A TECHNOLOGICAL AND ECONOMIC EXPLORATION OF PHOSPHATE RECOVERY FROM CENTRALISED SEWAGE TREATMENT IN A TRANSITIONING ECONOMY CONTEXT

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Phosphate is one of the substances which waste water treatment works (WWTW) have to lower to concentrations below regulatory levels. More recently, there has been a global shift towards treating waste water as a "water-carried waste", presenting opportunities for nutrient recovery. South Africa has commenced its tranistion to a low carbon and resource-efficient economy, all whilst it battles to provide universal access to basic sanitation needs and is faced with massive infrastructure maintenance as well as upgrading backlogs in the sanitation sector. Although phopshate recovery methods exist, there is little evidence to indicate that these techniques would be economically viable or socially accepted in South Africa.

This paper explores the the potential for centralized recovery of nutrients, through the conceptual design and techno-economic pre-feasibility assessment of two phosphate recovery options, at the largest WWTW in the Western Cape, South Africa. This assessment revealed that the digestate stream at the 200 ML/day Cape Flats WWTW (CFWWTW) has the potential to produce ~470 kg/d of struvite fertilizer, only recovering 4-8% of the plant costs in 20 years. When contrasted with the more familiar, yet less sustainable chemical precipiation process, low-grade and high-grade struvite production establishment costs are 10 and 25 times higher, respectively. Still, to reduce effluent phosphate loading to within regulated standards, the low-grade struvite production option at an estimated net present cost of R25,4 million over a 20 year life time is much more affordable than chemical precipitation at a net present cost of R51,2 million.

Low-grade struvite production is thus concluded to be the most ecologically and economically sustainable option from a life-cycle-costs perspective. Although it is a simple process, it is not cheap. Municipalities will have to consider the lower operating costs, as well as the environmental benefit of producing a useful phosphate fertilizer over the immediate capital investment.

Keywords: Nutrient Recovery; Struvite; Techno-economic assessement

Topic: Sustainable waste water management

INTRODUCTION

Wastewater is increasingly viewed as a "water-carried waste", presenting opportunities for recovery of both nutrients and energy. Amongst the sewage-borne resources, phosphorous is an important, non-substitutable nutrient for all life forms, particularly in the growth of plants, and is therefore essential in ensuring universal food security. Human activities have disturbed the natural phosphorus cycle and remain heavily dependent on mining of non-renewable rock phosphate. It is estimated that 78% to 90% of the global phosphate demand is directly attributed to the production of synthetic fertilizers and livestock feed additives in the agriculture industry (Liu et al., 2008; Kalmykova et al., 2012).

In tackling the growing global food crisis, it will be important to consider the quality and usefulness of the recovered phosphate product for potential agronomical use (Schröder, et al., 2009). Urine separation and sewage nutrient recovery technologies that yield high quality and useful products are being explored and implemented globally. Due to South Africa's sanitation, economic and agricultural backlogs, it should be in the best interest of the South African society to not only treat the access to sanitation issue as a high priority, but to also consider the employment of such ecologically and economically sustainable sanitation solutions to meet future economic needs.

Technology transfer is difficult across different cultures and geographical boundaries, varying environmental types, and further complicated by health and social risks, and may thus fail to penetrate a new or existing market. Various aspects of societal, environmental and economic effects on technology development have been investigated globally, but mostly as isolated sub-systems. Research by Balkema (2002) and Muga & Mulchelci (2008) show progress towards a more holistic approach to technology sustainability assessments. These frameworks are conceptual and have been applied to existing nutrient recovery case studies, but are yet to be applied in the prefeasibility step of phosphate recovery techniques, yet alone in the South African context. The need for a more holistic approach, which includes both a social and techno-economic assessment of potential technologies, has shaped the aims and methodology of our research on phosphate recovery (Sikosana et al., 2014; Sikosana, 2015).

It was thus an overarching objective of our research to determine whether phosphate recovery technologies are likely to produce a socially acceptable product and what determines their affordability. In this paper we focus on the latter and present the techno-economic analysis of a case study, which demonstrates how a nutrient recovery process could be incorporated into a biological waste water treatment works in South Africa. Links are made to our earlier social acceptability study (Sikosana et.al, 2014), which maps potential market avenues for recovered phosphate - an improtant factor used to determine both pricing and economic viability.

Background

The sludge liquor stream in a biological WWTW with anaerobic digestion has been identified as one of the most promising points for nutrient recovery (Strom, 2006; Bilyk et al., 2011). In the South African context and more specifically in the Western Cape, the 200 ML/day Cape Flats WWTW (CFWWTW) is a good example of a treatment facility in which such a phosphate-enriched stream arises, and forms the basis of this techno-economic analysis.

