Adding Value to Waste Waster

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1. INTRODUCTION

Water is a limited (indeed limiting) resource in South Africa. Yet it is taken for granted and typically thrown away with little thought for other users downstream, who then need to spend more money to clean the water so that it can be used. And then they take it for granted and throw it away with little thought for the people further downstream who have to spend even more to clean it for their use. And so the cycle continues downstream. At each step it costs more, and at the end of the river, the water has been cleaned a number of times, yet this cost is not factored into the overall cost of the water. The challenge then, is to maximise the use and treatment of the water at the various points of use to reduce the overall cost.

The abuse of water resources can occur with things like the poor operation and maintenance of waste water treatment works (WWTW). Final effluent may be partially treated, poorly treated or not treated at all. The impact on the river it discharges into is not just environmental but social as well, as it adds costs to clean the water further downstream. And people need to pay for that treatment. So, if the water from poorly operated WWTW could be polished before it released, it could have a cost saving for other users. And if the polishing can create jobs and improve the water quality, then it could locally alleviate poverty.

AECOM is currently running a Pilot Research Facility with the Agricultural Research Council, to assess the potential to use partially treated WWTW effluent for hydroponic crop production. The pilot plant is focused on two main aspects: Use effluent water to grow plants hydroponically, and grow fish in the treated (i.e. due to nutrient uptake by the plants) water to produce protein. The fish water is then re-treated in a secondary hydroponic unit before it is discharged to the river system. Nitrates and phosphates are removed by the plants and the resultant water effluent will decrease the risk of eutrophication and consequent damage to the riverine ecosystems.

Hydroponic crop production creates jobs, contributes to food security, and improves water quality. Fish farming produces dietary protein bone meal for a variety of uses, and nutrients for the second hydroponic unit. This paper presents the results of the pilot plant research to date.

2. BACKGROUND TO THE STATE OF WWTWS IN SOUTH AFRICA

The state of South Africa’s Waste Water Treatment Works (WWTWs) has been under the spotlight in recent years. Coverage in the media, governmental reports, and the health implications of failing infrastructure have raised public awareness and government focus. The current state of works throughout the country is reflected in the 2014 Green Drop Progress Report. The Green Drop Report is prepared by the Department of Water and Sanitation (DWS). It assesses each WWTW on a risk basis using Design capacity, Operational flow, Number of non-compliance trends in effluent quality and Compliance to skills standards.

A total of 152 municipalities and 824 facilities were assessed. Results for the 2014 assessment period include:

- The majority of plants (259) are in high risk positions, followed by 218 plants in medium risk and 212 plants in critical risk positions.
- The decline in the number of plants in low risk domain (to higher risk ratings), which decreased from 199 to 135 during the period 2013 – 2014, is cause for concern.
- 71.7%of all municipal WWTWs digressed to higher risk ratings from 2013 to 2014;
- 57% of all municipal WWTWs can be categorised as high risk or critical risk.

One of the major challenges municipalities face regarding sanitation service delivery in South Africa is the discharge of raw sewage, overflowing from dysfunctional pump stations and WWTWs, into the river systems and dams that supply water to other local authorities located in the downstream catchment areas.

A 2013 Infrastructure News report concluded that the poor condition of water and sanitation infrastructure was as a result of:

- Insufficient funding allocation for the rehabilitation and/or replacement of components that have reached the end of their design life
- Inadequate maintenance budgets, which could be attributed to municipalities' limited income base.

The report further expanded on the following operational deficiencies:

