WATER RESEARCH COMMISSION

WORKING PAPER

SaNiTi – A WRC research strategy and response to transforming sanitation into the future

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Summary

This working paper presents SANITI – *Sanitation Transformation Initiative* – in which a new paradigm for sanitation is being supported and guided from previous research programmes. This paper was developed to facilitate learning of the WRC's investment in sanitation and to inform readers on logical progression towards the SANITI strategy.

The scope of this paper can be summarised as following:

- Provide a contextualisation for SANITI.
- Provide the rationale and logic for the development and support of the WRC's most recent sanitation strategy – SANITI

1. CONTEXTUALISATION OF CHALLENGES ASSOCIATED WITH SANITATION SERVICE DELIVERY

This section provides an overview of the challenges that the country has faced in sanitation service provision.

1.1. Historical inequalities

Previous apartheid spatial geography planning meant that large proportions of the indigenous population did not receive adequate potable water and sanitation provision. Full waterborne systems were scarce in these areas. When South Africa's first democratically elected government came to power in 1994, the government provision of basic water and sanitation for unserved citizens became a priority.

Since then, a framework of legislation, policies and guidelines was developed to support the achievement of this goal. The *National Sanitation Policy – White Paper* developed in 1996 defined the basic level of sanitation for a household as a *Ventilated Improved Pit* (VIP) latrine, which falls under the United Nations (UN) technical category of improved sanitation (see **Figure 1**).

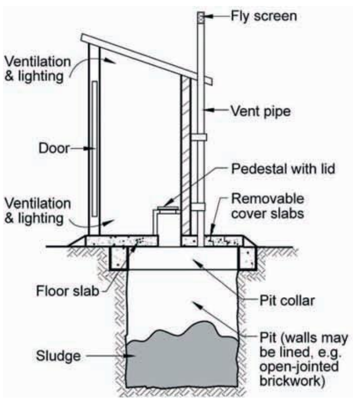

Figure 1. Side-view schematic of a Ventilated Improved Pit (VIP) latrine (from Guidelines for Human Settlement Planning and Design)

Later, the *White Paper on Basic Sanitation* (DWAF, 2001) highlighted the challenge of cost recovery from rural households with respect to water and sanitation which was followed by the *Strategic Framework for Water Services* (DWAF, 2003). The latter policy document provided guidance to *Water Services Authorities* (WSAs) in providing free basic sanitation infrastructure by the then target of 2014, promoting health and hygiene and subsidising the operation and maintenance costs. VIP latrines were considered an adequate infrastructure for sanitary purposes and, according to the Strategic Framework for Water Services, this free basic sanitation service should be maintained at government expense (Still and Foxon, 2012). Further, as Still and Foxon (2012) noted, the policy document suggests but does prescribe appropriate technology with WSAs needing to address the following situations:

- in urban areas and high-density residential areas, waterborne sanitation is considered the most appropriate solution.
- in rural areas, on-site sanitation technical solutions are deemed an appropriate solution.

- in intermediate areas, such as peri-urban areas, the WSA would need to consider the most appropriate technology and needs to exercise caution when selecting waterborne options.

The expansion of municipal boundaries of major cities also resulted in the inheritance of non-sewered sanitation technologies which municipalities had to deal with.

1.2. Rapid urbanisation

Between 64% and 67% of South Africa's population is urbanised. It is predicted that this figure will rise to 71% by 2030 and by 2050, 8 in 10 people will be living in urban areas (Parliamentary Monitoring Group, 2016). This will increase demand on basic infrastructure requirements. South Africa can be considered as a Young Urban nation; the country's population has a significant proportion of the population under the age of 40 years. The national rate of urbanisation is much higher than experienced in other developing countries (India at 32%, Vietnam at 33%, Nigeria at 47%, China at 54%) (de Kock, 2016). **Figure 2**, as an example, shows the densification of peri-urban area in the city of Durban over a 5-year period (2008 to 2013). The urban migration trend experienced has meant that municipalities have to deliver sanitation services under challenging planning scenarios: 1) in informal areas without formalised housing arrangements and 2) government subsidised housing areas of which there is an ever-increasing backlog. For the former, it is technically challenging to provide sanitation services to individual homes within an informal housing arrangement. The laying of sewers in unplanned housing sites limits the municipalities technical approach. Temporary options, such as chemical toilets, can be provided but are expensive to implement while latrine technologies may require frequent emptying cycles in areas not conducive to such a task (planned road infrastructure, dense informal housing arrangements).

Figure 2. Comparison of urban development from 2008 (left) vs 2013 (right). Photos courtesy of eThekwini Water & Sanitation.

For subsidised housing, sanitation provision needs to be supplemented by a number of human settlement services, such as potable water supply and electricity, which can lead to increases in the service delivery timeframe. This challenge is exacerbated by the limitations of current technological approaches used to provide sanitation services.

1.3. Constrained water supply

The majority of South Africa's urban population sanitation needs are addressed through reticulated waterborne systems. The requirement for the technical functioning of these systems is water. Research produced through the WRC and its partners have shown that South Africa is over-exploiting its water resources and that withdrawals are expected to increase over the next 20 years (Donnenfield, Corrkes, & Hedden, 2018). It has been predicted that planned water supply enhancements are not adequate for our future water demands and that a basket of interventions and strategies are required to reconcile the future water demand and supply gap (Donnenfield, Corrkes, & Hedden, 2018). As the Cape Town drought of 2017 has shown the flushing of 9-12 litres of potable water with faeces may not be viable in near future and represents one area amongst many where South Africa's high per capita usage (235 litres per person daily compared to a global average of 173 litres) could be reduced. Another avenue for alternate water supply could be the reuse of treated sanitation-derived wastewater. In neighbouring Namibia, this strategy of direct wastewater-to-tap has been relatively successful as water management strategy but has only been implemented in pockets within South Africa. The reasons for this have less to with technical capabilities than other factors (social, strategic).

The availability of water and the cost of its supply (in terms of existing infrastructure and cost for providers and users), it also major determinant in selecting for dry sanitation technologies as explained further in the next section.

1.4. Binary sanitation engineering paradigm

When considering technology choices for service provision, the choice has generally been full reticulated flush or latrine-based technologies. The technology choice is based on the following interlinked determinants: proximity in relation to existing sewer network, cost (on-site alternatives are generally around 5-50% cheaper than activated sludge processes linked to reticulated sewerage), and availability of resources (water, energy, financial resources). As the Executive Manager of Water Use, Wastewater Resources and Sanitation Futures, Mr. Jay Bhagwan, states, "We either provide a full flush toilet or a hole in the ground (latrine). The poor are usually given the hole in the ground solution".

VIP latrines and their derivatives were installed since 1994 as it did not require sewer laying and associated infrastructure (transfer pumps, wastewater treatment facilities, requirement for constant water supply). The dry sanitation solution, if properly serviced, operated and maintained, provides a barrier to sanitation-related infectious diseases. Around 30% of the entire South African population relying on this technology and its derivatives (**Figure 3**).

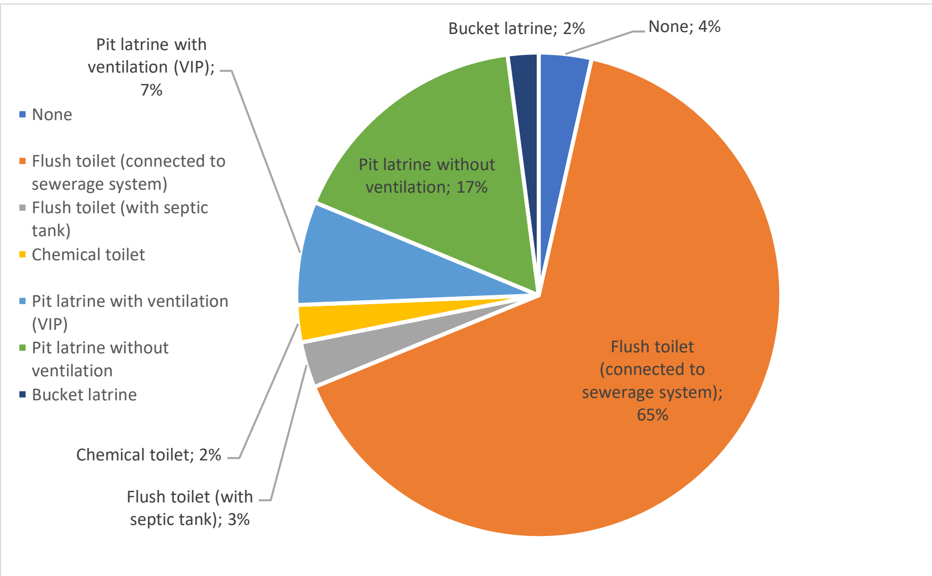

Figure 3. Household sanitation statistics (Statistics South Africa, 2019)

Large-scale infrastructure programmes were implemented to build VIPs on the premise that sludge would not accumulate and therefore not require emptying. In reality, the opposite was proving true; latrines were filling up and many thousands of these systems were reaching their capacity faster than anticipated. The consequence of the rapid latrine building programmes – while delivering essential services within the technical constraints – had brought upon another set of challenges related to the servicing, operation and maintenance of the implemented solution.

This challenge has not been resolved; to date, there are many municipalities that struggle to deal with faecal sludge from dry sanitation systems. From a technical perspective, faecal sludge is a sticky paste containing a variety of pathogenic microorganisms. The sludge is not conducive to a vacuum and is practically better to be emptied by manual labour using shovels and forks. This work is not pleasant and requires personnel be safeguarded, using *personal protective equipment* (PPE), deworming, and immunisations against infectious agents contained within the sludge. When vacuum trucks are used, it can require significant effort to gain access to latrines (where road infrastructure is limited) and water to enable the honeysucker to remove sludge from the latrine. Another challenge is related to the operational requirement for disposal; scientific studies commissioned by the WRC have shown that the sludge is concentrated in pathogens and nutrients (Bhagwan, Still, Buckley, & Foxon, 2008). Due to its nature, Microbiological Class C landfills are recommended for sludge disposal of which there are limited number willing to accept this sludge nationally (Harrison & Wilson, 2012). Logistical costs required to transport sludges to recommended disposal sites can escalate disposal costs while the low biodegradability and nutrient content of the sludge means that digestion-based systems and blending with wastewater streams are not an effective disposal strategy, respectively.

