it is likely that the municipality will have to continue paying for sludge removal. However, where there is economy of scale and a more viable business model is possible, the municipality may be able to start charging those who take the sludge.
3. **Short contract periods**: The current contract is only for 1 year, and if the municipality re-advertises, they will only be able to pursue a 3-year contract due to the limitations in the MFMA. This further contributes to the costliness of the approach, as the potential for a business to grow over 3 years is low.
4. **Disposal process fully outsourced**: While the contract requires that the disposal methods comply with the *Sludge Guidelines*, the complete outsourcing means that the municipality does not monitor what happens to the sludge once it leaves the WWTP. While it gives them one less thing to worry about, it also brings an element of uncertainty to the environmental safety of the method. This may be a concern given that the sludge microbial classification is B, which has some minor restrictions in terms of how it is applied and how plants are harvested. If the sludge classification were improved to A, safety would not be a concern.

ANNEXURE I: CASE STUDY 9

Case study 9 – Amalooloo Dry Sanitation Pilot Operation and Maintenance Solution

If you want to provide a sustainable, workable solution, [you have] to look at each and every component of the of the sanitation value chain. – Lumar Fourie, Amalooloo

Project description

Bertram (Pty) Ltd, trading as Amalooloo, was established in 1986 in South Africa and began specialising in sanitation in 2000. Most of their work has focused on development, manufacturing, and installation of on-site sanitation systems, including low flush and dry toilets. Understanding the importance of maintenance for sustainable sanitation, they began developing operations and maintenance solutions for their toilets.

> *We're proud of our products and the quality we provide… [but] like anything in life, [if] there's no maintenance done on it, there will be no sustainability.* – Director, Amalooloo

In 2018, 100 Amalooloo urine diverting, dry sanitation toilets were installed in Ga-Moretsele in a district municipality in Limpopo. The municipality asked about the operations and maintenance (O&M) of these units, and Amalooloo agreed to partner with them and fund an O&M pilot project for those 100 units. This included the collection of dried excreta from the units, transport to an O&M centre in the community, processing of the excreta, and production of a soil conditioner. The process is illustrated in Figure 1.

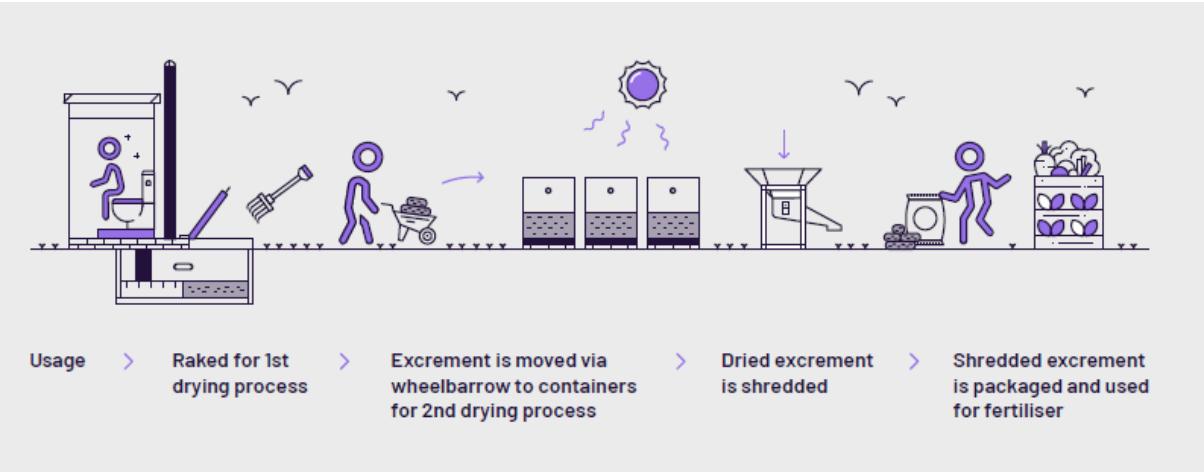


Figure 29: O&M process for dry MyLoo toilets (source: MyLoo brochure, Amalooloo)

In Ga-Moretsele, the 100 toilets are serviced by three salaried individuals. The team conducts approximately monthly visits to households for inspections and ongoing user education, and they empty the containment approximately quarterly. Emptied dried excreta is transported in wheelbarrows to the O&M centre, where it undergoes additional drying in a steel bin which is heated by the sun to between 50-55 degrees Celsius. The steel bin has a capacity of 0.6 cubic metres (1m x 1m x 0.6m). Once the product reaches around 4% moisture content, it is shredded. The organic shredded waste is then incinerated up to 300 degrees Celsius for 3 minutes to eliminate remaining pathogens, then sieved and packaged. The packaged material can act as a soil conditioner or ground filler and is currently given away to members of the community. The inorganic waste (i.e., trash) is

incinerated using the same incinerator at 300 degrees Celsius for 3 minutes. The project is summarised in Table 1.

Table 41: Overview of Amalooloo O&M project

Project title	Operation and maintenance of Amalooloo dry sanitation system, with sludge beneficiation
Municipality type	District Municipality
Organisation(s) involved	Amalooloo
Type(s) of sludge processed	Faecal sludge
Other waste streams processed?	None
Description of technology and process	A community of 100 households is served by Amalooloo's dry sanitation toilets, which separate liquids from faeces at the pedestal. Excreta is dried in a vault, and drying is enhanced by 2 ventilation pipes. Dried excreta is emptied by a team of 3 people and taken to an O&M centre, where it is dried further in a stainless-steel bin. Inorganic material is separated and incinerated. The organic shredded waste is incinerated at 300 degrees Celsius for 3 min to eliminate and possible remaining pathogens or microbes. It is then packaged for use as a soil conditioner or ground filler.
Description of end use/disposal	After drying to 3-4% moisture, the material is shredded, sieved, and bagged for reuse as a soil conditioner.
Volumes of sludge processed per day (kg/yr)	Approximately 530 kg/yr (dried sludge removed from substructure)
Transport distance to processing facility	Negligible
Transport distance to end-use	Varies
Approximate population served	228 (85 households)
Date when project was initiated	2018
Date when project ended	Ongoing

Data collected

An interview was conducted with the Director of Amalooloo, who then shared the following documentation which was used in the case study:

1. Operational expenses for the project
2. Beneficiary list
3. Classification data
4. Videos and product brochures
5. Data on sludge collection weight

The researcher also corresponded further with the participant via e-mail with additional questions.

Motivation

Initially, Amalooloo installed dry toilets on behalf of the municipality, and the municipality expressed interest in O&M solutions. Amalooloo saw this as an opportunity to pilot and demonstrate a model that they could share with the municipality as a long-term solution. Through COVID-19, the municipal interest "fizzled out", but Amalooloo decided to continue funding the project.

For Amalooloo, this pilot has served as a research hub for them to develop a model for O&M of their dry sanitation system and to progressively improve the sludge beneficiation process. They are aware of the sanitation service chain, and as a business have chosen to “look at each and every component of the [service] chain” to produce a sustainable solution. This project, which is at the pilot scale, is different from their normal government-funded projects, which are supply-only. They “are trying to change the narrative for municipalities to start buying into the whole concept”, including operations and maintenance, and this pilot project is one step in that direction.