- Because of budget constraints, maintenance of service vehicles and construction plant is neglected. Vehicle and plant breakdowns are therefore a common occurrence and, together with the non-availability of replacements, hamper the municipality's ability to perform elementary Operation and Management tasks and to respond to infrastructure failures in time.
- At most water and wastewater treatment facilities, basic equipment such as spanners, screwdrivers, brooms, shovels, rakes and wheelbarrows – tools necessary to perform routine tasks – are missing. Personnel at these facilities are often expected to do hazardous work without being issued with the required protective clothing. The most extreme example observed was at a wastewater treatment plant where operators were cleaning inlet screens without wearing rubber gloves.
- A number of WWTWs do not have a potable water supply, making it impossible for operators to wash screens, scum baffles and overflow weirs, or hose down equipment to prevent sludge accumulation. Needless to say, non-compliance with Department of Water and Sanitation (DWS) standards for treated effluent is the norm.
- Poor housekeeping is common at most WWT facilities, with sites littered with junk, overgrown with weeds and equipment covered in dust. This could be an indication that supervision is lacking and that operators are left to their own devices.
- Onerous supply chain management procedures within municipalities add to the frustrations of technical personnel stationed at remote sites. Feedback from supervisory staff reveals that obtaining an order number even for fuel or spares is subject to delays due to poor interdepartmental communication and cooperation. This limits the ability of maintenance teams to respond to infrastructure failures promptly.
- Senior managers are reluctant to delegate authority to supervisory staff, which is probably an internal arrangement to limit unauthorised expenditure. All requests for fuel, spares, water purification chemicals, etc., need to be approved by a senior manager, regardless of the extent of the emergency. The unfortunate consequence is lengthy delays in attending to breakdowns when managers are on leave or away.

The implications of the deterioration or poor performance of WWTWs can be broadly categorised as follows (excerpt from a CSIR Perspective on Water in South Africa, 2010):

"Eutrophication is the process whereby excessive growth of algae and other aquatic plants is encouraged as a result of the enrichment of water with plant nutrients, particularly nitrogen and phosphate forms (Nitrogen dioxide NO_2, Nitrate NO_3, Ammonium NH_4 and Phosphate PO_4). The accumulation of nutrients in excess of natural requirements results in nutrient enrichment – eutrophication – and this has important impacts on the composition and functioning of the natural aquatic biota" (Oberholsteret al., 2009a,b).

"South Africa's climatic conditions, combined with various factors, have resulted in large-scale changes to aquatic ecosystems and subsequent eutrophication of rivers and water storage reservoirs. The most important factors affecting water resources are:

- Discharge of treated and untreated sewage effluent;
- Excessive nutrient loads in return flows from agriculture;
- Modification of river flow regimes; and
- Changing land use or landcover patterns.

"In most eutrophic reservoirs and rivers in South Africa the dominant phytoplankton genera are usually the cyanobacteria Microcystisand Anabaena (Van Ginkel, 2004). The excessive growth of toxic cyanobacteria ("blue-green algae") leads to problems in water purification due to the presence of toxic metabolites and taste- and odour-causing compounds. Because nutrients are present in sewage effluent, the problem is exacerbated wherever there is a concentration of humans or animals.

Heavy metal ions become bound to organic matter under certain pH conditions and may also cause problems for industrial uses such as in the production of carbonated soft drinks (Pitoiset al., 2000). Furthermore, treatment processes that use potassium permanganate or chlorine may release the biotoxins from the cyanobacteria, and the toxins may subsequently enter the domestic water supply" (CSIR, 2010).

In 2012, the Institute for Natural Resources published the results of a financial modelling research project, funded by the Water Research Commission, to determine the cost of eutrophication in the Vaal Dam. The results found that the treatment costs of eutrophication for selected metrics were:

- Annual agricultural costs caused by phosphorous varied from R145/ha to R455/ha.
- Property costs in relation to chlorophyll a varied from R 850/m^2 to R3,340/m^2.
- Water treatment costs due for ammonia varied from 0.1 cents/kL to R18 ~~cents~~/kL.
- The costs of exceeding Resource Water Quality Objectives for chlorophyll a and phosphate (each 30 µg/L) varied considerably but were as much as R2,900/ha for agriculture, R18,800/ m^2 for property prices, and R1.44/kL for water treatment.

Thus, poorly managed, failing infrastructure and a lack of skills and resources mean that WWTWs in South Africa are contributing to the deterioration of the country's water resources, which impacts people,the environment, industry, and the economy at large.