From a user perspective, dry sanitation technologies are not considered the “best” option. Dry sanitation is considered as the “poor person’s toilet”. Studies commissioned by the WRC and partners within South Africa have shown a strong user preference for a flush toilet over dry sanitation technologies. Often, the latrine’s servicing lifespan is significantly reduced by detritus intrusion into the latrines (Brouckaert, Foxon, & Wood, 2013). These findings highlight the complexity of sanitation provision in which the service provider has to match user needs and preferences to limited technical, natural and financial resources. Further, it points to the lack of suitable technology alternatives that can encompass these design requirements.

At the other end of sanitation engineering spectrum is reticulated full flush systems. The flush toilet remains the “gold standard” from a user perspective. Although the flush toilet can be associated with various on-site systems, such as a septic tank, in this document it is referenced in terms of the conventional reticulated sewerage system applied for urban areas. This system is typified by a network of sewers linked to communities and which transport large volumes of wastewater to a collection, treatment and disposal point. The inclusion of water in the design allows for the sludge challenge to be transported to a centralised facility whereas in dry on-site sanitation, the sludge challenge is localised at point-of-generation (**Figure 4**).

Historically, the roots of this approach can be traced back to the outbreak of waterborne diseases, especially Cholera, on the European continent. Once scientific evidence linking the outbreak of waterborne diseases to poor sanitation became clearer, there was an increased motivation to transport household human excreta away from ever-expanding urban populations. Water is an essential component of this approach in order to transport human excreta from point to the next. While this strategy led to the significant reduction of waterborne disease outbreaks in Europe (Lofrano

& Brown, 2010), it is wasteful as considerable amounts of limited and potentially potable water is contaminated with human excreta and other pollutants for the sole purpose of transporting pollutants from one catchment to the next.

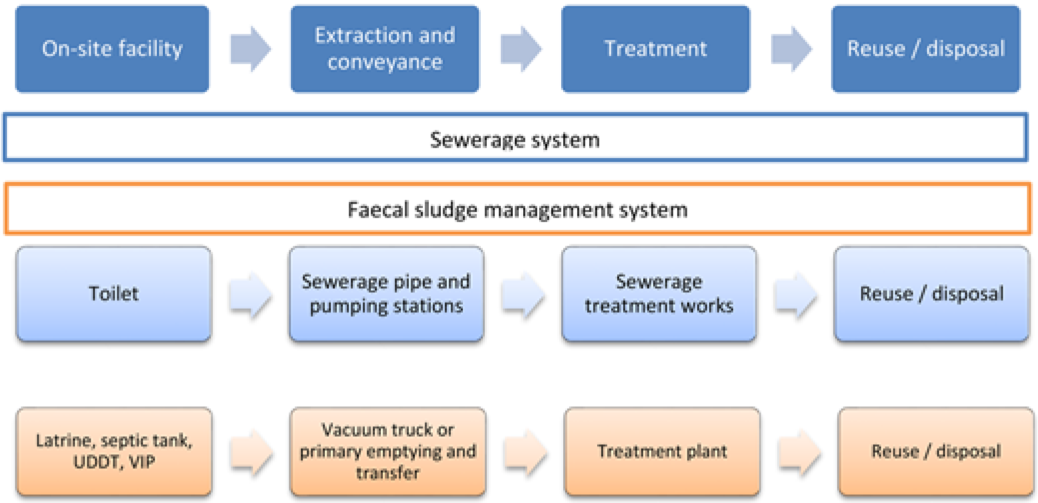

Figure 4. Comparison of sewered and non-sewered system supply value chain (Source: Daudey, 2018).

While developed countries have continuously improved conventional wastewater-based strategies to become more reliable and efficient as time progressed, developing countries have struggled to implement this technology successfully. There are a number of reasons for this:

- There is a significant unserved population in developing countries and the infrastructure provision has to address these backlogs while in urban areas, also keep pace with the rapid population growth and urbanisation.
- Developing countries require significant investment for centralised sewerage infrastructure while meeting several technical requirements including excavations are needed for laying pipes, reliable water infrastructure and supply, and energy-intensive pumps and treatment systems.

Research has indicated that the financial investment required for such systems may be beyond the reach for most developing countries as even in developed countries, these systems are directly cross-subsidised to enable them being financially sustainable.

Connection to a sewer system can be costly; a generalised estimate put forward by the WHO/UNICEF indicated that cost per person connecting to the sewer network is 5% to 50% higher than on-site alternatives (WHO/UNICEF, 2000). Other estimates indicate that the cost of this treatment option can be nearly double to that of a septic tank and up to 9 times that for a latrine (**Figure 5**) (Daudey, 2018). Cost can be major driver for the technical approach used. Von Sperling (1996) hypothesised that the four main aspects considered by developing countries in the selection of a wastewater treatment were:

1. infrastructure costs,
2. Sustainability,
3. Operational costs, and
4. Simplicity.

Conversely, the developed countries perceived efficiency, reliability, sludge disposal and land requirement as the major drivers for technology selection (Von Sperling, 1996).

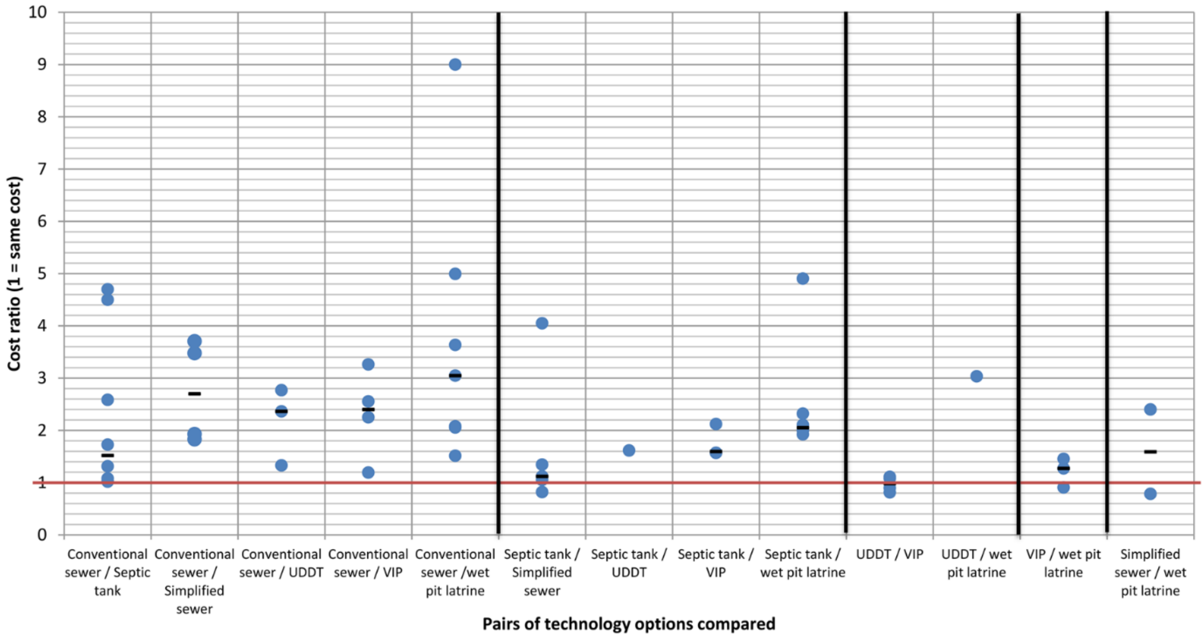

Figure 5. Compilation of lifecycle cost ratios of various full sanitation chain solutions based on literature review from Daudey (2018). A cost ratio above 1 indicates that the first type of sanitation system mentioned is more expensive than the second type of sanitation system mentioned and vice versa (Daudey, 2018).

Besides the infrastructure investment, a suite of other resources, such as water, energy, and high-level designers, technicians and operators, are required to properly manage wastewater plants and their auxiliary equipment. The lack of these resources can result in infrastructure deterioration and / or unreliable services (Eales, 2008; Hawkins, Blackett, & Heymans, 2013; United Nations (U.N)-Water, 2015). Eales (2008) noted that in South Africa, only a small percentage of plants were operated and maintained adequately with there being a critical shortage of skilled staff to operate and maintain the treatment works. A critical evaluation of the Green Drop Certification programme has highlighted similar themes (Ntoembela, Funcke, Meissner, Steyn, & Masangane, 2016). Other challenges are the design capacity of current wastewater treatment facilities to deal with increasing pollution loads, unstable energy supply, and the lack of investment in current infrastructure.

Some of these issues have manifested themselves in the bucket eradication programme in areas without bulk sewers, inadequate wastewater treatment capacity and adequate water supply. WRC Research Report 2016/1/12: *Evaluation of Sanitation Upgrading Programmes: The Case of the Bucket Eradication Programme* by Hlathi Development Services provided insights in what worked well and what did not in municipalities implementing the bucket eradication programme which are highlighted in **Table 1** (Mjoli, 2012)**.**

Table 1. Main insights into the Bucket Eradication programme (Mjoli, 2012).