The Cape Flats WWTW has experienced issues with mineral precipitation (mostly struvite) that has led to the poor performance of the digestate centrifuge, as well as blockages in the pipes leading to the Thermal Drying Plant. Batch dewatering may cause nutrient peaks and instability in secondary processes, hence causing effluent nutrient spikes and spontaneous struvite precipitation (Bilyk et al., 2011). Excess phosphorus in the waste activated sludge (WAS) as well as the loss of CO_2 (which increases pH) along the sludge treatment line are the main causes of struvite precipitation (Van Rensburg et al., n.d.). An additional nutrient sink would recover these excess nutrients and could mitigate blockages in the AD sludge centrifuge and pipeline. Therefore this research explores the technical and economic viability of a globally proven and advanced crystallisation technology at the CFWWTW to address this issue.

MATERIALS AND METHODS

Engineeirng economic assessment methods were used to investigate the potential for centralized recovery of nutrients through the conceptual design and a techno-economic pre-feasibility assessment of two phosphate recovery options at the largest WWTW in the Western Cape, the CFWWTW. Option 1 considers the recovery of high-grade dried struvite crystals, Option 2 is concerned with a lower grade struvite slurry. These options were contrasted with a more traditional chemical precipitation process, a phosphate removal technique commonly practiced in South Africa – Option 3. On visiting the Cape Flats WWTW, significant fluctuations in process operations were observed. Therefore, the process model and techno-economic assessment were based on theoretical plant data and literature values pertaining to the CFWWTW.

This techno-economic assessment consisted of the following steps:

Concept design

Concept designs for three phosphate-focused project interventions were developed to assess the potential for struvite production as a viable side stream treatment option for the CFWWTW. The approach to conceptual design involved:

- Generation of three distinct alternatives, informed by the technology review and analysis of global case studies presented in Sikosana et al. (2014), as well as knowledge of the plant configuration at the CFWWTW;
- Development of process flow diagrams and process summaries;
- Linking the potential products to the market routes identified in the South African based market assessment presented in Sikosana et al. (2014)

Technical assessment (Mass and Energy balances)

Option 1, 2 and 3 (described in more detail in the results section) were then evaluated based on the following key technical criteria, which are summarized in Tables 1 and 2:

- Production rate of solid products (kg/d and kg/year)
- Energy use (kWh/d)
- Chemical consumption rates (kg/d)
- Land requirements (m^2)
- Additional labour requirements (over and above the needs for the existing WWTW)
- Additional maintenance requirements (over and above the needs for the existing WWTW)

Table 1: Design criteria for the technical assessment of all Options

Description	Unit	Value	Comment / Source
CFWWTW Flowrate	ML/day	125	Plant data (average)
Side stream DS %	%	3,5	Plant specifications
Side stream flowrate	m^3/day	1060	Calculated from maximum design capacity of dewatering centrifuge
Side stream pH		4.8	Plant data
Phosphate concentration	mg/L	89-190	Used highest loading (Van Rensburg et al., n.d.)
Magnesium concentration	mg/L	29-67	Used highest loading (Van Rensburg et al., n.d.)
Ammonia concentration	mg/L	In excess	Assumed
Moisture content of filtered struvite	g/g (Water dry Solids)	1.5	Assumed
Temperature		25 °C	Ambient

Table 1: Design criteria for the technical assessment of all Options

Description	Unit	Value	Comment / Source
Option 1 and 2			
Conversion	%	90	(Rahman et al., 2013)
Reaction Kinetics	h^{-1}	7,9	(Rahman et al., 2013) (Ohlinger et al., 2000)
pH		8,7	(Ohlinger et al., 2000)
Option 3			
Molar feed ratio PO_4:Al (orthophosphate: aluminium)	mol:mol	1:1	(Strom, 2006) (Minnesota pollution control agency, 2006) (Lenntech, 2005)
Reactor conversion	mol%	90%	(Strom, 2006); (Minnesota pollution control agency, 2006)
Clarifier effluent DS	%	5	(UNEP, 2001; Bowers, 2011)
Dewatered sludge DS	%	25	(Turovskiy & Mathai, 2006)

Financial assessment

Based on the struvite production rates and chemical input requirements, engineering economic calculations were used to evaluate the financial feasibility of struvite production at the CFWWTW. The economic viability of struvite production was assessed based on the following economic indicators:

- Plant establishment costs: Capital expenditure (CAPEX)
- Operating expenditure (OPEX)
- Cost recovery from struvite production (revenue)
- Net present value/net present costs (NPV/NPC) costs over a 20 year investment period

Comparison of the three options was made based on the NPV/NPC values achieved. The economic assessment criteria used in NPV/NPC calculations for all three options is summarized in Table 2.

Sensitivity analysis

Various assumptions were made for the baseline techno-economic evaluation. Therefore, it was necessary to consider to what extent variations in process parameters would affect these resutls and how best they could be controlled. The impacts of various parameters on the NPV costs and hence feasibility, were tested. The most significant parameters were:

- maintenance costs (as a percentage of CAPEX);
- retail price of struvite fertilizer (Option 1 and 2);
- CAPEX (all options);
- discount rate

These parameters, with the exception of sludge disposal, struvite selling price and discount rate, were varied over a range from -50% to 100% increase and their effect on NPV compared to the base case.