Sludge Classification

Sludge is removed from the toilets on a quarterly basis and then processed. The end product is analysed by an independent laboratory. The laboratory always analyses for heavy metals and soil nutrient characteristics, but microbiological analysis is not as frequently done. The most recent analysis (6 October 2023) found that the product was well stabilised, free of inorganic contaminants (heavy metals), and that the nutrient and organic content could be beneficial to soil and plant health. It is important to note that the dried processed organic waste can also be used as a ground filler and not solely for the purpose as a fertilizer. The moisture content of the shredded material was 4.24%, indicating effective levels of drying in the process. These results did not include microbial analysis.

Costs

The costs presented here exclude the cost of toilets but do include the establishment of an O&M centre for the toilets, as well as the beneficiation of the collected sludge.

Capital costs

The O&M facility consists of the following components:

1. Shipping container repurposed to an office
2. 2x demonstration disabled toilets
3. Waste processing area, including steel bins and incinerator
4. Tools for processing
5. Site civils, including paving, fencing, etc.

The facility is shown in Figure 2 and is installed on land owned by the tribal authority. According to figures provided by Amalooloo, the total cost of establishing the centre was R152 262 in 2018.



Figure 30: Amalooloo O&M centre, Ga-Moretsele

Running costs

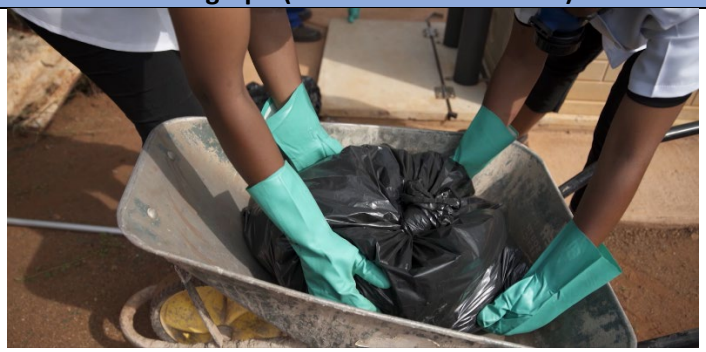
Operational expenses were shared by the Director of Amalooloo, and the costs for 2022 financial year are shown in Table 2. The primary cost is the salaries of three employees who empty the toilets, run the beneficiation process, and conduct household user education visits. A detailed list of tasks carried out by this team is provided in Table 3.

Table 42: Running costs for the Amalooloo O&M centre pilot, 2022 Financial Year

Running cost type	Total (2022 FY)	% of total	Avg. cost per month	Cost per HH/yr
Salaries (3x employees)	R167 772	76%	R13 981	R1 678
Rental cost (paid to tribal authority)	R45 356	20%	R3 780	R454
Casual wages	R3 518	2%	R293	R35
Other misc. costs	R5 498	2%	R458	R55
Total	**R222 144**		**R18 512**	**R2 221**

Table 43: Tasks undertaken by O&M staff

Description of Task	Photograph (from Amalooloo video)
Emptying dried waste from each toilet, 4x per year Emptying is done using simple tools (spade and rake)	 

Description of Task	Photograph (from Amalooloo video)
Transporting dried waste to the O&M centre, on foot, using a wheelbarrow	
Transferring dried product to steel bin for further drying	
Shredding dried waste	
Separating inorganic waste and incinerating separately at 300 degrees Celsius	

Description of Task	Photograph (from Amalooloo video)
Sieving organic product	
Packaging product for distribution	
Giving product away to people who request it	
Visiting households (outside of emptying) to conduct user education and inspect units – 1x per month	

Scaling up

Amalooloo reported that to achieve sustainability, the project will need to be scaled up to 1 000 households and adopted by the Sekhukhune District Municipality. This will reduce the operational cost per toilet and require some additional capital expenditure. The existing O&M centre will provide sufficient space for servicing 1 000 households, but the following upgrades to the O&M centre would be required[17]:

1. Purchase of a vehicle for transporting the dried excreta (e.g., a three wheeler (tuk-tuk), which costs between R65,000 and R110,500).
2. Fabrication of one or two more stainless steel drying bins (R5 000-R7 500)

The Director said that the existing O&M site is large enough to scale to 1 000 households. Thus, rental cost will not increase. Furthermore, he stated that the 3 employees currently do not work at full capacity and could likely handle the servicing of 1 000 households with the same salary. If the team uses a tuk-tuk for transporting the dried excreta, the main additional operational cost will be fuel and maintenance for the tuk-tuk. Assuming 2km travel per household, 4 times per year, the tuk-tuk will travel approximately 8 000 km per year. Assuming a standard cost per km of approximately R4.00, the cost for running the tuk-tuk will be approximately R32 000 per year[18].

Assuming operational expenditure increases to R255,000 per annum, the cost per household for 1 000 households will be R255 per household per annum, or R21.25 per month. This would be most efficient if the 1 000 households were within one village. If the workers must collect sludge from multiple villages, the travel will drive up the costs of this solution. The more efficient method would be to establish one appropriately sized treatment plant per village and employing people for as many hours as are needed to collect and process the sludge. A small business could investigate the following options for achieving sustainability:

1. Charging a monthly fee to households for the service. Ideally, this would at least cover the operational costs plus a mark-up to allow the business to grow. According to the Director of Amalooloo, approximately 20% of households in the current pilot have expressed a willingness to pay for the servicing of their toilet. They suspect that a model where users are incentivised in some way to pay for the servicing of their toilet may work, though the details of this are not yet solidified.
2. Investigating options for selling the product. This may require partnership with local farmers or producers of blended fertiliser product, who have high demand for quality organic product.

Furthermore, given the fact that government is mandated to provide sustainable sanitation services to indigent households, the district municipality could institute a small subsidy to fund the operations, even partially, with households covering a portion of the cost.

[17] Not included here is the cost to install an addition 900 toilets in the community. The MyLoo top structure costs between R4800 and R5000, excluding the substructure (DWS, nd.).

[18] Average Transport Cost Per KM In South Africa - 2023/2024 (safacts.co.za)

Benefits and drawbacks

This process and technology have now been piloted for several years. The benefits of this approach to operation and maintenance and processing of faecal sludge include:

1. **On-site containment provides some treatment:** The MyLoo toilets produce sludge with low moisture content, which reduces the emptying and transport costs and the volume of waste to be processed.
2. **Regular visits to households lead to improved behaviours**: As stated by the Director, they very seldom deal with trash in the sludge now that they have been regularly visiting the households and reminding them of how to use the toilets.
3. **Low-cost option**: The sludge treatment process is relatively low cost, with no chemical or energy inputs required.
4. **Job creation**: Creation of sustainable jobs within the community.
5. **Production of a useful by-product,** that can either be used beneficially within the community or sold for income. If by-product is not used or in demand, it can be safely disposed of.