What worked	What didn't	Challenges
Buy-in from all political levels and spheres of government	One-size fits all toilet	Adequate funds, specifically municipalities with limited revenue streams
Deployment of engineers to under-capacitated areas	Supply-driven approach with little emphasis on sustainability, specifically O&M	Affordability of waterborne services for the poor
Eradication of bucket system with improved sanitation	Limited emphasis on community involvement and education including hygiene campaigns.	Inappropriate cleansing materials by poor households
		Lack of funds for new or upgrades for WWTW
		Critical shortage of skills for O&M

1.5. Municipal sludge handling and disposal

One of the challenges of using biological-based treatment systems is that sludge accumulates and must be disposed of. Sludge disposal – whether from wastewater treatment works or on-site sanitation – is a major challenge faced by municipalities in South Africa. Land disposal is a common disposal method used for both types of municipal sludges but options for this are becoming reduced (Herselman, Steyn, & Synman, 2006; Harrison & Wilson, 2012).

1.6. Energy constraints

South Africa has been facing an energy crisis and associated high costs over the last two decades have exposed the risk to sustainable water and wastewater management, including operations of critical infrastructure. The WRC has supported funding towards unlocking the energy potential within water and wastewater services and have identified key areas having the greatest potential to recover energy, including estimates of recoverable energy, appropriate technologies and innovations with potential for implementation to recover energy in the South African context and the need to couple energy recovery with energy efficiency as part of best practice in the water and wastewater sector.

1.7. Concluding remarks

The limited investment in alternative toilet technology has limited approaches available by municipalities to reach unserved communities within development framework timelines. The new sanitation paradigm is required that encompasses the best advantages of flush toilets and dry latrines.

2. THE FAECAL SLUDGE MANAGEMENT (FSM) CHALLENGE

Since 1994, large-scale infrastructure programmes have been implemented to build VIPs to achieve national service delivery goals. Current estimates indicate that around 30% of the entire South African population rely on VIP toilets and their derivatives (Statistics South Africa, 2019). A national audit of water and sanitation projects conducted on behalf of the then *Department of Water Affairs and Forestry* (now DWS) indicated that at 60% of the facilities surveyed, municipalities were only conducting reactive maintenance while 40% of municipalities had inadequate maintenance capacity (SALGA, 2009). Many thousands of these dry sanitation systems were reaching their capacity faster than anticipated (**Figure 6**). A tipping point was being reached as many municipalities did not have operation and maintenance procedures, budgets and plans for VIP toilets, with some pits requiring emptying as frequently as twice a month (Mjoli, 2010; Still & Koxon, 2012).

In the early 2000s, the WRC strategically invested in developing innovation around the *Faecal Sludge Management* (FSM) supply chain. At the same time, the eThekwini Municipality, which has the city of Durban as its core, was undertaking an emptying programme on all VIP latrines, of which 60 000 were inherited from local entities when its municipal boundaries were expanded. Many of the pits encountered during the programme were reported to be older than 10-years and in urgent need of emptying (Brouckaert, Foxon, & Wood, 2013). This task could only be achieved via manual excavation as the latrines contained various volumes of detritus content (Still & Koxon, 2012a). Moreover, there were difficulties in disposing of the emptied faecal sludge safely as the nearest municipal sewage treatment works could not handle the additional pollutant loading.

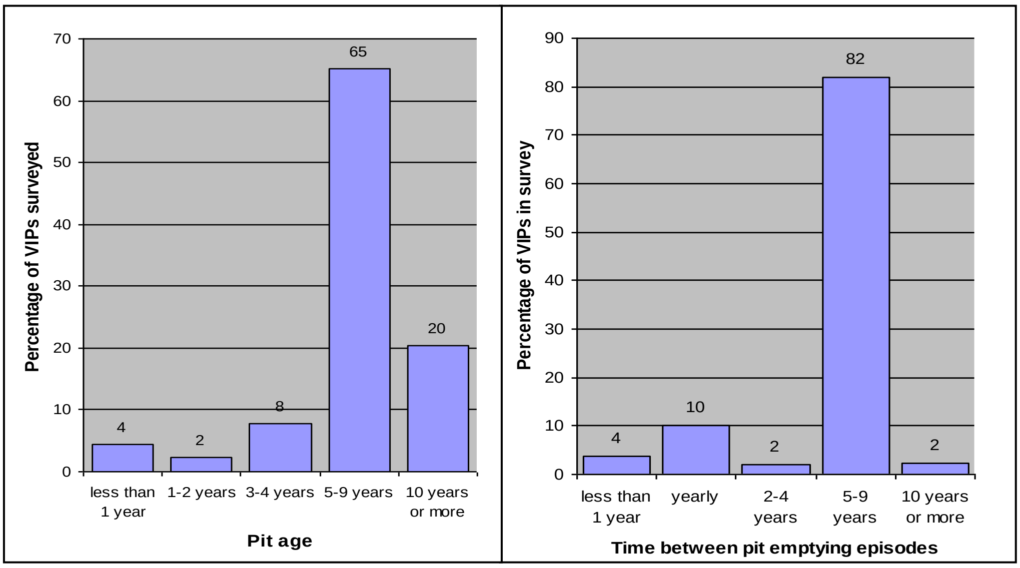

Figure 6. Pit ages and interval required before emptying (Still & Koxon, 2012a)

To add to the complexity of the situation, there was limited technical know-how of how deal with full pit toilets and the faecal sludge. Vacuum tankers could not be used in all cases while faecal sludge did not implicitly fall under existing sludge disposal guidelines (Still & Koxon, 2012a).

The result and response was an incremental research strategy by the WRC in partnership with eThekwini Municipality and a number of research institutions aimed at improving the knowledge base needed to support the development of strategies and innovative technical solutions to deal with dry sanitation. The WRC investment aimed to provide a strong knowledge base and platform to these sanitation challenges which can stimulate local innovations and the lessons applied to other municipalities facing similar difficulties. The three-pronged strategy aimed at providing elucidating the following:

1. Understanding sludge accumulation rates in VIPs and strategies for emptying full pits (Still & Koxon, 2012a)
2. Scientifically elucidating the treatment processes occurring in VIP latrines and their variants (Still & Foxon, 2012b)
3. Developing pit emptying technologies (Still & O'Riordan, 2012).

The results from that research initiative are summarised in **Table 2**.

Table 2. Summary of research findings (Bakare, 2012; Still, Salisbury, Foxon, Buckley, & Bhagwan, 2010; Still & Foxon, 2012b; Brouckaert, Foxon, & Wood, 2013)

Pits filling faster than their design life. The serving interval of pits is strongly dependent on the presence / absence of detritus. It was predicted that the capacity of VIP latrine could be extended by 15 to 25 years by preventing detritus entering pits.
Pit additives. Twenty-one percent of WSAs promoted or provided bio-enzyme additives to householders. Research showed that neither controlled laboratory trials nor field trials provided any evidence that pit additives could significantly reduce the rate of sludge accumulation in VIP latrines or reduce the volume of sludge in the pits.
Pit latrines behave as storage vessels. The faecal sludge in the VIP latrines analysed had undergone significant levels of stabilisation and therefore not subject to the same treatment applications as fresh human excreta. The aerobic biodegradability ranges from 50% at the top of the sludge heap to around 20% at the bottom half.
Faecal sludge poses a significant health risk. Sixty percent of households analysed tested positive for *Ascaris* while the examination of face masks worn by manual pit emptiers showed that the exposure to parasitic helminths were high.
The cost of managing faecal sludges from full latrines is high and in some instances comparable to the costs of installing new latrines.

The findings from that extensive dry sanitation programme had illustrated the technical challenges of managing VIP latrines and also UDDTs. The health challenges were placed under the spotlight in WRC Research Report No. 2134/1/18 (Louton, Beukes, Naidoo, & Still, 2018).

With full waterborne sanitation proving to be unaffordable and technically limiting but still held as the *gold standard* for users, new alternatives were required that could bridge the gap between the cost-effectiveness of on-site sanitation and user acceptance of water flushing technologies. The WRC research that began to focus on these gap technologies and the sanitation portfolio revamped through a consultative process.

3. STIMULATING A NEW SANITATION PARADIGM – SaNiTi

Around the mid-2010s, there was a realisation that both international and national development goals for universal sanitation access will continue to unattainable if the current technologies and practices were to continue. While significant strides have been made with respect to sanitation provision since 1994, there remains significant portion of the unserved that has been proven to challenging to provide services to and this has been exacerbated by secondary backlogs; people that have been provided with an appropriate sanitation solution but require another intervention through capital re-investment due to the deterioration of the initial investment and infrastructure. The research undertaken through WRC and partners have shown that while users may aspire to full waterborne sanitation, this is not technically feasible. At the other end of technical spectrum, the implementation of the VIP has shown fault lines along user acceptance and the O&M challenges of emptying and disposal of accumulated faecal sludges. Compounding this challenge is the that of water scarcity and that universal access to waterborne sanitation may not be realised due to the prohibitive costs and the availability of water.

Recognising the need for paradigm disruption, the WRC initiated the *Sanitation Transformation Initiative* (SANITI) – the acronym serving as play on the word *sanity* and the term's use aims to bring prominence or the insanity of doing the same thing over and expecting a different result. There remains no silver bullet to sanitation with toilets being but one part of the sanitation solution chain. What is required is a strategic re-think of how sanitation is provided; a change to a systems approach in which all aspects of sanitation are inter-related and inter-dependent and the adoption of business models, such as circular economy and market entry and market-based research, as part of the approach (**Figure 7**).