Table 2: Economic assessment criteria for Option 1,2 and 3

Description	Unit	Value	Source/comment
Price of magnesium chloride	R/kg	8.30	Protea Chemicals, 2014
Price of aluminium sulfate	R/kg	1,16	
Price of electricity	R/kWh	1.00	Within range of peak/off-peak charges from COCT for commercial users
Wages	R/h	80.00	Assumed
Water	R/kL	12.51	COCT website
Transport and disposal of solid biosolids	R/kg	0.5	(Sikosana et al., 2014)
Maintenance costs		4%	chemical precipitation (Tetra Tech, 2013)

RESULTS AND DISCUSSION

Technical assessment

Concept design

The CFWWTW anaerobic digester liquor stream has a phosphorus concentration of 89 to 190 mg/L and magnesium (Mg) from 29 to 67 mg/L (Van Rensburg et al., n.d.) as well as a design flowrate of approximately 1060 m^3/day. Table 4 summarizes the design basis and concept design features for all process options. Figure 1, is a process schematice, illustrating a high-grade struvite production facility; Options 2 and 3 were designed as variations of this process.

Table 3: Describes key design features of the three concept designs

	Option 1	Option 2	Option 3
Basis of design	OSTARA installation (OSTARA, 2013)	Multiform Harvest (Bilyk et al., 2011)	Typical installations (Tetra Tech, 2013)
Technology	Crystallisation: Fluidized bed reactor	Crystallisation: Fluidized bed reactor	Chemical ppt: stirred tank reactor
Objective	To recover excess orthophospahte by producing high quality, crystalline struvite for sale in premium markets (potenitally food production)	To recover excess orthophospahte by producing low quality, powdery struvite for sale in low end markets and processing plants	Removal and disposal of excess orthophosphates in process side streams
Process summary	Use of large reactor unit with recycle for high quality crystal formation Struvite is filtered and dried (92 % DS)	Use of smaller (than OSTARA) reactors to produce a low quality struvite slurry No recycling of reactor effluent Collected struvite is (20% DS)	Chemicals dosed to induce precipitation Sludge is dewatered (25% DS)

Unlike the OSTARA process shown in Figure 1 below, the Multiform Harvest process produces a less refined product (20wt% DS), which is collected from the bottom of the reactor in a skip, reftrofitted with a filter. This skip is collected weekly from the WWTW and may be further treated off-site before sale in secondary markets. The conical fluidized bed reactors are typically smaller than the OSTARA installations, with a lower retention time and do not require recirculation pumps. In addition, unlike Option 1, no drying or bagging equipment is required which drastically reduces capital costs.

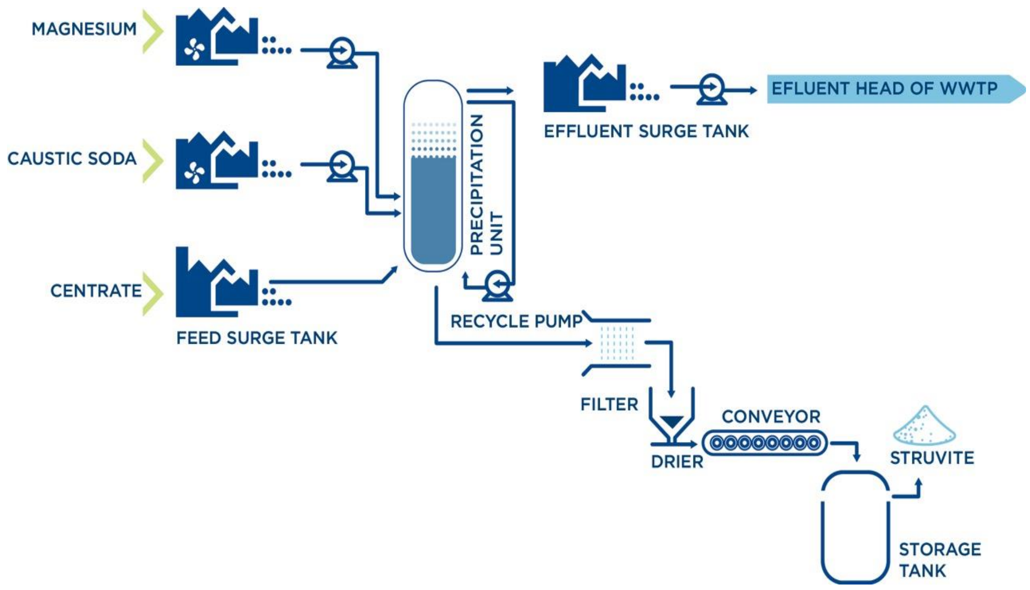

Figure 1: Process description of nutrient recovery facility to form high quality struvite production, which is processed and packaged onsite

Technical assessment summary

At 90% conversion, both Option 1 and Option 2 produce approximately 469 kg/day of struvite (on a dry basis), recovering 58 kg/day of phosphorus. When packaged and dried, this amounts to 510 kg/day (92% DS) high-grade struvite and 568 kg/day (80% DS) low-grade (wet) struvite. Chemical precipitation results in 242 kg/day of chemical sludge (aluminium hydroxide + phosphate) and an additional 25% suspended solids removal (WEF, 2005), to give 601 kg/day of dry sludge. Once mechanically dewatered to 25% dry solids, 2400 kg/day excess sludge is to be disposed of. This is an 0,2 % increase in the overall Cape Flats sludge production. Aluminium solution dosage is about 2630 kg/day, 5 times that of magnesium dosing material required for Option 1 and 2.