The drawbacks of this approach for FS management include:

1. **Requires a paradigm shift** among municipalities to begin thinking about the longevity of on-site sanitation systems and instituting *regular* maintenance activities for on-site systems. While the annual cost of running such an operation may be low, and the operation will provide jobs for community members, it will require a drastic shift from emptying VIP toilets approximately once every 5 years on tender. The shift will be even more pronounced in municipalities that currently do not plan for emptying of their on-site sanitation systems.
2. **By-product is a relatively low-value product**: While the organic material has a beneficial use, input from other private companies specialising in agricultural products has confirmed that compost alone is low value (i.e., income generation potential is low). Ideally, if income generation is seen as an important component of the beneficiation process, the product should be enhanced with other fertiliser to improve the nutrient value and thus increase the value of the product. However, if the product is just used internally by the municipality for their own gardening or given away to the community, the product alone is perfectly sufficient.
3. **Technology not easily transferrable to communities using other forms of on-site sanitation:** The technical aspects of the process (i.e., emptying, transport, and treatment) will likely not work well in communities with VIPs, which are common in most communities using on-site dry systems. This is due to the different characteristics of faecal sludge from VIPs compared to the type of toilet installed in this case study. However, it would work well in other communities with other dehydrating toilets, ideally urine-diverting.

Opportunities

Amalooloo has approached the DWS and taken them for a site visit of their O&M operation. DWS is interested in the project and supports the upscaling to 1 000 households and active involvement by the district municipality. Scaling the pilot project up with allow for a more realistic picture of the cost of running this operation, providing a model that could be replicated in other low-density communities across South Africa.

ANNEXURE J: CASE STUDY 10

Case Study 10: Private emptying of faecal sludge

Project description

This case study focuses on the work of SaniSquad, a small local business that was formed as part of a Water Research Commission study on social entrepreneurship for pit latrine emptying. SaniSquad is based in Pietermaritzburg and serves communities in the peri-urban areas around the city that rely on on-site sanitation. While the business was originally envisaged to provide emptying services for on-site sanitation, the business expanded to include other sanitation-related services as a way to supplement their income. SaniSquad utilises both semi-mechanised and fully manual emptying, depending on the contents of the on-site containment. Semi-mechanised emptying is done with the Pitvaq machine, a local product that can fit into the back of a bakkie and can be carried over steep terrain and through narrow pathways that are inaccessible to honeysuckers.

Faecal sludge (FS) that is emptied by SaniSquad is primarily buried in trenches on site (i.e., deep row entrenchment), because this is the lowest cost option and households in this area have sufficient space. SaniSquad has also been asked in certain cases to transport faecal sludge off site for research and development purposes. This includes research being done around faecal sludge treatment and beneficiation at the University of KwaZulu-Natal (UKZN). In the cases where FS is transported, this is done so in drums with tight-fitting lids, loaded on the back of the bakkie.

SaniSquad began advertising their emptying services in 2020 and set up a work depot in the area where they work. During the door-to-door advertising efforts, SaniSquad assessed how willing people were to pay for emptying services and the pricing threshold. They offered emptying options, primarily determined by how much sludge was removed from the containment, in response to people's ability to pay for services. Several photographs of the SaniSquad's tools and operation are shown below. This project is summarised in Table 1.



Figure 31: Pitvaq Vacuum Tank



Figure 32: Pitvaq being wheeled along a narrow household path



Figure 33: Team members carrying sludge in sealed drums to a disposal trench



Figure 34: Examples of VIP latrine vault contents – if safely buried, trash can remain. Otherwise, it must be screened or fished out or separated at the processing site.



Figure 35: Stirring the sludge using a long-handled spade



Figure 36: On-site sludge disposal



Figure 37: SaniSquad depot site



Figure 38: Wash and shower area

Table 44: Overview of SaniSquad emptying services

Project title	SaniSquad
Municipality type	Local municipality
Organisation(s) involved	SaniSquad
Type(s) of sludge processed	Faecal sludge
Other waste streams processed?	n/a
Description of technology and process	SaniSquad uses either manual or semi-mechanised emptying (Pitvaq), depending on the pit contents.
Description of end use/disposal	Emptied faecal sludge is generally buried in trenches on site, with a minimum soil cover of 300mm.
Volumes of sludge processed per day (m^3/day)	Varies
Transport distance to processing facility	n/a
Transport distance to end-use	n/a
Approximate population served	Varies
Date when project was initiated	2020
Date when project ended	Ongoing

Data collected

This case study was based solely on secondary data from the WRC project that supported the establishment of SaniSquad. This included:

1. Final Report for the WRC study, titled “Testing the Business Case for the Pitvaq Pit Emptying Machine” (Still, Kubheka, and Neethling, 2022)
2. Cost data for services, supplied by SaniSquad

Motivation

The primary motivation of the SaniSquad operation is to establish a viable business that supports local employment and provides safe sanitation services to households. SaniSquad fills a void in an area where the municipality is not providing emptying services for households. Data collected by PID in 2018 highlighted at least half of the 30 000 VIP Toilets constructed between 2006 and 2011 were urgently in need of emptying. This suggested that there should be a market among households for emptying, since no budget or plan was in place for the municipality to do it.

To expand the business opportunities, SaniSquad advertises additional services including, inter alia, installing low-flush pedestals, building leach pits and septic tanks, refurbishing toilets, or moving toilet top structure to new pits, and the initial SaniSquad team had the experience necessary to do this work. SaniSquad was originally conceived as a social franchising model, though this is currently the only franchise in operation. This franchising model was tested and demonstrated through the WRC study.

Sludge Classification

Faecal sludge removed from on-site sanitation systems is not classified and is simply buried on site. Because the sludge is safely buried, there is little risk of pathogens in the sludge polluting the environment.

Costs

The capital cost for establishing the franchise was R250 000 (published in 2023), including the depot construction as well as all tools (e.g., Pitvaq, spades, drums, PPE). Rates for emptying services are summarised below, based on rates provided by SaniSquad. The costs have been updated to 2024 costs.

Table 45: Rates from SaniSquad for emptying, depending on end-use/disposal

Item	With burial on site (R/m^3)	Transport off site (R/m^3)
Emptying and placing FS in drums	R1 336	R1 336
Digging burial trench	R125	R0
Backfilling trench	R15	R0
Transportation to disposal site 25km away	R0	R450
TOTAL	**R1 477**	**R1 784**

The costs above present the rates for doing business with individual households. If SaniSquad were to tender for a large-scale contract with a municipality, these rates would be lower as efficiencies could be realised with a large-scale operation, thus reducing costs. However, if the contract were implemented in a different location, establishment and equipment costs would need to be included, thus increasing the cost for emptying services.

Benefits and drawbacks

The benefits and drawbacks of this solution are presented below.

Benefits:

- **Local job creation:** SaniSquad employs and trains members from the local community as emptiers. The manual nature of the emptying process, even when using the Pitvaq, means that if this work were scaled up, more job opportunities would become available.
- **Different tools for different situations**: While this project began as a demonstration of the Pitvaq, the reality is that SaniSquad needs to be equally comfortable emptying with spades as with the Pitvaq. The two have merit in different scenarios, primarily depending on the characteristics of the sludge being emptied. In wet pits or septic tanks, the Pitvaq helps the emptiers to work quickly and safely. However, in this area, most VIP pits are relatively dry with trash in them, and for these, long-handled spades are necessary.
- **Demonstration of health and safety procedures:** SaniSquad has been largely supported by PID during their start up period, and PID has many years of experience in pit emptying, particularly health and safety requirements. Because of this, the facility for SaniSquad represents much of the guidance on worker safety at a relatively low cost, using local materials. Furthermore, SaniSquad's emptying practices demonstrate health and safety measures such as wearing PPE and using a groundsheet to protect the environment from spills.