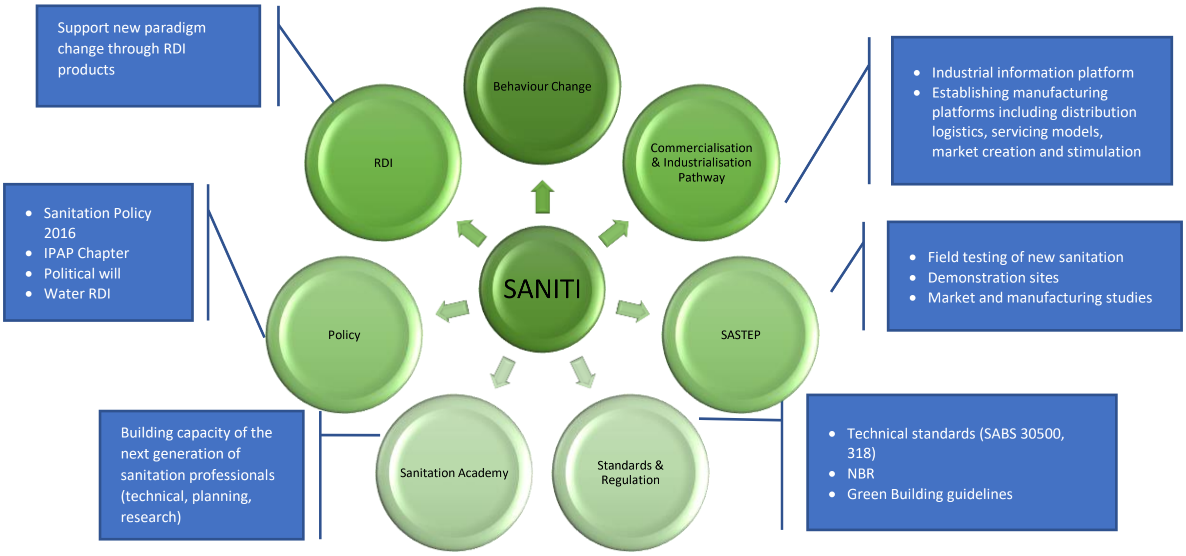

Figure 7. SANITI – the systems approach used that focus on multi-faceted areas that inter-dependent and inter-connected.

The SANITI strategy incorporates the elements of behaviour change, industrial development, policy development for new sanitation, technology standards and regulations, technology testbeds, *Research, Development and Innovation* (RDI) focused on supporting the strategy and sanitation academy which build the next cohort of skill and artisans required to service this new frontier. The outcome will result in:

- New sanitation that meets user needs and expectations while less demanding of natural resources. The new sanitation must be replicable on a large-scale and the components easily sourced throughout the supply chain.
- Circular economy principles in which products in the value chain are recycled or re-used with the addition of other revenue streams.
- Establishing market needs and demands.
- Presenting a RDI pathway to achieve technical, policy and procurement targets in line with the vision.
- Creating a sanitation manufacturing industry around the technical advancements and creating several new jobs and employment around this.

In disrupting the current paradigm and creating a new market, Government will have to play the leadership role; a role of the enabler and the role facilitator. It is also about transforming a very entrenched public supply model which will have to evolve if we are to be successful. The WRC will support transforming the sanitation environment towards a new technological environment which will see sanitation going off-the-grid and associated with a circular economy approach to this new sanitation services market. This approach offers new opportunities for stimulating the development of an industry which will potentially meet several national objectives of job creation, small-to-medium enterprise development, micro and macro enterprise development etc. while turning this challenge into an opportunity towards a circular economy for sanitation.

The following is already in progress:

- POLICY AND POLITICIAL WILL – In the new Sanitation Policy 2016, the policy position of incorporating circular economy principles has been made. This formally sets Government impetus and commitment in this direction. At the Sanitation Indaba "It's not all about flushing" event held in Durban in 2015, the then Deputy President and now President of South Africa issued a clarion call "To ensure sustainable sanitation for all, we have to do things differently" and provided impetus "to generate new sanitation solutions that are sustainable and will meet our current and future need". The call for new models of sanitations and new sanitation were repeated in the launch of the Presidency's SAFE programme for schools.
- INDUSTRY – The *Department of Trade and Industry* (DTI), *Department of Science and Innovation* (DSI) and the WRC have established an industrial platform for new off-grid sanitation in a DTI policy of 2017. This is a strong signal to transform the sanitation space towards a strong industrial and innovation base for solutions and production. Localisation and manufacturing also stimulates and creates a new industry with products and services and meaningfully many new jobs.
- STANDARDS – Working with the *South African Bureau of Standards* (SABS), the *International Standards Organisation* (ISO) 30500 and PC318 Standards on non-sewered sanitation has been adopted. This is very important element in this new sanitation economy. Products and innovations must subscribe to national standards and quality.
- REGULATIONS – The DWS is working on new regulations, however, one of the key instruments undergoing revisions is the *National Building Regulations* (NBR) to include the new off grid sanitation solutions. This adds the stimulus for both the state and the public institutions to ensure quick uptake of solutions. Through the SASTEP (*South African Sanitation Technology Enterprise Programme*), protocols have been developed to assist manufacturers with meeting various low-flushing requirements.
- DEMONSTRATION – A dedicated national programme in the form of SASTEP, which allows a pipeline for new innovations to be demonstrated and tested and supporting the entry into the market. Several demonstrations of off-grid solutions have been implemented in South Africa.
- RDI – Numerous RDI products have been produced through the WRC funding model to support the transition away from conventional technologies and practices through rigorous scientific undertakings. Some of the products will be elaborated later in the next section.

3.1. Reorganisation of thrust and future outlook

The conceptualisation of SANITI led to the strategic development of research focus and funding resulting in new thrusts *in Key Strategic Area (KSA) 3* at the WRC (previously *Water and Wastewater Management* – now *Water Use, Wastewater Resources and Sanitation Futures*) in 2019/20.

The newly formed Thrust 4: SANITI was initiated with the purpose of providing impetus to the development of non-sewered sanitation solutions which would assist sanitation service providers to be more efficient and cost-effective. The Thrust consists of 4 programmes that are aligned to the vision of SANITI (**Figure 8**):

1. **Re-Engineered Toilets** – The scope of this programme will include the development of innovative toilet options that combine the benefits of flush systems and dry sanitation systems while eliminating their limitations (reducing flush volumes, eliminating pathogens and sludge production, non-requirement for laying of sewers, appealing to users). Solutions developed must take into account Circular Economy principles as part of their design and operation, including the recycling of water and nutrients, energy-saving/generation and capability to generate by-products of commercial value.
2. **Sanitation Sensitive Design** – The development of institutional and municipal financial, planning, management, social and communication models that align to the objectives of SANITI is required for this new form of service delivery to achieve critical mass. The focus of this programme will therefore be the development, testing and evaluation of these models to ensure sustainability of approach. This programme will address institutional and municipal sustainable service provision through incorporation of "sanitation as a business" approaches; creating enabling environments for new sanitation models; training, education and awareness aspects which contribute to sanitation sensitive design; and improved city-wide hygiene behaviours and health indicators.
3. **Municipal Sludge Valorisation** – Municipal wastewater sludges and faecal sludges from non-sewered systems are technically challenging to deal with. There is a need for cost-effective solutions to deal with municipal wastewater and faecal sludges. The scope of this programme is to promote the development of appropriate and cost-effective techniques for municipal and faecal sludge treatment and/or valorisation. The focus of this programme on research, development and innovation that optimises current treatment options and future valorisation-focused systems.
4. **Sanitation-linked Business (SANIBUS)** – The scope of this programme will include the development, inclusion, application and evaluation of business approaches as part of sanitation service provision. Traditionally, sanitation provision is subsidised through the public sector with little expectation of full cost recovery. The private sector can play an important role in accelerating sanitation provision by offering alternate sanitation products and services at appropriate prices while generating income. This programme will focus on the development, application and evaluation of business plans for the dual purpose of income generation and sanitation provision. This will include market research and analysis, financing arrangements, business legislation analysis, product and service development; business management, and financial planning associated with new sanitation models.

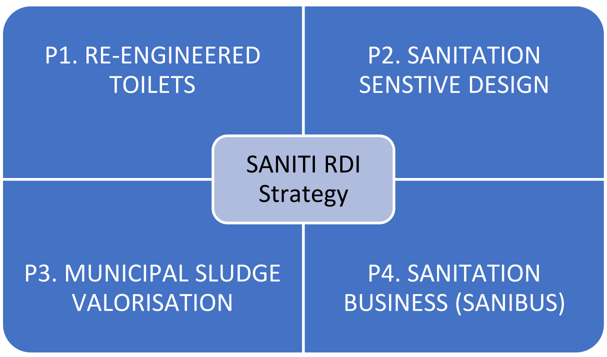

Figure 8. Programmes as part of the New Thrust: SANITI

While the initiation of the SANITI Thrust within the WRC may have occurred in 2019/20, most projects commissioned starting in the 2010s by the WRC have in effect been aligned to new programmes and been guided by previous research outcomes (e.g. the experience of filling latrines an dry sanitation in general and the need for new sanitation models). The sections provide some highlights of projects commissioned in line with new programmes, past and present.

3.1.1 Re-engineered toilets

Taking into the account the previous outcomes of research, it has been recognised that there needs to be a radical shift in the sanitation paradigm currently used. The new paradigm for sanitation, proposed in this document and set as programme within the new Thrust, is based on technology disrupters that can safely treat human excreta, and matches user preferences without the need for sewers, or reliance on large quantities of water and/or energy supplies. Through innovation and smart-chain supply, universal access can be achieved sustainably, and linked to water security and business opportunities. The opportunity arises for leapfrogging these solutions in growing cities in the developing world, reducing water consumption and eliminating pollutant pathways.

The developing world, including South Africa, are limited in technical applications that can match their *on-the-ground* conditions. This limitation can be directly attributed to the lack of innovation in toilet design. The front-end design of the flush toilet has not changed considerably over a period of 150 years. The S-shape pipe to limit odours in toilets and drains was developed by Alexander Cummings in 1775; this design is still being used in flush toilets today.

Recognising the health and economic benefits of hygienic sanitation, the BMGF WASH programme initiated the *Reinvent The Toilet Challenge* (RTTC) in 2011 to address the technical limitations of current sanitation approaches. This includes:

I. protect public and environmental health
II. eliminating the need for sewer laying, sludge accumulation and constant water supply
III. recover valuable resources, such as energy, water and nutrients
IV. cost less than US$ 0.05 cents per user per day
V. promotes economic sustainability, and
VI. having an aspirational product that will attract both developing and developed country contexts.