Smilar to literature, chemical precipitation had a higher energy footprint, but only slightly, than that of low-grade struvite production. High-grade struvite production carries a significant electrical/carbon footprint, which can not be ignored.

Table 4: Technical summary for Option 1, 2 and 3

	Option1	**Option 2**	**Option 3**
Phosphate recovery %	90	90	90
Orthophosphate kg/day	178	178	178
Struvite (kg/d) (40% DS)	Wet: 1173 Dry: 469	Wet: 1173 Dry: 469	-
Package struivte (kg/d)	(8% DS): 510	(20% DS): 568	-
Excess sludge (kg/d)	-	-	Dry: 601 Wet: 2400
Utilities (kWh/day)	727	204	159
Land requirements (m^2)	325	250	77
Chemical dosing (kg/d)	MgCl: 540	MgCl: 540	Alum: 2630
Employees	2	2	2
Major equipment m^3			
FBR reactor	50,3	50,3 or (2X25)	Flash tank: 7,37
Feed buffer tank	382	382	382

Link to potential markets

Expert interviews were conducted in a preceding study by Sikosana et al. (2014), to assess the acceptability of phosphate fertilizer production from human waste, as well as the potential markets within the South African context. It is believed by the industry experts that the South African organic market and its consumer may not be ready for fertilizers produced from human waste to be used in food production. Better acceptability could be experienced within the inorganic fertilizer production market, regardless of source, if struvite is proven to be safe and a purification process is identified. More feasible markets could lie within ornamental plant fertilization, commercial fertilizer production and fertilizer use within closed community gardens. Therefore, there is potentially a larger market for lower grade struvite. Based on these findings, the possible market avenues for high- and low-grade as well as chemical precipitation products were mapped out in Figure 2 below. These avenues will thus determine and differentiate the market value of these three process products.