Drawbacks:

- **Inability of households to pay for services**: Most customers have shared that they need the service, but they cannot afford to pay for it. SaniSquad requires a deposit for services, and this proves challenging for most. While credit options have been considered, providing too much credit can be risky, especially for a small business. In addition, SaniSquad competes with other service providers that provide a lower level of service for a lower cost. This reality is evidenced by the large number of quotes submitted by SaniSquad vs. a low number of jobs completed.
- **Households waiting for the municipality to empty their toilets:** Some community members feel it is the municipality's responsibility to empty their full toilets and all costs should be borne by the municipality. While the municipality does not and has never emptied their toilets for free, this belief causes people to expect a free (or very low cost) service. While waiting for the municipal emptying, households make plans around their full toilets (e.g., using an old homebuilt pit toilet).
- **Household concerns about on-site disposal**: One household that requested the service had a problem with on-site disposal, saying that they did not want the sludge disposed in their yard. However, they were also unwilling to pay for the additional cost of transporting sludge off site. This requires education among households regarding the risks and remediation of risks when safely burying sludge.

ANNEXURE K: CASE STUDY 11

Case study 11 – Emptying of faecal sludge from UDDTs and burial on site (retrospective)

Project description

Urine-diverting double pit toilets (UDDTs) were built across a metro municipality over a period of approximately 15 years. While it was originally proposed that households would empty their own UDDTs, political pressure led to the municipality instituting an emptying programme for these toilets. In 2015, a tender was advertised for the removal of waste from 50 000 UDDTs over a period of 24 months. Sludge from 38 000 would be buried on site with a tree planted over the disposal pit, and sludge from the remaining 12 000 would be transported to a black soldier fly treatment plant. This case study focuses on the burial of sludge on site (i.e., deep row entrenchment).

Table 46: Overview of Case Study 11

Project title	Emptying and disposal on site of faecal sludge from UDDTs
Municipality type	Metro municipality
Organisation(s) involved	Municipality, contractors, researchers
Type(s) of sludge processed	Faecal Sludge from UDDTs
Other waste streams processed?	n/a
Description of technology and process	UDDTs separate urine from faeces, which drop into a vault and dries over time. Provision of two vaults allows for switching from one vault to the other, allowing the contents of the first vault to dry out. The sludge is dry enough to be emptied using spades.
Description of end use/disposal	Sludge is buried in trenches on site and should be backfilled with at least 300mm soil. At each site, a tree is to be buried over the sludge and protected with mesh.
Sludge processed	Approximately 26 600 m^3 total (assuming 0.7m^3 per UD)
Transport distance to processing facility	n/a
Transport distance to end-use	0
Approximate population served	127 000
Date when project was initiated	2015
Date when project ended	2017

Data collected

This case study is retrospective and based solely on secondary data. Analysis and business modelling were done in 2017 as part of a Bill and Melinda Gates Foundation project. The following secondary data sources were consulted for this case study:

1. Report titled “Business Modelling of UD Emptying Contract – Report of Findings”
2. Cost-modelling spreadsheet comparing tender rates from the bill of quantities and modelled rates. In this study, the focus is on tendered rates.
3. Tender document from municipality (2015)

Motivation

The tender document states that this project was implemented “as part of [the municipality’s] strategy to provide a solution to the sanitation needs of its outlying wards.”

Sludge Classification

The sludge from UDDTs was not classified in line with the *Sludge Guidelines*, because the guidelines speak to sludge from WWTPs. However, the UDDT sludge was characterised based on some characteristics summarised in Table 2.

Table 47: UDDT sludge characterisation (Buckley et al., 2008)

Property (% mass)	Range	Average
Moisture content	7 - 31	14
Total solids	69 - 93	86
Inorganic solids	58 - 92	82
Organic solids	1.5 - 11	3.7
COD (g/g)	0.006 - 0.28	0.07

Costs

The costs are summarised below based on tenderer's rates for the contract. The business modelling assessment report identified that tendered rates for emptying and burial on site were higher than expected. The rates provided below include preliminary and general costs for running the contract under "Management costs".

Table 48: Contract rates for manual emptying and burial on site, adjusted to 2024 prices[19]

	R/UD	R/m³ (assume 0.7m³ sludge in UD)
Attachment of back panels	R152	R218
Manual removal of sludge	R303	R433
Disposal in trench on site	R513	R733
Supply and planting of trees with protection	R332	R475
Management costs	R131	R187
TOTAL	**R1 431**	**R2 044**

[19] Price adjustments done using https://inflationcalc.co.za which calculates based on data from Stats SA.

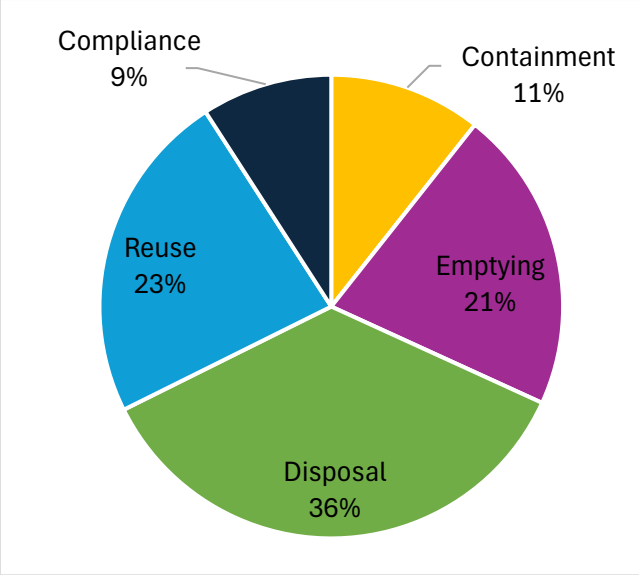


Figure 39: Cost breakdown of manual emptying and disposal costs from emptying contract

Benefits and drawbacks

This case study provides a relatively simple option for dealing with faecal sludge from UDDTs. While the approach depends on the characteristics of the faecal sludge, this approach would be possible with any faecal sludge that can be manually emptied (i.e., with spades). Some benefits and drawbacks of this approach are presented below.

Benefits:

1. **No sludge transportation:** Burial on site removes the cost of transport and also eliminates the risk of environmental spills during transport.
2. **Benefits of buried sludge:** Though the sludge is buried and not directly reused, planting a tree over the buried sludge allows the household to reap some benefits from the buried sludge. Nutrients and organic matter in the sludge support the tree growth and permanently improve soil quality.

Drawbacks/challenges:

1. **Supervision requirements:** Emptying and burial at individual households requires supervision by the municipality to ensure compliance. While the contract was written with detailed requirements in terms of health and safety, these protocols were not widely practiced by the sub-contractor due to a lack of supervision from the municipality.
2. **Risks of contact with sludge:** If health and safety measures are effectively implemented, the risk of sludge exposure is low. However, as observed in the study, the health and safety measures were not implemented in full, leading to contact with sludge and risk of health complications during manual emptying with spades.

ANNEXURE L: CASE STUDY 12

Case study 12 – Emptying of faecal sludge from UDDTs and Black Soldier Fly treatment (retrospective)

Project description

Urine-diverting double pit toilets (UDDTs) were built across a metro municipality over a period of approximately 15 years. While it was originally proposed that households would empty their own UDDTs, political pressure led to the municipality instituting an emptying programme for these toilets. In 2015, a tender was advertised for the removal of waste from 50 000 UDDTs over a period of 24 months. Sludge from 38 000 UDDTs would be buried on site with a tree planted over the disposal pit, and sludge from the remaining 12 000 would be transported to pilot black soldier fly treatment plant. This case study focuses on the transport of sludge to the black soldier fly treatment plant.