Since the launch of the RTTC, a number of toilet products across the sanitation value chain have been developed. Products have progressed from an early-stage Technology Readiness Level to real-world piloting and demonstration. Unlike technologies routinely used today, biological-based processes are not the sole treatment process used. Physical and chemical treatment processes, such as liquid/solid separation, hydrothermal carbonisation, incineration and electrochemical treatment, have been scientifically evaluated and incorporated as *in-situ* toilet features. The introduction of these processes is aimed at treating human excreta at *point-of-source* thereby eliminating sewers and to completely or significantly reduce environmental pollutants and sludge accumulation. Demonstration-ready models are currently being evaluated in South Africa as part of the *South African Sanitation Technology Entrepreneurship Programme* (SASTEP) Programme to ensure durability and reliability, develop specifications and manufacturability, and understand soft-issues relating to usage, including user acceptance and the re-use of valorised waste products.

Concurrently, process standards for non-sewered sanitation have been adopted by the ISO with South Africa, via the SABS, being the second country in Africa, after Senegal, to adopt the new standard. The localisation of non-sewered sanitation standards serves as an important cog in providing product confidence and assurance and should be embraced by all sanitation stakeholders including innovators, building industry, regulators and municipalities.

Re-engineered toilets allow for the revamp of the traditional *Sanitation Ladder* paradigm currently used (moving from latrines to full waterborne) (**Figure 9**). The innovative approach to toilet engineering can be condensed as a single step through innovative engineering approaches (**Figure 10**). The management needs for a service provider becomes compressed as technical functions are also condensed into the toilet through re-engineering approaches. ISO validation and certification will ensure product process performance according to a public health and environmental standard. Solutions for greywater management and hygiene behaviour would need to be undertaken to complement re-engineered toilet solutions as part of the larger WASH strategy.

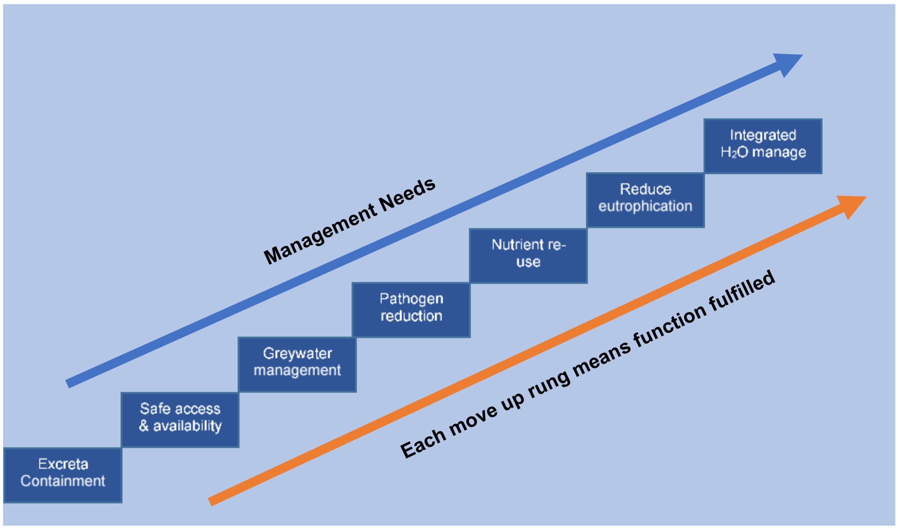

Figure 9. The Sanitation Ladder revamped from a technology-based approach to a function-based approach. Adopted from (Kvarnström, McConvilee, Brakcen, Johansson, & Fogde, 2011).

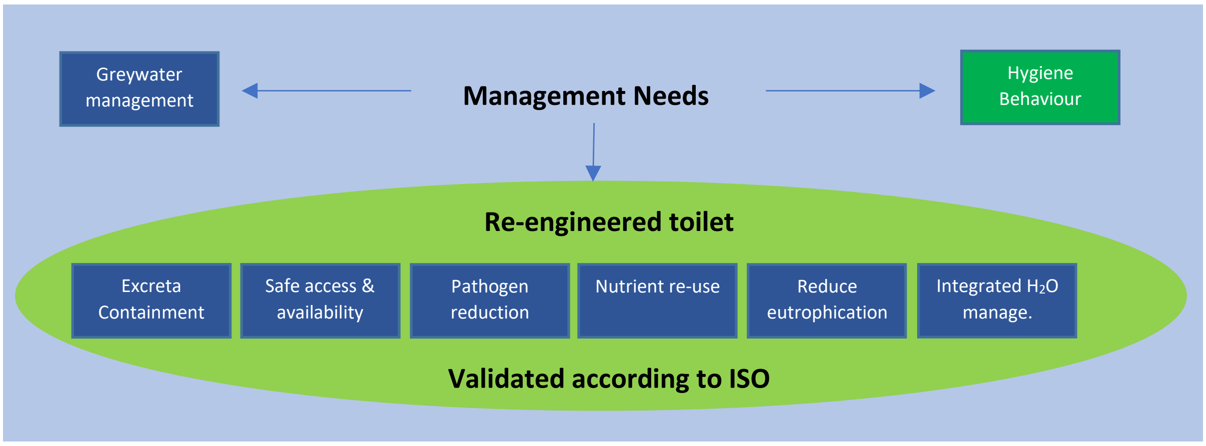

Figure 10. Re-engineered toilets are able to compress function-based rungs into a single step. As part of the WASH strategy, solutions will be required for greywater management and hygiene behaviour.

The SASTEP is an initiative funded by the *Department of Science and Innovation* (DSI) and BMGF, with the WRC serving as the programme implementor that aims to facilitate testing, provide policy guidance and create marketplace for re-engineered toilets that offer opportunity for resource recovery. While innovative toilets developed through BMGF are being introduced and field-tested, there is an opportunity for the WRC to develop local technologies. The purpose will be to grow the research and scientific community into developing solutions tailored for the South African environment while also initiating a market for South African based innovations that could be channelled through the SASTEP.

Recognising the health and economic benefits of hygienic sanitation and the need to stimulate local innovation, the WRC launched its own localised Re-Engineered Toilet Programme – SMARTSAN (S*mart Sanitation*) – in 2020/21. The programme aims to introduce and catalyse local RDI in new treatment processes to sanitation, such as liquid/solid separation, hydrothermal carbonisation, incineration and electrochemical treatment. The introduction of these processes is aimed at treating human excreta at point-of-source thereby eliminating sewers and to completely or significantly reduce environmental pollutants and sludge accumulation.

Through the complementary WRC-led SASTEP, technologies developed through the SMARTSAN will be supported through evidence-based research for technology adoption, market infiltration policy and regulatory enablers and commercialisation opportunities.

SMARTSAN will provide a localised technology pipeline for SASTEP that aims to stimulate a local sanitation industry based on manufacturing and services that would increase access to improved sanitation, reduce pollution, improve water security, create jobs and entrepreneurial opportunities and contribute to the country's *Gross Domestic Product* (GDP) (**Figure 11**). SASTEP is aligned to the *Department of Trade & Industry* (DTI) *Industrial Policy Action Plan* (IPAP) strategy to address commercialisation, localisation and manufacturing by bringing on board capable commercial partners to provide an industrial support base for the local and regional markets. The intent of the SASTEP programme is to support and accelerate the application and uptake of the new sanitation technologies through evidence-based policy adjustments, demonstration, testing and science-based improvements towards localisation and industrialisation. Innovative sanitation technologies and solutions that can be further developed, piloted and commercialised will be assisted with further development (if required), followed by rigorous field testing and demonstration to evaluate end-user acceptance and commercial viability of the technology. Technologies that are successfully field-tested are matched with appropriate funding mechanisms to commercialise and take the final product to market. Through these interconnected programmes, a revolutionary concept or innovation developed in SMARTSAN will be supported along the innovation value chain to become disruptive.