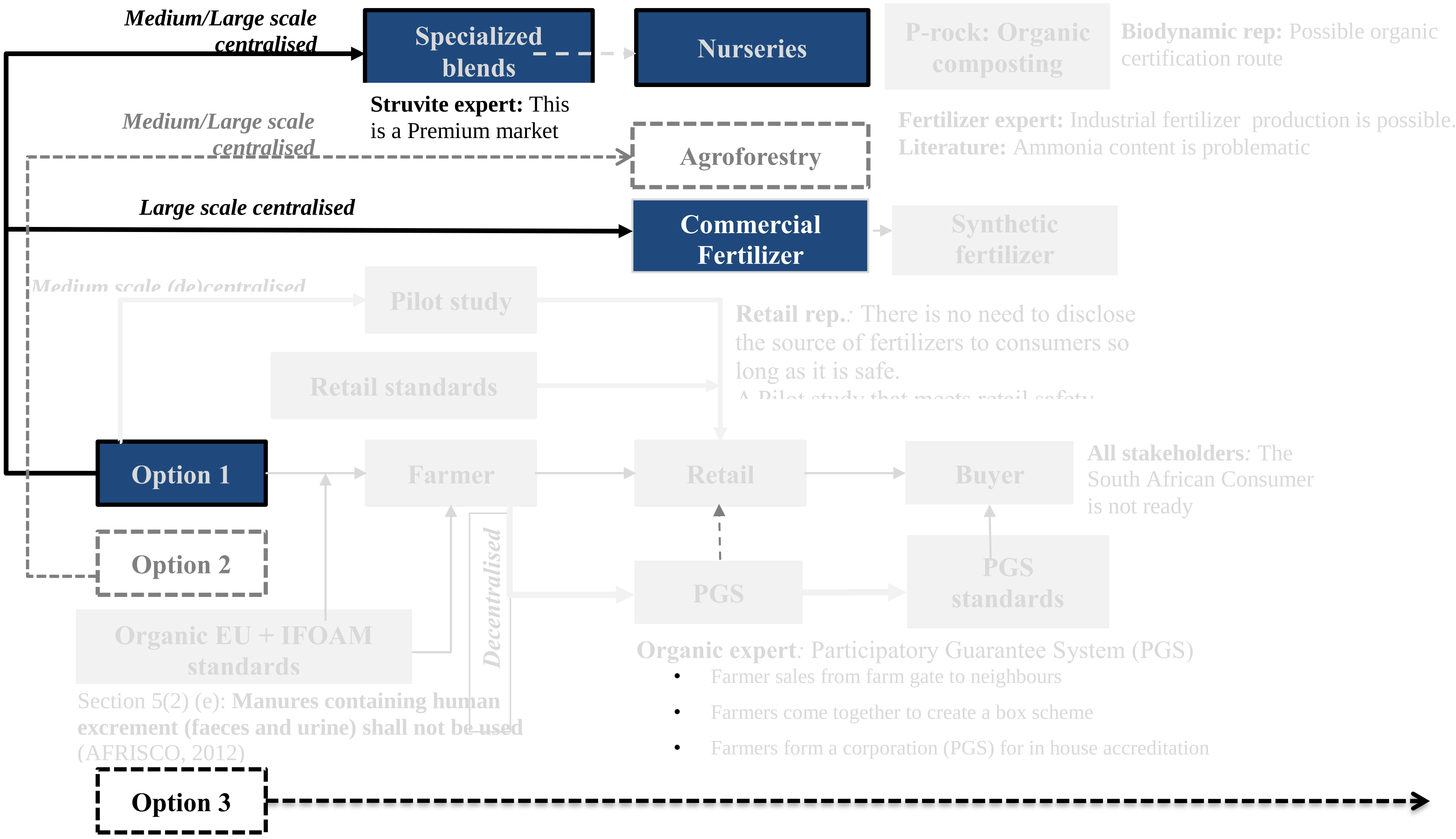

Figure 2: Potential market routes of products from Option 1, 2 and 3, to determine their market value within the South African context.

Economic assessment

At 90% conversion, 470 kg/day of dry struvite can be produced at a cost of R22/kg struvite for high-grade and R8.90/kg struvite for unprocessed fertilizer. This production rate recovers a mere 4.21% and 7.98% of the operating costs for Options 2 and 1 respectively. Chemical precipitation produces 2400 kg/day (25wtd% DS) excess sludge for landfill disposal. Phosphate removal at the CFWWTW will incur additional treatment costs of R0,05, R0,03 and R0,12 per kilo litre to the business-as-usual rate, for Option 1, 2 and 3 respectively. In comparison to recovering water for re-use at a cost of R7,00/kL and sewage costs at R2,90/kL, all options come in cheaper.

The ex ante net present costs are R76,2-, R25,4- and R51,1 million for option 1,2 and 3 respectively. Higher operating costs due to chemical dosing and sludge disposal amplify the net present costs of Option 3. The high flowrate to phosphate loading ratio makes the high capital cost associated with on-site processing of high-grade struvite impractical. Despite the higher market value, low production rates of high quality struvite will not generate enough revenue to recover the cost of production let alone the investment.

Table 5: Summary of Economic assessment for all three options

	Option 1	**Option 2**	**Option 3**
CAPEX	76,5	20,6	2,49
OPEX	3,97	1,51	5,18
Sludge handling R	N/A	N/A	44000
Selling price of struvite R/kg	1,84	0,37	N/A
Revenue	315 000	63 300	0
Cost/kg struvite	22,1	9,01	N/A
Cost/kg PO_4 recovered (removed)	56,6	23,5	86,2
Cost/kg P recovered (removed)	173	72,0	263
Treatment cost/kL (influent)	0,05	0,03	0,12
Net projected costs (R million)	76,2	25,4	51,2

Sensitivity analysis

The base case techno-economic assessment was calculated using approximations, which relied on assumptions, heuristics and literature data. Therefore it is useful to assess the sensitivity of this assessment to changes in key parameters. This will account for uncertainty in the design criteria and assumptions made. In addition, this will identify the main design parameters that could positively affect the feasibility of the proposed options.

Comparing Option 1 and Option 2

Figure 3, shows the effects of a -50% to 100% increase in selling price, CAPEX and related maintenance costs on the NPV for both Option 1 and 2. Changes in Option 1 CAPEX and maintenance drastically influence the NPC. Changes in selling price have very little effect on the overall profitability of the plant in both instances. With the base case design criteria, Option 2 will always have net present costs lower than those of Option 1.