Table 49: Overview of Case Study 12

Project title	Emptying and disposal on site of faecal sludge from UDDTs
Municipality type	Metro municipality
Organisation(s) involved	Municipality, contractors, researchers
Type(s) of sludge processed	Faecal Sludge from UDDTs
Other waste streams processed?	Food waste
Description of technology and process	UDDTs separate urine from faeces, which drop into a vault and dries over time. Provision of two vaults allows for switching from one vault to the other, allowing the contents of the first vault to dry out. The sludge is dry enough to be emptied using spades. Faecal sludge is placed in bins and then transported to a Black Soldier Fly treatment facility.
Description of end use/disposal	Black soldier fly treatment can produce 3 useful by-products that can be sold if the market allows. The potential by-products include fertiliser, biochar, dried larvae, protein, and/or oil.
Volumes of sludge processed per day (m^3/day)	2-3 tons per day (treatment capacity)
Transport distance to processing facility	n/a
Transport distance to end-use	20 km
Approximate population served	40 000
Date when project was initiated	2015
Date when project ended	2018

Data collected

This case study is retrospective and based solely on secondary data. Analysis and business modelling were done in 2017 as part of a Bill and Melinda Gates Foundation project. The following secondary data sources were consulted for this case study:

4. Report titled “Business Modelling of UD Emptying Contract – Report of Findings”
5. Cost-modelling spreadsheet comparing tender rates from the bill of quantities and modelled rates. In this study, the focus is on tendered rates.
6. Tender document from municipality (2015)
7. Commercialisation report on black soldier fly facility (Grau and Alcock, 2019)

Motivation

Construction of a BSF treatment plant was seen as a cost-efficient way to deal with faecal sludge more by generating saleable products. In addition, treatment of the faecal sludge limits environmental risks of burial of sludge on-site. While these risks are generally low, there are instances where this approach is not recommended, for example, where the groundwater table is high and where groundwater is widely used in the community.

Sludge Classification

The sludge from UDDTs was not classified, as the *Sludge Guidelines* specifically speak to sludge from WWTPs. UDDT sludge was characterised by Buckley et al. (2008), and these characteristics are shown in Table 2.

Table 50: UDDT sludge characterisation (Buckley et al., 2008)

Property (% mass)	Range	Average
Moisture content	7 - 31	14
Total solids	69 - 93	86
Inorganic solids	58 - 92	82
Organic solids	1.5 - 11	3.7
COD (g/g)	0.006 - 0.28	0.07

Costs

The contract rates are presented in Table 3, assuming the entire service chain is managed and funded by the municipality (i.e., emptying, transport, and BSF treatment).

Table 51: Contract rates for emptying, transport, and treatment in BSF plant (assuming BSF plant operated by municipality), adjusted to 2024 prices[20]

	R/UD	R/m³ (assume 0.7m³ volume)
Attachment of back panels	R152	R218
Manual removal sludge and transfer to pickup point	R303	R433
Transport of sludge based on one-way distance (20km)	R132	R189
Management costs	R131	R187
OPEX (BSF plant)	R1 214	R1 734
TOTAL	**R1 932**	**R2 760**

[20] Price adjustments done using https://inflationcalc.co.za which calculates based on data from Stats SA.

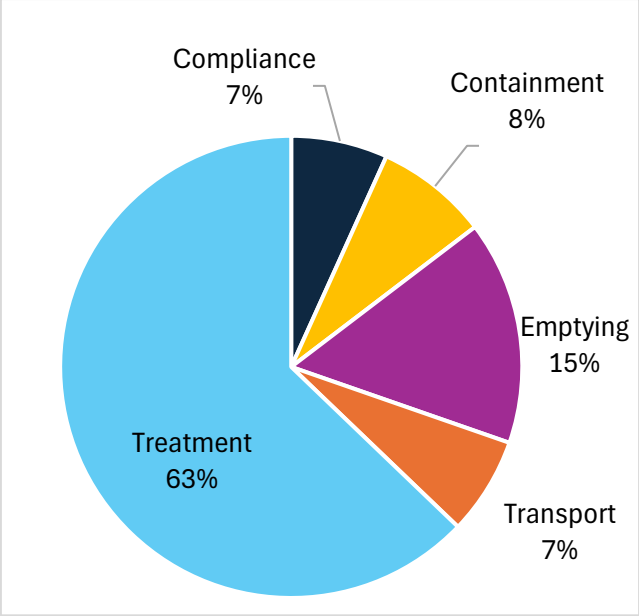


Figure 40: Cost breakdown of manual emptying and disposal costs from emptying contract

The BSF process can produce by-products that can generate some income, provided there is a market. Two streams come out of the process, namely, larvae and residue. These are separated at the end of the process and can then be transformed into saleable products. Larvae can be processed into protein meal and oil, and residue can be used as fertiliser or processed into biochar. In addition, the commercialisation report identified that dried larvae on its own may have a market, particularly where existing operations are processing and selling oil and protein but not keeping up with demand for the products. This can simplify the process, as there is no need to generate a market or pursue licensing for sale of a product to the public. The potential income from these products is shown in Table 4, based on the findings from the commercialisation report.

Table 52: Potential income from BSF process products

Product	Potential income per m^3 sludge processed	Application(s)
Dried larvae	R 519	- Blend with nutrients to produce a fertiliser – fertiliser must be licensed - Use to produce protein or oil (see below)
Protein	R 683	Animal feed – must be licensed
Oil	R 224	Animal feed – must be licensed

Based on the above, if the municipality operates the BSF treatment facility and makes maximum income on protein and oil, the overall cost to the municipality would be approximately R1 852 per m^3 of sludge. Alternatively, if the BSF process were run by a private company, the municipality would manage the emptying and transport of sludge and pay a gate fee to dispose of sludge at the treatment facility. Based on an approximate gate fee of R819 per cubic metre (2024 prices), the cost to the municipality would be approximately R1 845/m^3 sludge. However, the business modelling report highlights that at this gate fee, break-even would not be likely, and thus the gate fee would likely increase. Even if the total cost to the municipality increased to R2 000 per cubic metre of sludge, this would be lower than the cost for the scenario in Table 3, in which the municipality funds all aspects of

emptying, transport and treatment and does not have any income from by-products (i.e., worst-case scenario).

The setup where treatment is managed by a private business which generates income on saleable products is advantageous, because it removes risk from the municipality and allows the municipality to focus on service delivery rather than business opportunities.

Benefits and drawbacks

Benefits:

1. **Beneficiation of sludge:** In this case study, a beneficiation method was piloted to turn sludge into useful, income-generating products. This is helpful in terms of turning faecal sludge from a waste into a resource.
2. **Potential for co-treatment with primary sludge:** The commercialisation report states that co-treatment with primary sludge dried to 70% MC can increase profit potential per ton of sludge. This would be in place of food waste that was used in the pilot. Thus, where a BSF plant is established, there could be an opportunity to manage both primary WW sludge and faecal sludge.