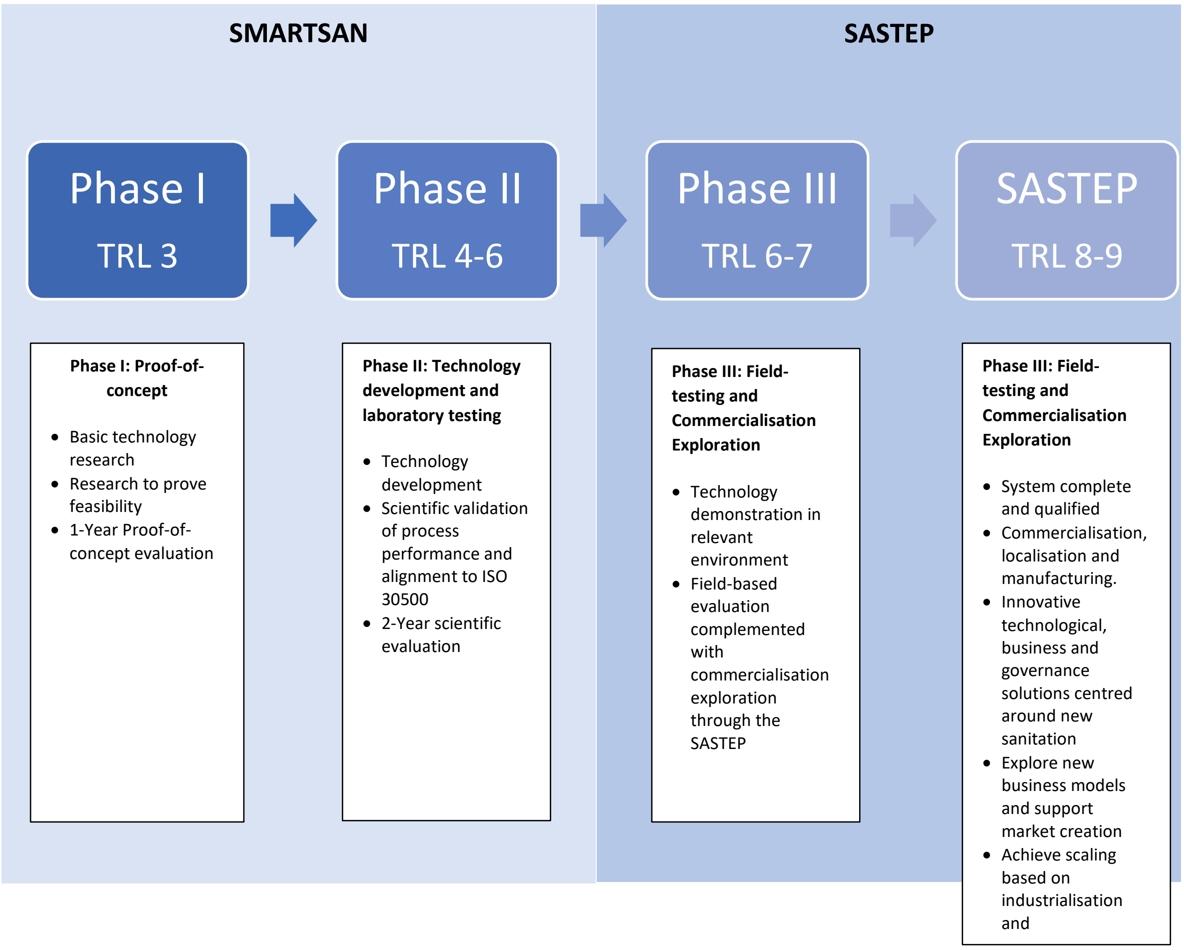

Figure 11. SMARTSAN pipeline into SASTEP. SMARTSAN aims to catalyse innovation while SASTEP provides the commercialisation and industrialisation platform

The WRC has a history of stimulating research funding into promising sanitation solutions. The earliest project was the WRC low / pour flush. In 2009, the WRC commissioned a study investigating the feasibility of adapting the pour flush technology to the South African context. A prototype was developed which could be flushed with as little as one litre of water (with toilet paper as cleansing material; if newspaper is used then a second flush is needed) and the first units were installed in the field in September 2010. A further 20 units were installed in 2011 and have been in use since. A low flush adaptation was then developed and successfully tested in schools near Durban. User responses were very positive, and blockages were rare. This successful R&D exercise demonstrated that contrary to the general preconception, pour flush actually could work in Africa, and work well.

Following the initial work, further installations were carried out, bringing the total number of demonstration pour flush toilets to above 1 000, 300 of which were built in 2015 or before (**Figure 12**). In addition to the demonstration pour flush toilets, the technology has seen additional growth elsewhere through the promotion efforts of public and private institutions and organisations. Thus, as of 2018, the total number of pour flush toilets in South Africa exceeded 16 000.

Figure 12. WRC seed funding for development, piloting and demonstration allowed for confidence in implementation as demonstrated by the sources of funding for pour flush installation.

The pour flush uptake in South Africa has increased exponentially in the last 8 years and that this increase in pour flush toilets is accompanied by positive user experiences in general. The increase in pour flush uptake has been due, in large part, to marketing efforts by manufacturers of pour flush toilets. While initial pilot projects had positive feedback from most users, many of them have not yet led to widespread municipal adoption, which is likely due to a lack of knowledge and knowledge sharing among municipal officials. Over the course of 8 years, pour flush toilets in South Africa have gone from ideation to prototyping, piloting, commercialisation, and large-scale implementation.

An assessment of pour flush technology in South Africa was commissioned by the WRC in 2018 (Neethling, Kubheka, Majozi, & Still, 2020). This study demonstrated the general positive experiences of users across locations, with the greatest negative experiences being associated with extreme water shortages and inconvenience. To make pour flush toilets more accepted among rural householders, convenience should be improved, particularly with getting water to the toilet for flushing. This was by far the most common feedback received in this study. This study has presented some alternatives to carrying buckets of water to the toilet each time while also continuing to avoid creating a direct water connection between cistern and toilet pedestal.

Overall, pour flush toilets are currently the most likely opponent to VIP toilets in the rural sanitation landscape in South Africa. The addition of another viable technology option is a positive advancement, as it will allow municipalities and householders greater agency when implementing projects. This does, however, also require more critical thinking on the side of municipal decisionmakers, since VIP toilets have for so long been the accepted standard. Though the pour flush technology has successfully been demonstrated, it is clear that there is still a long way to go in educating municipal officials about its potential and ensuring that standards and specifications enable wider spread implementation of pour flush toilets.

In 2019, WRC Research Report No. 2735 demonstrated the potential for acceptance of the introduction of urinals for girls and women in school and public toilets in South Africa. Though the concept is relatively new and unknown, it is clear that there are existing problems which female urinals can effectively solve. Poor situations in school and public toilets do not keep girls and women from using them, and thus improved options are likely to be used. Field trials with a wall-mounted urinal demonstrated that as long as urinals are kept clean; adequate education is provided; and privacy is provided, adoption and acceptance of the technology in schools is likely. Not only should female urinals be seen as a way to increase the number of toilet seats in a school, but they should be considered as a way to improve girls' experience with using the toilet at schools. This study highlighted that girls would prefer to use urinals if they were available at school, mostly due to their cleanliness and improved hygiene. Providing girls with an alternative to sitting on a dirty seat over a deep pit of sludge should be given priority. If urinals are provided for girls, girls will be forced much less frequently to use pit or full-flush toilets, which at schools, often put their health and safety at risk.

In 2021, WRC Research Report 2892 developed a prototype waterless fertiliser-producing urinal. Waterless urinals offer an excellent method for separating urine and are well suited for office blocks because they do not require water for flushing, can reduce operating costs for buildings, water utilities can offer building owners fee discounts and because they can provide novel nutrient recovery opportunities. The innovation makes use of calcium hydroxide as a cost-effective stabilization method to prevent the degradation of urea. An internal mixing mechanism is able to maintain a high pH (>12) and thus prevent urea hydrolysis. The mechanism can be operated both mechanically (spring-operated) or electrically, but the spring-operated mechanism will likely be easier to implement since it does not require a source of electrical power. The incorporation of membranes allowed the process to concentrate stabilised urine.

3.1.2 Sanitation sensitive design

In 2018, the WRC commissioned a research project – K5/2813 – that aimed to catalyse the establishment of a *Brown Drop* certification programme for on-site sanitation systems based on a national *Shit Flow Diagrams* (SFDs), a tool developed that provides easily visualised graphic of how faecal waste is managed through the sanitation supply chain. Eight (8) SFD reports were produced through the research project had showed the benefit of the tool in sanitation planning and developing a holistic plan that includes wastewater and on-site sanitation technologies. The results from that study showed the value of SFDs in assisting sanitation planning and management strategies and the associated reduction in health and environmental risks. Further findings, specific to the South African SFD study, was the need to move beyond identifying the municipal SFD status and provide input for closing the service gap and developing and implementing a remedial action plan. In 2020/2021, the WRC launched a National SFD Programme. The SFD Programme will focus on developing and implementing a strategy – SFD South Africa (SFD SA) – to facilitate the uptake of SFDs as regulatory tool with a focus of developing, building and stimulating a knowledge unit to facilitate skills uptake and knowledge transfer of SFDs nationally. The process will involve understanding the methodological approach to SFD development and provide necessary skills and tools to students / regulators / municipal officials to develop SFDs.

3.1.3 Municipal sludge valorisation

This programme has been set-up to combine sludge management from municipal sewered and non-sewered systems. Previously, the sewered and non-sewered research programmes were in separate programmes. This programme has been developed based on stakeholder engagement.

The previous research experience has shown that there is a need for circular economy principles to be applied in sludge management. Disposal of sludges has become concern for municipalities due to various logistical challenges associated with current recommended practices. The conversion of sludge into value-add products offers the opportunity for additional revenue streams and is line with global research trends.

Circular Economy is a sustainable model of production and consumption and comprises of a collection of strategies: reducing, reusing, sharing, leasing, repairing, refurbishing and recycling existing materials and products (News European Parliament, 2015) for as long as possible, thereby extending the life cycle of products which results in reshaping the global economy to eliminate waste (Kunzig, 2020). When a product reaches the end of its life, its materials are kept within the economy wherever possible and can be productively used repeatedly, creating further value. The circular economy model contrasts the "traditional linear model" which involves a take-make-consume-throw away pattern (News European Parliament, 2015).

Applying circular economy principles can protect and actively improve the environment by avoiding the use of non-renewable resources and conserving or elevating renewable resources. Circular economy shows the potential applications for sanitation by providing numerous opportunities for multiple circular flows through recovering valuable resources and providing an additional income stream and reducing the sanitation service cost to the user (creating incentive and stimulating sustainable sanitation) (Moya, Sakrabani, & Parker, 2019).

Waste, in the form of "Toilet resources", presents a major part of the bio-cycle that is unused and handled separately from other resources. Converting toilet waste into valuable resources generate economic value that can be used to equip and sustain sanitation facilities and has social and environmental benefits (reducing pollution and providing green energy). (Toilet Board Coalition, 2016). This approach also increases health and hygiene among communities due to the safe removal and treatment of toilet resources. Toilet resources include water, energy, nutrient recovery and the creation of products.

Many businesses have adopted the circular economy approach as a shift from the wasteful, linear models. The strategy has become integrated in the planning of many countries. Vitens, the largest drinking water company in the Netherlands, are creating innovative approaches to ensure safe and sustainable drinking water to the country. A new City Hall was constructed in Venlo, Netherlands, in alignment with cradle-to-cradle principles (Circle Economy, n.d.).