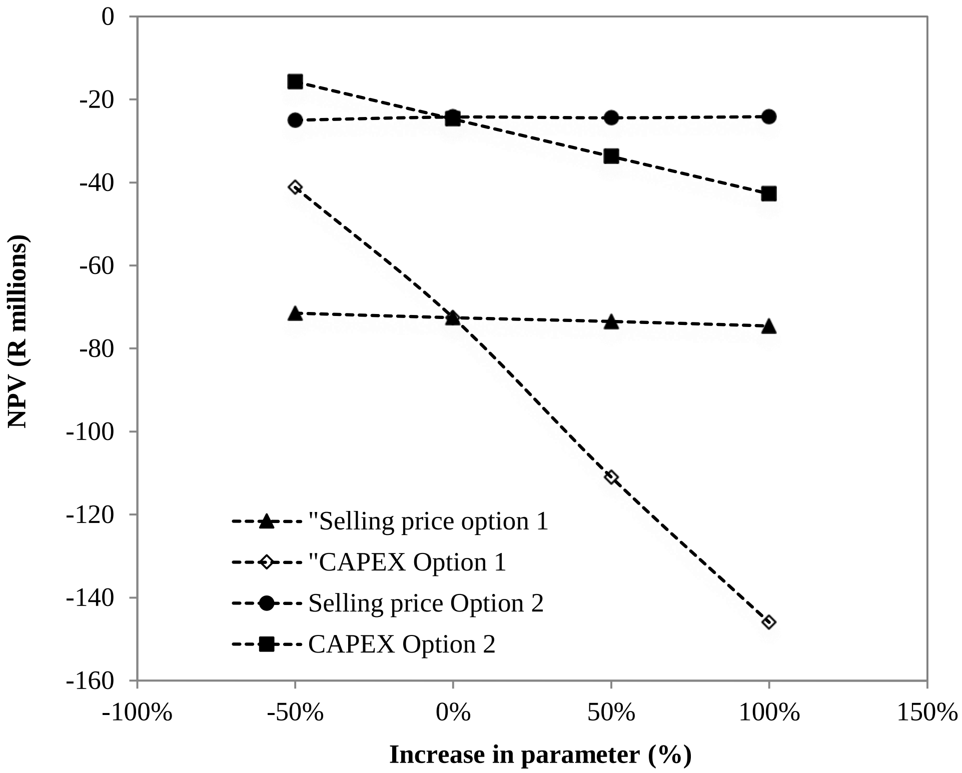

Figure 3: Plot of varying parameters (selling price and CAPEX) to identify key parameters for Option 1 and 2

Best case Option 1 vs. base case Option 2

If the municipality were to consider the production of high-grade struvite over the unprocessed low-grade, key process parameters will have to adjusted to yield an NPV within an acceptable cost bracket. In this case, Option 1's NPV is most affected by CAPEX. If a prefabricated OSTARA Pearl 2000 reactor is used, the NPC may reduce to as low as R48 million. At best the high-grade struvite can sell at the literature value of R6,60/kg struvite, resulting in an NPC of R41,4 million; 1,6 times greater than that of Option 2. To come in even lower at R32,5 million, maintenance can be lowered to the business-as-usual amount of 2%. It is evident that unless the phosphate concentration in this CFWWTW side stream increases, Option 2 will always come in cheaper than Option 1.

Comparing Option 2 and Option 3

Figure 4 compares the effects of Option 2 and 3 NPC with the change in chemical dosing costs and CAPEX. Chemical dosage costs have the highest effect on Option 3s NPC, but has little effect on that of Option 2. However, even with a 50% drop in chemical price, Option 2 is still more affordable than Option 3 as a phosphate removal method at the CFWWTW.