Drawbacks/challenges:

1. **Cost of treatment:** The operational expenses for running the treatment facility are high. If the municipality runs the facility and bears this cost, income generation becomes critical to offsetting costs. This does not even consider the capital cost of establishing the treatment facility, which in the case of this BSF plant was over R10 million in 2015.
2. **Transport of faecal sludge:** In contrast to Case Study 11, in which faecal sludge was buried on site, this case requires transport of sludge off-site, which has a cost of approximately R189 per cubic metre. In addition to the cost, transporting sludge off-site introduces risk of environmental pollution during the transport process.
3. **Income-generation hurdles:** Several hurdles to income generation exist including existence of a sufficient market and the need for licensing of the products. Prior to establishing this system, an in-depth market study would need to be done to determine potential buyers of the products.
4. **Variation in feedstock:** Faecal sludge has variable characteristics dependent on several factors. This can impact the treatment process at the BSF plant.
5. **Need for supplementary feedstock:** The BSF process requires an additional feedstock, which complicates the process. In the pilot project, food waste was used, which requires identifying a source of food waste and getting it to the treatment plant. The researchers suggested that primary sludge could be used in its place, but it still would require consideration around how to get this sludge to the treatment plant.
6. **Treatment plant requires constant FS input:** To ensure ongoing operation and income-generation opportunities, the BSF treatment facility would require a constant stream of faecal sludge to be delivered. This does not work well with the current FSM situation in South Africa, where emptying is seldom done by municipalities and, where it is, is done on a 2- or 3-year contract basis. Emptying of on-site systems is not generally seen as an ongoing activity, but if BSF treatment was selected, this would need to change. This is not a bad thing, but it is a hurdle to be overcome.

7. **Space required:** To operate well, a BSF plant needs a very large area. This is because the sludge must be spread as thin as 10 mm otherwise the larvae will not make a significant difference to the sludge volume during the larvae maturation phase.
8. **Technical Challenges:** The BSF plant experienced many operational challenges, such as: the difficulty and cost of removing trash from the FS supply; the low productivity of the BSF larvae during the winter months; and the difficulty of separating the mature BSF larvae from the sludge. The pilot plant did not work smoothly at any stage and was closed down before it achieved full functionality.

Opportunities

The most cost-effective arrangement in this case would be the complete outsourcing of faecal sludge treatment and beneficiation to a company with expertise in this area. This could take the form of a public private partnership (PPP), in which the private company invests in the CAPEX for the facility and then reaps the full benefits of income from the products sold. This would require a business with:

- Available capital/funding
- Expertise in BSF treatment of organic wastes
- Access to an appropriate site
- Evidence of a market for the higher-grade products coming out of the BSF process.

In terms of the site, the approach taken here to use WWTP land and repurpose inactive drying beds can assist, as it will limit the compliance limitations to establishing the site.

All of these coming together at one time could feel a bit like kismet. Even if this type of private partner were eager to be involved, the PPP process would need to be followed, as outlined in the Department of Treasury's PPP Manual.

ANNEXURE M: CASE STUDY 13

Case study 13 – Emptying of faecal sludge from chemical and container toilets and treatment in WWTP

Project description

In the metro, 18.9% of households are informal dwellings spread across several informal settlements.[21] Various sanitation solutions are provided by the Department of Human Settlements. Due to the lack of bulk infrastructure and the density of housing in these areas, the following different systems are utilised:

1. Communal chemical toilets, hired from a contractor
2. Communal container toilets, which are owned by the municipality and serviced by a contractor
3. Portable flush toilets (PFTs), provided to individual households
4. Conservancy tanks to serve small number of households with flush toilets, in a designated "incremental development area"

While the servicing of each of these systems varies slightly, all are regularly serviced by service providers, appointed on 3-year contracts. The emptied waste is transported to one of the wastewater treatment plants (WWTPs), where it is screened before entering the WWTP headworks.

Table 53: Overview of Case Study 14

Project title	Collection of faecal sludge from informal settlements and treatment in WWTPs
Municipality type	Metro
Organisation(s) involved	Department of Human Settlements, private service providers appointed by DHS
Type(s) of sludge processed	Faecal sludge from on-site sanitation systems with sealed containment
Other waste streams processed?	N/A
Description of technology and process	Chemical toilets and conservancy tanks are emptied using vacuum tankers, whereas container toilets and PFTs have their container removed and transported to the WWTP. Faecal sludge from all of these is delivered to the WWTP. Prior to the WWTP headworks, the faecal sludge is screened to remove refuse.
Description of end use/disposal	Sludge is treated along with sewage. In this metro, sludge from the WWTP is disposed of in the hazardous landfill (primary sludge) or to agriculture (waste activated sludge).
Volumes of sludge processed per day (m^3/day)	
Transport distance to processing facility	Varies
Transport distance to end-use	Varies
Approximate population served	

The municipality has established a designated "faecal sludge management" (FSM) facility upstream of the WWTP headworks. This facility primarily provides a designated discharge area for the vacuum

[21] STATS SA. (2023). General Household Survey.

tankers and trucks carrying the containers and PFTs. The only pre-treatment provided for the faecal sludge is screening for trash. Furthermore, the municipality recently upgraded the facility to provide a cleaning area for the containers and PFTs, which incorporates conveyor belts and washing machines, to reduce the need for manual cleaning and thus reducing human contact with faecal sludge.

Data collected

- One interview with two Monitoring and Evaluation (M&E) Officers from the Informal Settlements Branch
- Spreadsheet supplied by the Informal Settlements Branch detailing the servicing of container toilets

Motivation

The Informal Settlements Basic Services branch is required to ensure basic service provision to households in informal settlements, which includes sanitation provision. The primary motivation for their approach to sanitation in informal settlements is service provision, as well as the constraints that come with having no bulk infrastructure in the area. For this reason, on-site toilets are provided in these areas. The four systems are described below, with the specific motivation described:

Table 54: Sanitation systems used and reasons

Sanitation system description	Motivation
Chemical toilets hired from service providers	Necessary for service provision
Container toilets owned by the municipality	Necessary for service provision, and assets owned by the municipality
Portable flush toilets	Provided to individual households as a way to provide a household-level toilet and improve safety
Conservancy tank	Installed in a remote incremental development area that is far from bulk sewers

On the faecal sludge disposal side, the decision to discharge at an existing WWTP is largely due to efficiency in using infrastructure that is already there. Furthermore, the unit has an agreement with the Wastewater unit so that they do not have to pay discharge fees, thus lowering costs. The participants indicated that if the WWTP runs out of capacity to handle the faecal sludge, they would need to consider alternatives.

In terms of upgrading their process at the FSM facility, the unit was determined to improve working conditions for those tasked with cleaning the container toilets and PFTs. The upgraded facility reduces direct contact with the soiled containers, improving health and safety.

> *I think when it comes to the nature of the work, we emphasize health and safety, especially for the workers that are transporting and handling the toilets, the containers and the PFTs. So, we do emphasize health and safety on site on a daily basis, in our contract management meetings on a monthly basis. So, our focus is on health and safety and the well-being of the worker.*

Sludge Classification

The faecal sludge discharged to the WWTP is not classified or analysed by the municipality. Sludge being disposed of after the WWT process is classified by the municipality's scientific services branch.

Costs

Cost information was only provided for the container toilets. These consist of 100 litre containers and serve approximately 74 000 households with 11 000 toilets (between 6-7 households per toilet). The annual cost of emptying these toilets is approximately R59.9 million. In addition to emptying and transport to the WWTP, the service provider provides janitorial services. The reported costs for these are summarised in Table 3.