Since 2006, *Sustainable Organic Integrated Livelihoods* (SOIL) has been transforming toilet wastes into rich, organic compost (containing: Carbon, Nitrogen, Phosphorous and Potassium) as a natural resource for Haiti, returning nutrients back into Haiti's badly- depleted soil, creating opportunities in under-resourced communities (SOIL, n.d.), and preventing unsafe dumping of waste which can lead to infectious diseases. SOIL provides its customers with urine-diverting toilets, collects faeces and transforms it into compost. Toilet customers add cover materials in the form of sugar cane bagasse or peanut husks to obtain optimal carbon and nitrogen ratios for composting. The faecal waste is then emptied into a large composting bin at a waste treatment facility where it is treated. Temperature, moisture, pH and *E.coli* concentrations are monitored throughout the composting process. The process is compliant with WHO standards for thermophilic composting and produces a safe final product which SOIL then sells to NGOs (Moya, Sakrabani, & Parker, 2019).

Sanergy, a social enterprise, provides safe sanitation in urban slums of Nairobi through shared dry toilets, since 2011. Faecal waste is collected and emptied into a mixing tank at a waste treatment facility, where organic wastes are added. After the mixing, the material is laid out in windows and monitored for temperature, moisture, pH, CO_2, pathogen concentration and germination tests. The resulting compost is sieved, bagged and sold for agricultural use once it meets the WHO guideline standards. Sanergy fertilizer sales include vegetable growers, who receive a good return on investment from using the fertilizer (Moya, Sakrabani, & Parker, 2019).

The *Integrated Waste Management Facility* (IWMF) in Singapore, aims to negate the need for landfill and create renewable, carbon-neutral energy for the majority of the population (Gulati, 2020) with benefits including optimal land usage, maximum energy and resource recovery, minimising environmental impact and creating IWMF-TWRP (Tuas Water Reclamation Plant) co-location synergies (National Environment Agency, 2020).

Loowatt, based in Antananarivo, Madagascar embraces the circular economy approach with their Loowatt's waterless toilet. The Loowatt toilet uses human waste to produce biogas (a renewable carbon-neutral source of energy) which can be used for local electricity generation. This toilet addresses water scarcity while providing an improved form of sanitation. (Gulati, 2020). Loowatt has served millions of people with waterless flush toilets from the U.K to Madagascar. Due to 60% of the world's faecal sludge disposed of unsafely, the Loowatt waste management system considers the entire end-to-end process, with environmental sustainability at its core. "Simply put- Loowatt turns waste into energy. Poo into power". Once the Loowatt toilet is flushed, waste is stored in containers, collected and emptied into anaerobic digesters or transported to processing plants to generate electricity, cooking gas and organic fertilizer (Loowatt, 2021).

A multi-case study was conducted with the efforts to enable circular economy for sanitation in India. The case studies were identified through the *Sustainable Sanitation Alliance* (SuSanA). The aim of the project was to study the outcomes of different approaches to the circular economy for sanitation in Devanahalli, Dharwad, Nashik and Hyderabad (India) (Mallory, et al., 2020).

- Devanahalli: a small town with a population of 30 000. A *Faecal Sludge Treatment Plant* (FSTP) was designed and put into effect to treat faecal sludge from pit emptiers, where biogas was produced, stabilised and dried. The faecal sludge was then mixed with municipal solid waste for co-composting to produce and sell.
- Dharwad: a city located in North-Western India, with an estimated population of 2.02 million. Direct disposal of faecal sludge by pit emptiers at farms to the surrounding areas for agriculture, where an entrepreneur began accepting, drying and selling faecal sludge at his farm (health risk).
- Nashik: a city located in Western India with an estimated population of 1.63 million. In 2015, a waste-to-energy plant was built to treat and recycle faecal sludge and municipal solid waste (Combination of FS and organic waste) for the production of biogas and compost.
- Hyderabad: a city located in Southern India with a population of 7.33 million people. Sewage treatment plants were constructed, to prevent pollution from entering the Musi River. The sewage treatment process produces biogas for internal electricity generation while returning treated water back into the Musi River. Compost is then produced and sold to farmers.
- Puducherry: a union territory of India with an estimated population of 274 000. Container-based sanitation systems were implemented by Sanitation First (a non-profit-organisation). This sanitation system involves the separation of urine and excreta. The urine and excreta are then collected separately and converted into liquid fertiliser and soil conditioners, respectively.

Each of the case studies showed a diverse cross-section of wastes used (sewage, faecal sludge, municipal solid waste, separated excreta and urine, raw sludge) and had to work towards overcoming a variety of factors affecting decreased productivity and effectiveness of the circular sanitation economy (Mallory, et al., 2020). These include:

- A lack of enforcement of collection of waste, transport and separation of waste led to sites struggling to obtain sufficient waste for full operation, particularly those that relied on desludging trucks transporting waste to the sites.
- Another difficulty was that solid waste contained plastic that would need a large amount of effort and time separating. This was true for Nashik and Devanahalli. Hyderabad faced the difficulty of too much sewage entering the treatment facility with a lower waste capacity, leaving the excess waste to be discharged into lakes or the dry beds of the Musi River.
- Policies and subsidies have a direct impact on the success of the circular economy for sanitation. In Hyderabad, Nashik and Devanahalli, municipalities actively participated in the coordination, funding and implementation of new Circular Economy treatment plants, however, the Nashik treatment plant took 11 years to construct (due to poor management), while Hyderabad and Devanahalli Circular Economy treatment plants were built within 2 years (Mallory, et al., 2020). Subsidies for organic fertilisers are not readily available to all organisations. Sanitation First were not able to access the subsidy as it is limited to city-scale manufacturing plants and existing fertiliser companies.
- A better perception of human waste-derived fertilisers can be increased through testing the safety of fertiliser (inactivation of pathogens, such as E.coli and Salmonella) by private or government laboratories. A lack of accessibility to laboratory testing or if pathogens are detected in the fertiliser, may lead to halting production until the process could be improved (Nashik).

As identified through the stakeholder consultation, the political and legislative barriers are needed to overcome before circular economy principles can be scaled. The new Thrust and Programmes are aimed to provide scientific support towards this strategy. Some key areas identified include (Toilet Board Coalition, 2016):

1. Inactivation and removal of pathogens and other contaminants: businesses participating in circular economy in sanitation need assurance of the elimination of pathogens, in products, to safe levels and certified for safe usage for consumers and environments. Laboratories are not always available to test for pathogens in products, therefore, it cannot be guaranteed that pathogens are eliminated. National regulations for the development of agreed standards and certifications are limited. Other contaminants also need to be managed, such as the removal of pharmaceuticals present in toilet resources and parasites present in the treatment systems. Quality assurance needs to be established to solve disease cycles as well as developing partnerships to use and develop safer ingredients, to avoid the accumulation of unregulated chemicals.

2. There are also negative perceptions from consumers derived from using human excreta that need to be managed carefully by participating companies.

3. Another barrier to the circular economy in sanitation is malodour associated with toilet use and sanitation-based businesses. Malodour needs to be effectively managed and allow for proper ventilation infrastructures.

4. A major challenge in sanitation is security and quality of supply. Investments are required for providing correct toilet hardware and efficient and reliable collection systems to ensure appropriate quality and volume of waste is extracted.

5. New technological advancements for the circular economy in sanitation have little information for their requirements for maintenance affecting case projections, pricing and maintenance costs.

6. The economics at scale for product improvements for businesses in the current market offerings need to be explored further for the effect on circular economy in sanitation.

7. The existing Linear model of “take-make-consume-throw” may impede new processes and technologies in the circular economy model. A change in process will have various forms of resistance that needs to be overcome. Established systems, such as existing waste resource charges, fertiliser subsidies and local food supply chain charges can face resistance to change. Circular model systems should be built to enhance operations and economics.

8. The circular economy approach has a wider impact on health improvements but this impact does not directly create revenue streams and therefore need other mechanisms (such as service fees) to create the missing revenue streams.

In order to shift from a wasteful linear economy to a more sustainable circular economy, we need to change our mindsets to realise the potential of a circular economy. A circular economy should be the focus and centre of all policymaker’s minds regardless of the development status of a country (Ellen MacArthur Foundation, 2015). A circular economy rebuilds the overall system health. The circular economy concept recognises the importance of the economy needing to work effectively at all scales – for large and small businesses, for organisations and individuals, globally and locally (Ellen MacArthur Foundation, 2017b). A circular economy will also help end the sanitation crisis by reducing the amount of wasted water, recycling human waste and creating valuable products for the industrial and agricultural sectors. A transition to a circular economy reduces the negative impacts created by a linear economy and builds a shift to bring about long-term resilience, generate business and economic opportunities and provides social and environmental benefits (Ellen MacArthur Foundation, 2017b). As the world’s population keeps growing so do the demands for raw materials. The circular economy is achieving rapid awareness and adoption by businesses and political leaders as they are realising that economic and population growth are depleting resources and producing “waste” at levels that cannot be sustained.

The WRC has produced significant research outputs in this regard. In 2012, the WRC commission a study to optimise the *Latrine Dehydration Pasteurisation* (LaDePa) innovation (Mirara, Singh, Septien, Velkushanova, & Buckley, 2018). The innovation was co-developed by Particle Separation System and the eThekwini Municipality in response to logistical challenges associated with faecal sludge disposal. This machine is used to process the faecal sludge that was removed from latrines into dry and pasteurised pellets, which can be used as a soil conditioner or fertiliser, or which could be combusted as a fuel. In the developed technology, the pellets are pasteurised and dried using a combination convective and infrared radiation heating. The drying and pasteurisation of faecal sludge would allow for on-site disposal of treated faecal sludge through the mobile treatment plant. The research undertaken was proven to be novel as at that time, there was little scientific information available on the thermal drying of faecal sludge and its applications.

In 2018, the WRC commissioned a study that explored the production of bricks from urine. The project aimed to produce valuable products in the form of building material using a product that would ultimately be flushed down the toilet. The source of the urine was men’s urinals which were collected and processed. The bio-brick production relies on *Microbiological Induced Calcium Carbonate Precipitation* (MICP) using urine as feed material to bacteria induces calcium carbonate precipitation. When this injected into a column of masonry sand, the precipitate acts as a cementation media and fills the pores between the sand to form a bio-brick.