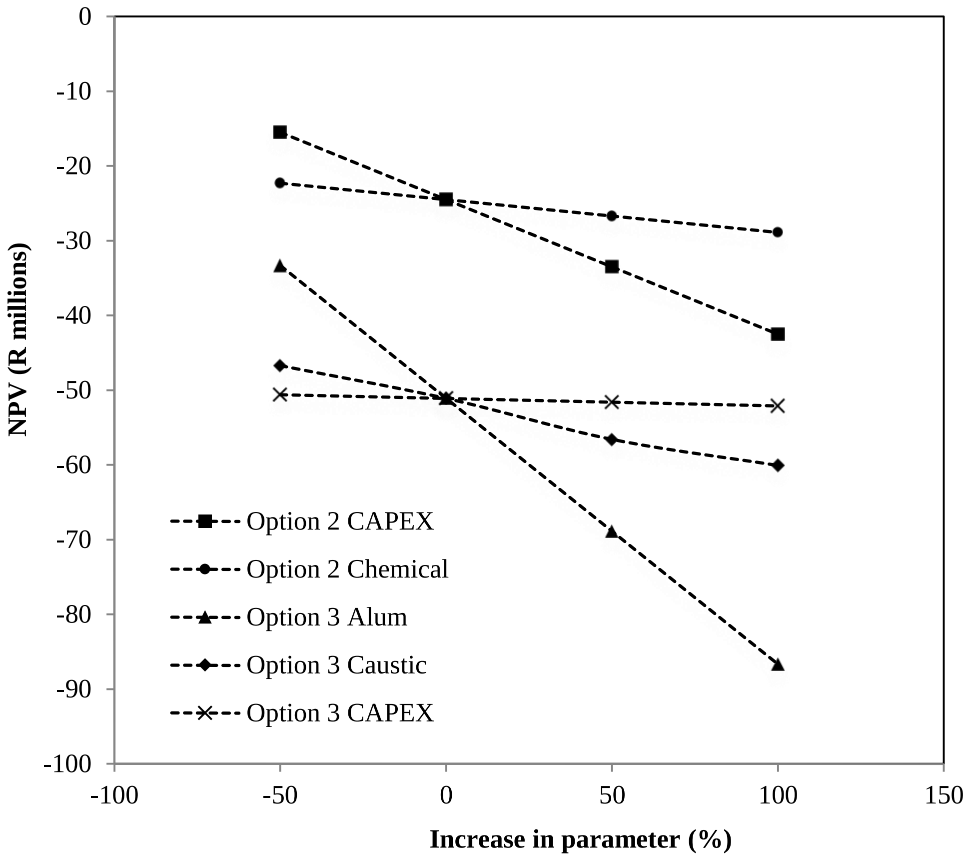

Figure 4: Sensitivity of NPVs to varying chemical costs

Best case Option 3 vs. base case Option 2

Key process parameters can vary in a number ways and may make these two Options even more comparable or at the very best with NPVs within 10% of each other. If Option 3 can use an existing clarifier and belt press for dewatering, the CAPEX value can drop to R0,78 million and the NPC to R50,7 million. At best alum sells for R1,08/kg, this results in a NPC of R38,6 million, 1,5 times that of Option 2. If possible, the excess sludge may be treated in the Thermal drying plant, eliminating sludge disposal costs and reducing the NPC to R34,6 million. Even then, the base case design of Option 2 comes in cheaper than Option 3 over a 20-year period. However, as illustrated by Table 4, with these parameter changes, Option 3 comes within 10% of Option 1s best-case scenario. In this case Option 1 can come in cheaper than Option 3, but Option 2 is still the most economical option.

Table 6: Comparing the 3 options with a change in key parameters

Option	Best case option 1	Base case Option 2	Best Case Option 3
NPC R millions	32,5	25,4	34,6

Discount rate for all three options

When calculating the NPV over a given period, discount rates apply to and may differ for public, private and public-private partnership (PPP) investments. Typically public sector discount rates are lower and range between 3% and 10% and represent long-term project investments. Private investment or PPP schemes discount rates have been quoted to be as high as 15%, which usually accounts for capital financing (Burger and Hawkesworth, 2011). Figure 4, shows how the net present costs of all three options vary with a change in discount rate from 3-20%. Option 1 experiences the greatest drop in NPC from R100 million to under R63 million at 20%. At higher discount rates Options 2 and 3 become more comparable, at a little over R15 million difference in NPV between 15 and 20%. At 5%, rates more representative of public sector investment, Option 1, 2 and 3 increase to R90,5 ,R30,5 and R73,4 million respectively.

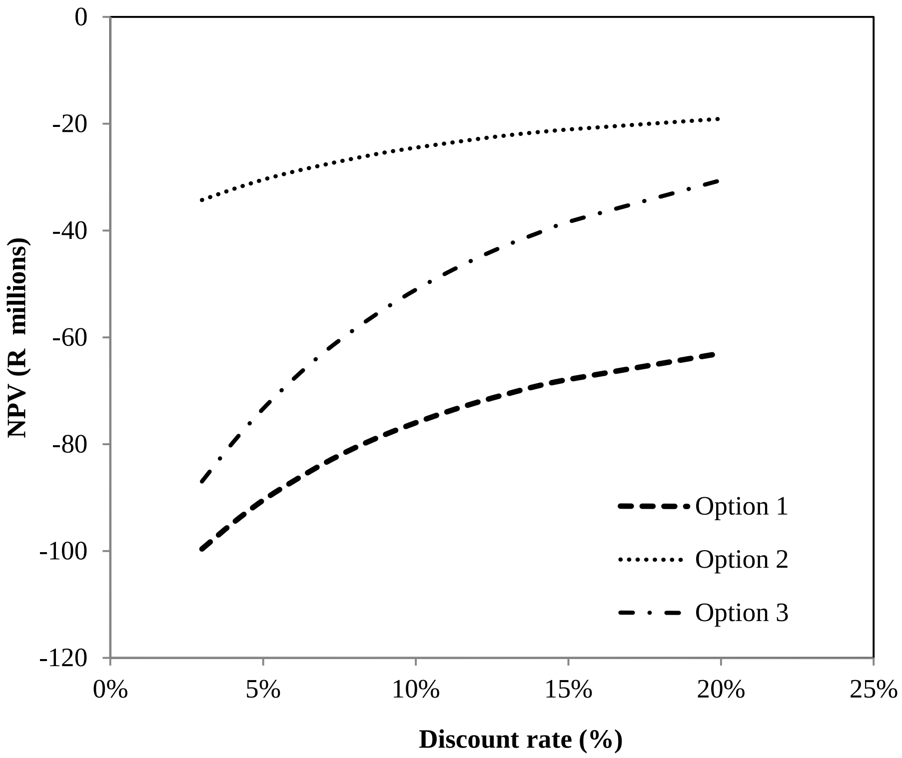

Figure 5: NPV costs with varying discount rate

CAPEX has the highest effect on NPV for both Option 1 and 2, whereas chemical dosing cost significantly affects chemical precipitation. Option 2 can be profitable within 19 years if the price of struvite is increased to about R14,00/kgstruvite. Despite changes in key design parameters for both Options 1 and 3, the Option 2 base case design criteria at the CFWWTW, will always come in cheaper. Therefore, if a WWTW is to reduce effluent phosphate loading to within legislative standards, low-grade struvite production has been shown to be the most ecologically and economically sustainable option from a life-cycle-costs perspective. From a social stand-point, the experts interviewed believe that the South African food market could resistance fertilizers derived from human waste, hence potentially ruling in favour of low-grade struvite for use in secondary non-food markets. Although it is a simple process, it is not cheap; the capital investment is 10 times that of South Africa's more familiar chemical precipitation route. Furthermore, the following theoritical and policy implications should be considered:

These findings may help further mobilize South Africa's shift to more sustainable waste water treatment techniques: Although common and affordable, chemical precipitation incurs significant costs and diverging the phosphate from waste water to solid waste merely shifts the environmental burden. Policy that will bar sewage sludge disposal to agriculture as of 2015 (CDM Executive Board, n.d.), seen against increasingly limited landfill space, already has decision-makers exploring new options for sludge treatment and disposal.

Low-grade struvite production is the most cost effective method: Similar to findings by Bilyk et al. (2010), low grade struvite production comes in cheapest of the three options investigated. Despite having the most attractive economics, local municipalities may find it hard to justify the high capital investment and unprofitable operations. Other than most struvite production case studies, which have shown profitable outcomes within the 20-year period, this is not the case here. However, this option does fall within the global cost bracket for struvite production at R8,90/kgstruvite and may be justified from this angle. Municipalities will have to consider the environmental benefits over the costs.

Identify and quantify the implications of phosphate recovery on WWTW plant operations: Side stream treatment does not only reduce nutrient dischrage into surrounding water bodies, but affects overall plant performance – in this case, nutrient concentrations typically received by both the secondary treatment and thermal drying plant will be affected. It is therefore essential to obtain more detail on such plant effects from installations globally and integrate these findings into a model for local WWTWs.

Phosphate loading to flowrate ratio affects profitability: High CAPEX associated with high-grade struvite production makes this the most costly choice, especially as the South African market may be better suited to lower grade struvite production. However, this process only marginally increases treatment costs to R1,42/kL which is well within an acceptable range for waste water treatment. Other WWTWs with a higher phosphate loading to flowrate ratio may yield economics in favour of high-grade production. But one may need to consider the substantial electrical/carbon footprint.

But even then, relative to phosphate run-off on farms and other urban sinks, the low amount of nutrients extractable from waste water profile makes it technically and economically difficult to justify. Mapping of an economy-wide phosphate pathway may identify larger sinks – organic matter sent to landfills may have more potential.

There is space for innovation: The CAPEX for struvite production is substantial. Locally constructed reactors, with improved kinetics, might come in cheaper than both the OSTARA and Multiform Harvest installations and may lead to both funding and research opportunities in SA.

Phosphate policy to address scarcity rather than just pollution: Although progressive, the recent South African legislation limiting effluent phosphate to 1 mg/L treats phosphate as a nuisance rather than an essential resource. Policy could be modified to promote the reduction, reuse and recycling of phosphate; this would inherently tackle the pollution issue. The Nutrient Credit Trading system described by Algeo & O'Callaghan (2013) is an example of such a policy.

Market considerations: government does not regulate the fertilizer markets. Both struvite processes were shown to be unprofitable, partly due to the low struvite prices, which are subject to South African phosphate fertilizer prices on the local market. As such, fertilizer policy and price regulations would help better understand the placement of struvite in the fertilizer market. In addition, this could increase fertilizer prices to values more comparable to the global market.

All in all, this study found various subtle links between socio-techno-economic assessments and speaks towards a greater need for a "systems approach". More synergies and contradictions can be found between stakeholders, related projects and policy, than what is stated.

CONCLUSIONS

This paper set out to compare three options for meeting phosphate discharge limits at a large biological waste water treatment works in Cape Town. Two options for phosphate recovery (high-grade vs low-grade struvite) were compared to chemical precipitation. The main findings are that:

- The net present costs for high-grade, low-grade and chemical precipitation installations at the Cape Flats Waste Water Treatment works (CFWWTW), discounted at 10% over a 20 year period were R76,2, R25,4 and R51,2 million respectively: low-grade production suited for secondary markets comes in cheapest, regardless of key parameter changes.
- Chemical precipitation CAPEX is the lowest: this is within the allocated budget for the planned CFWWTW upgrade.
- High phosphate loading to flowrate ratio is key: other WWTWs with a higher ratio may have yielded better economics.
- Struvite will have to establish its own market: the current phosphate market price is South Africa too low to offset the costs of phosphate recovery.
- PPP investment should be considered: higher discount rates (particularly between 15-20%) drastically improve the investment potential and financial viability of this project
- New policies for phosphate recovery: shift in viewing phosphate as a nuisance in WWTW to a valuable resource
- Fertilizer markets are needed: though needs to be given establish niches for struvite in the phosphate fertilizer market

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