Table 55: Reported costs for servicing container toilets

Item	Rate	Description of costs
Emptying containers 4x per week	R28 per toilet serviced (approximately R350/m^3, assuming toilets are 80% full when emptied)	Standard rate, regardless of distance to WWTP
Janitorial services	R589 per toilet per month (average)	Based on monthly janitorial contracts of R8 956 per janitor. On average, 1 janitor services 22 toilets each month

The above costs translate to a total cost of approximately R810 per cubic metre of faecal sludge for emptying and transport, along with cleaning of toilets. It is helpful to note that the 83 different locations where containers are serviced are, on average, 34 kilometres from the WWTP.

In addition to the above costs, the FSM facility requires a subcontractor to operate and maintain the facility, including operating the washing machines for the containers and PFTs. These costs were not provided by the municipality.

Lastly, the cost of *treating* the faecal sludge can be attributed to the cost of treating wastewater at the treatment plant. According to the 2022 Green Drop report, the production cost at the WWTP is approximately R9.92 per cubic metre of wastewater.

Benefits and drawbacks

Benefits:

1. **Ability to monitor service providers:** The service providers operate on a schedule, and therefore it is easy for the M&E officers to monitor their work and ensure it is done to the correct standard. Furthermore, having a single discharge point at the WWTP allows them to monitor that the faecal sludge reaches that point. "If they don't discharge at [the WWTP], they won't be paid for that load because they won't have evidence of any work being done." This helps ensure the services are provided and the environment is protected from unauthorised dumping.

Drawbacks/challenges:

1. **Transport distance:** As there is only one discharge point for the faecal sludge, some service providers travel very far from the areas they are servicing. The department has not been able

to make arrangements to discharge faecal sludge to WWTPs that are closer by, largely because the WW division is worried about the nature of the faecal sludge.

2. **Vulnerable to WWTP breakdowns:** The infrastructure at the WWTP where faecal sludge is discharged is old, and any breakdowns in the plant lead to a backup of faecal sludge. While the working relationship with the wastewater department is good, this reliance on their facility can limit the ability of the Human Settlements Department to deliver the service. This can be a problem for the container toilets and PFTs, which must be emptied, cleaned, and returned to the settlements. “So, when there's a delay in returning the toilets back to the informal settlement, people do have access to toilets, but the toilets are now filling up quicker than on normal service days.”
3. **Frequent emptying required:** The use of sealed containment in all of these communities leads to extremely frequent emptying. While container toilets are emptied 4 times each week, the conservancy tank must be emptied daily. This leads to excessive costs.

Opportunities

There may be opportunities to treat faecal sludge separately from wastewater, especially if the WWTP becomes overloaded with faecal sludge. According to the participants, this has not yet been considered and would need to be discussed at a higher level with multiple branches within the municipality. Research and development in South Africa in faecal sludge management and non-sewered sanitation solutions have potential to improve services for these informal settlements and potentially save funds.

The Informal Settlements Branch has considered opportunities to reduce the cost of servicing the one incremental development area which has waterborne sanitation connected to a single large conservancy tank. Currently, the opportunity identified is to install a pilot Decentralised Wastewater Treatment System (DEWATS) to treat the wastewater from this area. This will limit the transportation of faecal sludge from the conservancy tank to the WWTP, thus reducing operational costs. The pilot will be led and run by the Informal Settlements Branch. In the long-term, if this pilot were scaled up, it would likely be owned and operated by the Wastewater branch. This arrangement highlights a grey area in terms of management of different aspects of sanitation in different types of settlements.

ANNEXURE N: WASTEWATER SLUDGE MANAGEMENT BRIEF

What can be done to support and improve wastewater sludge management in South Africa?

Nearly twenty years ago when the *Guidelines for Utilisation and Disposal of Wastewater Sludge* were updated, on-site disposal was most widely used by South African municipalities, and beneficial use of sludge was limited (Snyman, 2010). Today, this reality remains largely unchanged. While understanding and awareness of the *Sludge Guidelines* is widespread due to the regulatory requirements to follow them, the gap between policy and implementation remains. This is evidenced by the 2022 Green Drop assessment, which found that approximately 80% of wastewater treatment plants (WWTPs) in South Africa were either stockpiling or storing their sludge in lagoons (i.e., on-site disposal).

To close the gap between policy and implementation, the Water Research Commission funded a study to gather case studies on what municipalities in South Africa are doing to manage their wastewater sludge. This study focused primarily on the cost implications of different options, with the aim of identifying ways to reduce costs and increase beneficial use of wastewater sludge. These findings may also help other municipalities to overcome any barriers to effectively managing their sludge.

What's the problem?

The 2022 Green Drop Report found that 81 percent of wastewater treatment plants (WWTPs) were not using their sludge but were storing sludge long-term either in lagoons or stockpiles. In 2006 when the *Guidelines for the Utilisation and Disposal of Wastewater Sludge* (hereafter referred to as the *Sludge Guidelines*) were first published, DWS had already deemed indefinite storage of sludge, or "stockpiling", as unacceptable. For many of the small treatment plants in the country, sludge production is low, and the cost of dealing with the sludge is high, which is why this practice is widespread. The Green Drop Report also states that only 23% of WWTPs classify their sludge according to the *Sludge Guidelines*.

The Green Drop Report highlights the importance of monitoring sludge compliance for improving processes, presenting the following results based on the 850 systems audited (DWS, 2022):

- only 13% monitor sludge streams
- only 15% have sludge management plans in place

Without data on sludge streams, it is not possible to plan for what should be done with sludge. It appears from these results that the important first step is to institute monitoring and classification of sludge streams to enable informed decision-making, as outlined in the *Sludge Guidelines*, which are currently being updated.

The focus in wastewater treatment (WWT) is generally on the effluent quality as the primary output from the process. However, while some municipalities struggle to get this right, they neglect the sludge that comes out of the WWT process. Sludge production in a WWT process can provide some indication of the effectiveness of treatment, and the sludge itself should be considered a potential source of pollution if not managed properly. Low sludge production likely indicates a problem with upstream WWT processes. It is important for DWS to enforce monitoring requirements for sludge streams as per the Water Use License requirements. While this forms part of the Green Drop Audit

process, it is one of many factors determining Green Drop score and therefore requires additional enforcement strategies.

What can be done?

Guidelines and regulations exist to guide the appropriate management of sludge emanating from the WWT process, and the Green Drop Audit process provides a key mechanism for regulating these practices. Municipalities that hope to achieve Green Drop status are motivated to monitor, appropriately manage, and reuse their wastewater sludge. However, those that are far from Green Drop status for other reasons may not be motivated in the same way. Greater oversight in addition to the Green Drop process is required to ensure WWTP compliance with sludge management guidelines.

Municipalities also need cost-effective methods for managing their sludge. The Water Research Commission (WRC) conducted a study titled *What are municipalities doing with their municipal sludge*, which was finalised in 2025. This research conducted eight case studies on municipal wastewater sludge management, with the aim, inter alia, of understanding the costs associated with different approaches. The outputs from this research, particularly the brief on the cost of wastewater sludge management, can assist with this need. Some specific, practical recommendations for municipalities are provided below.