While this process has been tested overseas, the project was initiated to evaluate whether this process could be replicated in South Africa, build localised scientific capability for urine treatment, and determine whether the product developed. Bio-bricks have been produced through the research. As part of the process of evaluating the business model, production costs of bio-bricks from urine were established.

In 2013, the WRC awarded Water for People Uganda a research grant to develop innovative tools and technologies for the emptying and beneficiation of pit latrine sludge. The project was part of SRFA Programme mentioned earlier. From the research project, various products were developed and scientifically evaluated across the sanitation value chain, including improved toilet systems, novel pit emptying technologies and innovative sludge beneficiation systems. From the research, two sludge beneficiation systems have been scaled up in Uganda. The process involves the dewatering and drying of sludge and its subsequent conversion into biochar briquettes – a charcoal substitute. The dried sludge is then mixed with molasses and carbonised in kilns to make charcoal briquettes (**Figure 13**). The pilot funded by the WRC enabled Water for People to test the approach, optimise operations and build the business case based on outputs. From the research, two plants were constructed.

Figure 13. Briquettes made from collected and processed faecal sludge in Uganda.

WRC Research Project No. 2586/1/20 examined the treatment and reuse potential of urine and faecal fractions from urine diversion dehydrating toilets in eThekwini Municipality (Olaniran, et al., 2020). At the time, the municipality was exploring the valorisation of urine into phosphate struvite, a fertiliser. One of the key research gaps identified was possibility that urine contamination could be occurring. The research investigated this aspect and found that there were indeed pathogens surviving the struvite production process and that the source of contamination was probably due to incorrect toilet usage as the pathogens were of faecal origin. The research optimised struvite production from urine and processing temperatures required to sterilise the struvite product. The second component of the study was to collect the faeces from UDDTs and evaluate whether *Black Solider Fly* (BSF) technology (*Hermetia illucens*) could be used to treat the faecal sludge. The fly is not a pest or a vector for disease and prefers decomposing organic waste in which a female lays her eggs. The eggs hatch into larvae and consume the decomposing organic waste. As the larvae reaches the pre-pupae development stage, they are rich in protein and lipid and crawl out of the food source to seek dry place to develop into flies. These protein larvae could then be cleaned, harvested, dried and processed to be used as feed for poultry or fish. The research showed that BSF larvae can grow on collected faeces from UDDTs and that the process can significantly reduce the pathogen load in faeces. BSF technology therefore has the potential to reduce of disposing of sludge in a safe and acceptable manner. In eThekwini Municipality, a demonstration plant has been established to test this approach by a local engineering firm with palm oil derivatives produced during an earlier trial. Further research is required to optimise the process to make operations more efficient, specifically on the production of oils from harvested larvae.

Current research includes the development of the Faecal Sludge Management Disposal and /or Beneficiation guidelines to complement the Wastewater Sludge Guidelines and Hydrothermal Polymerisation of sewered and non-sewered sludge sources. The WRC also initiated research into undertaking the various products that be derived from sanitation waste and establishing the market demand and standards for competing products.

3.1.4 SANIBUS

The introduction of business approaches as part of sanitation service provision can alleviate many of planning and operational associated with O&M. This section provides some highlights of projects that contributed to this area.

In 2014, the WRC sought to understand why school sanitation was failing with focus on rural areas which are served by pit toilets. This was in response to an unfortunate incident involving a child drowning in a school latrine; an incident that has again occurred in 2018. The study showed infrastructure provision not accompanied by an adequate management programme resulted in failure, even if that infrastructure was relatively new. One of the challenges that a principal has to do is to use his / her budget to provide the necessary tools for educating children. Within this budget, a portion needs to be used keep toilet facilities hygienic. However, this is not ringfenced. A School Sanitation Management Model was subsequently developed and provided for necessary training manuals and cleaning protocols which could be used to empower the principal to use a portion of his / her existing budget to keep toilet facilities hygienic.

Through the WRC funding, a pilot programme was tested using the new management model in 8 different schools under the jurisdiction of the KwaZulu-Natal Education Department which recognised the potential of new management model. In each school, the following were assigned: A Health & Safety Officer who was the school cleaner, a Health & Safety Manager who served as a staff member, and the principal who oversees all aspects of the school life. Training was provided for the Health & Safety Officer to ensure that they are adequately equipped and protected during their duties and have enough tools and supplies to the job. Consumables such as toilet paper, pads and liquid hand soap were budgeted for monthly supply in the beginning of the programme to ensure that learners' hygiene is protected. A cleaning protocol was established to ensure that the toilets are clean and free of disease transmission potential on a daily basis. The protocol recommended that the toilets are cleaned 3-times per day with focus being put on areas that are considered gems "hotspots". The programme also encouraged schools to come up with creative ways to engage learners in the monitoring of their toilets and how disease transmission occurs. The programme has been relatively successful with Unilever funding the extension of the model to 150 schools based in KZN and Northern Cape and serving over 100 000 learners.

The Social Franchising concept burrowed from the business sector has also shown to multiple benefits. The WRC with partners funded the concept from ideation to demonstration-scale. Franchising of the

O&M services was seen as way in which the quality of the water services could be consistent and guaranteed. At the same time, franchising would support the development of local micro-enterprises and broad based black economic empowerment within public service delivery area. Through the partnerships, it was envisaged that infrastructure owners would be access the higher level of expertise required for O&M which is lacking in remote areas. Moreover, locally based service provider solutions could be created or encouraged through micro-enterprises. For the pilot, Amanz'abuntu Services set up a subsidiary, Impilo Yabantu ("Water for People" in Xhosa) Services, to facilitate the training of local franchisors in the Butterworth Education District, Eastern Cape. Locals close to home base of each franchisee were recruited and trained. The trainee franchisors met with district staff and principals to establish a schedule and to allocate a service area that was in close proximity to trainee franchisors home base.

The trainee franchisors were supplied with basic cleaning equipment, a light delivery vehicle demarcated with the Impilo Yabantu logo and a digital camera to visually assess the effect of maintenance services on school toilets. Each franchise did an inspection of the facilities and reported back to the DoE managers on status of facilities and subsequently, the repair and maintenance costs for listed items agreed upon. This process enabled on-going service relationships to be developed. Through the pilot, around 400 schools in the Butterworth District benefitted from the franchise operations. The improvement of sanitation facilities with the pilot area has been so successful that the DoE has requested that the programme be extended to a further 3 districts housing 1 000 schools.

Through the partnership of the African Development Bank, the concept was demonstrated in the in East London, Eastern Cape. The East London project supported the cleaning and maintenance of school ablution facilities of the ECDOE, support hygiene initiatives including menstrual health management in schools, and beneficiate collected sludge from latrine toilets into bio-char; a charcoal substitute.

Current research being undertaken looks at private sector investment in O&M and determining the quality and quantity of valorised products that could be produced through new sanitation approaches and linking this to industrial and commercial standards.

4. KEY DRIVERS FOR A NEW SANITATION PARADIGM

4.1. Partnership and leadership

Many of the programmes initiated at a pilot and demonstration-scale have been achieved through partnerships with municipalities, DSI and international donors, such the BMGF and the African Development Bank. It is only through these pilots and demonstration that the operational requirements for a specific area are elucidated. This is accompanied by scientific monitoring and evaluation to optimise efficiencies and effectiveness of the solution to be scaled. Ring-fencing of a budget for new innovative solutions (5-10%) by key stakeholders could offer improved benefits over the long-term as shown by other partnerships.

4.2 Policy and regulatory enablers

New innovative technologies often encounter policy and regulatory barriers that prevent their implementation. The slow issuing of **Water Use Licence** (WULA), for example, can set back municipalities in their plans to deliver sustainable solutions. In areas outside the sewered boundary and which are densified, DEWATS, for example, can provide an appropriate solution provided the system managed well. However, some of these barriers prevent uptake of novel technology with municipalities unwilling to place latrines instead due to their O&M expenses.

Many municipal water engineers have requested the following:

1) Make the reuse of wastewater-to-tap a national policy. A national decision would allow municipalities to explore this option as part of a water management strategy. At the moment, municipalities have to go through lengthy consultative processes which delays planned interventions.
2) Make a national decision to reduce flushing potable water and recycle greywater flushing and have this driven through the NBR. This would allow the penetration of low flush toilets and household recycling system. Further, it will enable government to regulate (through SABS) products which cannot be done when not in place and users take unregulated measures during water restrictions.
3) Ring-fence budget for innovation.
4) A further recommendation by authors is to have a singular Circular Economy policy that encompasses Water, Energy and Food and cuts across regulatory departments.

To formalise the understanding of these enablers and barriers, the WRC has initiated projects that will delve into these issues. The projects are being undertaken through KSA3 and the SASTEP Programme.

4.3 De-risk piloting of solutions

A significant reason for the lack of technology uptake is risk-aversion even if the current option is not sustainable. To de-risk pilot solutions, assets could be zero-rated and risk mitigation plans included as part of the budget in case decommissioning is required.

4.4 Planning and management

Infrastructure and management cannot be separated. The WRC has developed several planning and management aimed at optimising operations. These products have been tested for the Blue & Green Drop programmes (WAP and W2RAP), rural household and school sanitation, SFDs and infrastructure audits (using ICT and GIS mapping). A budget could be ring-fenced to test these solutions, optimise for operations and incorporate as part of KPIs.

4.5 Monitoring and evaluation

Continuous and reliable data capturing is necessary to gauge the outcomes of interventions and is key for planning and management. Numerous data capture tools have been developed by WRC to meet this need and has been piloted.

4.6 Community engagement and education

As evidence highlighted in this paper has shown, the lack of consultation has financial consequences. Evidence has shown that infrastructure can deteriorate beyond normal O&M requirements in a matter of 5 years without community consultation and agreement.

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