For municipalities with sludge stockpiles:

- Start by classifying your sludge. You cannot manage what you do not measure or understand. Refer to the *Sludge Guidelines* to see which options are possible with your stockpiled sludge.
- If there is space within the boundary of the WWTP, deep row entrenchment (DRE) of stockpiled sludge might be a suitable, low-cost option. The WRC's *Guidelines for Deep Row Entrenchment* provide further information on this approach, which safely disposes of sludge while providing some benefit to the soil.
- Make operational budget available for handling your WW sludge. The *Overview of costs for managing wastewater sludge* output from this project's final report can give you a good idea of what kind of budget you will need. It gives approximate costs per cubic meter or ton of sludge, as well as some guidance for budgeting based on megalitres of wastewater treated.
- If agriculture application is an option, start with a contract to collect, transport, and apply sludge in nearby farms. Use this as an opportunity to build up a database of farmers who are interested in the benefits of sludge in their farms. This will be helpful for ongoing sludge disposal. Good options to consider for sludge application include animal fodder, industrial crops (e.g., timber, sugarcane, maize), and food crops grown above ground.

For municipalities that are looking for a more cost-effective WW sludge solution:

- Are you transporting sludge long distances? Start by investigating options for final disposal that are closer to the WWTP. Also, optimise your sludge treatment process through one or more of the following methods:
    - Improve anaerobic digestion so you can produce a more stable end product.
    - Dry sludge: Drying beds provide a low-cost and simple solution for this, but you need sufficient space. Belt presses require more capital investment, but they can be used in areas where space is a limitation. This is a worthwhile investment.
    - Further treatment: A1a sludge is easier to manage. It can be given away or sold to farmers more easily, and there are less restrictions on the amount applied to agricultural land. Composting is one low-tech option for improving sludge stability,

and it can also accommodate other organic waste streams. The WRC has also done work on additional innovative options for sludge treatment.

- Is there an opportunity to partner with a sludge beneficiation company? While some municipalities are interested in generating their own revenue, most municipal representatives interviewed in this study acknowledge that this is not necessarily their expertise or core business. Their focus is on providing services. For a sludge beneficiation business to be viable, longer-term arrangements are needed so that start-up costs are effectively covered for the private party.

  Longer-term contracts/agreements require approval by the municipal council, and official public-private partnerships need to be approved through the Department of Treasury. Two examples from this research are listed below. Both can demonstrate value for money, affordability, and adequate risk transfer to the private party, as required in the PPP process.
  - Application of digested sludge on municipal land being used to produce turf grass by a private company.
  - Further treatment of dried sludge by a private company using land within the WWTP and producing a saleable fertiliser.

- For larger municipalities with several WWTPs, designated sludge beneficiation facilities are an option. These can introduce efficiencies and greater control over sludge management. This approach will be taken in one metro municipality in South Africa over the next several years, and research on the impacts of this on sludge management outcomes will grow the sector. Some things to consider:
  - Is there a central location where such a facility could be installed? The facility should be located such that transport distances and amounts are minimised.
  - Does the municipality have any existing infrastructure that can be used to save on start-up costs?
  - Who are the potential users/customers of the treated sludge byproducts?

What actions should be taken?

A wider range of procurement arrangements must be pursued to address sludge management challenges. Most commonly, wastewater sludge disposal is managed through 3-year contracts for transport and disposal. This approach is costly to municipalities. Where sufficient sludge quantities are produced, public-private partnerships will have merit for improving cost effectiveness while also centring on the circular economy. South Africa has a framework for pursuing public-private partnerships through the official procurement process, but the municipalities in this study were generally reticent to pursue this route. There is a need for awareness raising and capacity building among municipalities on how to go about establishing partnerships with the private sector while complying with the Municipal Finance Management Act (MFMA).

Build awareness among the private sector of opportunities in wastewater sludge beneficiation. A small number of companies are doing this, and they have emphasised the fact that demand for their products is high. There is a market for other businesses in this space, and expanding the pool of private companies can assist with overcoming procurement challenges (such as, for example, only one company responding to specialised proposal calls) and making circular economy solutions more accessible throughout the country.

Planning for wastewater sludge management is an important first step. Municipalities cannot manage what they do not measure or understand, so the first step is monitoring sludge streams and classifying sludge. The *Sludge Guidelines* provide the starting point for understanding different options for WW sludge management. Sludge management is referred to in the Wastewater Risk Abatement Planning process, but it should also come through more strongly in other planning instruments. One research participant requested a template for a sludge management strategy, and others said that sludge management should come through in Water Services Development Plans (WSDPs).

Develop designated sludge treatment and beneficiation facilities*.* One metro that participated in this research has plans to develop three biosolids beneficiation facilities, which will enable them to further treat wastewater sludge from their 16 WWTPs and produce several useful byproducts in the process. This approach will simplify their sludge management approach and reduce costs of transport for agricultural disposal. This type of "out of the box" thinking can unlock new opportunities and ensure a focus on properly managing sludge.

Improve wastewater sludge quality and keep things simple*.* By improving the sludge classification, municipalities can open more options for disposal or beneficial use. This can be done through simple methods, and if possible, municipalities should use their existing infrastructure to accomplish this. For example, ensuring that anaerobic digesters are functioning optimally will produce more stable sludge. Where municipalities have extra land, solar drying of sludge in drying beds can improve sludge quality and reduce sludge quantity, while not requiring excessive energy inputs. Deep row entrenchment of wastewater sludge has also been demonstrated as a simple way to safely dispose of sludge while increasing the long-term soil fertility

Share practical lessons learned by municipalities to build capacity around sludge management*.* While researchers can summarise and disseminate information, municipalities implementing practical solutions have more relevant information to share with their colleagues. This study provided one platform to consolidate experiences and views from different municipalities, and additional platforms are needed to encourage learning.

> *I would say let us talk together and cross [pollinate] on the successes as well as challenges that [we] experience in sludge management… I think [we] can work together and [make South Africa] a better place.* – Municipal representative

Where can one find more information?

Guidelines for the Utilisation and Disposal of Wastewater sludge (Volumes 1 – 5) by H. Snyman and J. Herselman (2006). All volumes are available on the WRC Knowledge Hub. Access Volume 1 here: https://wrcwebsite.azurewebsites.net/wp-content/uploads/mdocs/TT%20261%20(vol%201)%20new.pdf

Guidelines for Deep Row Entrenchment of Faecal Sludge and Secondary Wastewater Sludge by Partners in Development (2022). Access it here: https://wrcwebsite.azurewebsites.net/wp-content/uploads/mdocs/TT%20880%20final%20web%20NEW.pdf

An Introduction to PPPs in South Africa by the National Business Initiative (NBI) (2019). Access it here: https://www.nbi.org.za/report/an-introduction-to-ppps-in-south-africa/

Industry Brief: Entering the Public Water Sector Market by GreenCape. Access it here: https://greencape.co.za/library/entering-the-public-water-sector/

Industry Brief: Circular economy solutions for primary, waste activated, and digested wastewater sludge by GreenCape. Access it here: https://greencape.co.za/library/industry-brief-sludge-beneficiation/

This brief is linked to Water Research Commission research project number C2023-2024-01290, titled *What are Municipalities doing with their Municipal Sludge? Understanding the current practices and the cost associated with municipal sludge disposal with case studies*. The Final Report for this study will be accessible via the WRC Knowledge Hub.

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