3. EFFLUENT WATER QUALITY

Effluent from WWTWs must comply with the standards set by the Department of Water and Sanitation (selected parameters in Table 1); standards which many WWTWs do not comply with. The management and removal of Biochemical Oxygen Demand, Nitrogen and Phosphate are the focus of this discussion.

Table 1: Wastewater limit values of relevant parameters applicable to discharge of wastewater into a water resource

Substance / Parameter	General Limit
Chemical Oxygen Demand (mg/L)	75 (i)*
Total Kjeldahl Nitrogen (mg/L)	51
Ortho-phosphate as Phosphorus (mg/L)	10

(Adapted from Table 3.2 of the General Authorisation Government Gazette 26187, No 399, 26 March 2004)

A pre-feasibility desktop assessment was done for an unnamed Municipal WWTW in South Africa (one of the poorer performing WWTWs according to the Green Drop assessment) to calculate the areal loading rates and the required nutrient removal to achieve polishing of WWTW effluent. Thekey water quality parameters of the unnamed WWTW referred to above are presented in Table 2.

Table 2: Water quality parameters for unnamed WWTW 2004 to 2009 (DWS, 2015)

		BOD	TKN	TP
Concentration (mg/L)		150	1.7	0.5
Average flow rate (m^3/day)	2000			
Kg/day		300	3.4	1

*BOD – Biochemical Oxygen Demand
TKN - Total Kjeldahl Nitrogen
TP – Total Phosphates

No examples were found for calculating the surface area required to treat WWTW effluent hydroponically. However, as with a wetland, a hydroponic system can be considered a permanently submerged area, thus areal loading rates for wetlands to treat effluent could approximate the potential treatment area required for hydroponics.

Tousignant (1999) explains the pollutant loading rate method, which uses the volume and concentration of incoming wastewater to determine the size and type of constructed wetland. Constructed wetlands can be designed on the basis of the mass loading of a given pollutant on a daily loading basis. Daily flows in cubic meters (m^3) multiplied by the concentration of a specific pollutant (mg/L) provides an approximation of the mass of pollutant (kg/day) requiring treatment, which can then be used to calculate the required treatment area along with the recommended loading rates (i.e. kg/ha per day for BOD, TKN or TP) (Hammer, 1994, cited by Tousignant, 1999).

Mass loading rates were taken from Tousignant (1999) and are presented in Table 3.

Table 3: Mass loading rates for wetlands

Maximum loading rates (kg/ha/day)	
BOD	100
TKN	5
TP	0.2

The calculation for the mass loading surface area for 2 megalitres per day is presented in Table 4.
Table 4: Surface area required to treat 2 megalitres per day of unnamed WWTW effluent.

		BOD	TKN	TP
Average flow rate (m^3/day)	2000			
Unnamed WWTW kg/day		300	3.4	1
Area required (ha) [divide by mass loading rates]		3	0.68	5

4. NUTRIENT REMOVAL THROUGH PLANT PRODUCTION

Research undertaken in the Western Cape has indicated that plant species take up nutrients differently and thus their efficiency of use in this is varied. Table 5 presents the removal efficiency of various plans (Milandri, 2011).

Table 5: Nutrient removal efficiency for various plants

	OP	NH_3	NO_3
Agapanthus (Common Agapanthus) (%)	92	91	71
Pennisetum (Kikuyu Grass)	91	99	81
Phragmites (Common Reed)	86	91	25

*OP – Ortho-phosphate
NH_3 – Ammonia
NO_3 – Nitrate

The study indicated that plants such as Agapanthusand Pennisetum are efficient at removing nutrients, whereas the traditional common reed isless so.

The desktop case study investigated the potential to use effluent from the WWTW to grow plants hydroponically to provide crops / produce, employment and improved water quality for discharge. The project concept is presented in Figure 1. In summary, the concept involves the polishing of WWTW effluent by means of diverting the effluent to a hydroponics farm to take up remaining excess nutrients, after which there may be the option of creating further value by utilising the polished water for aquaculture fish production (this is expanded upon in Section 6). The effluent from the fish production can be cleaned either through a biofilter system or a secondary hydroponic system prior to being released downstream into the pond/ dam/ stream as it exits the WWTW property.

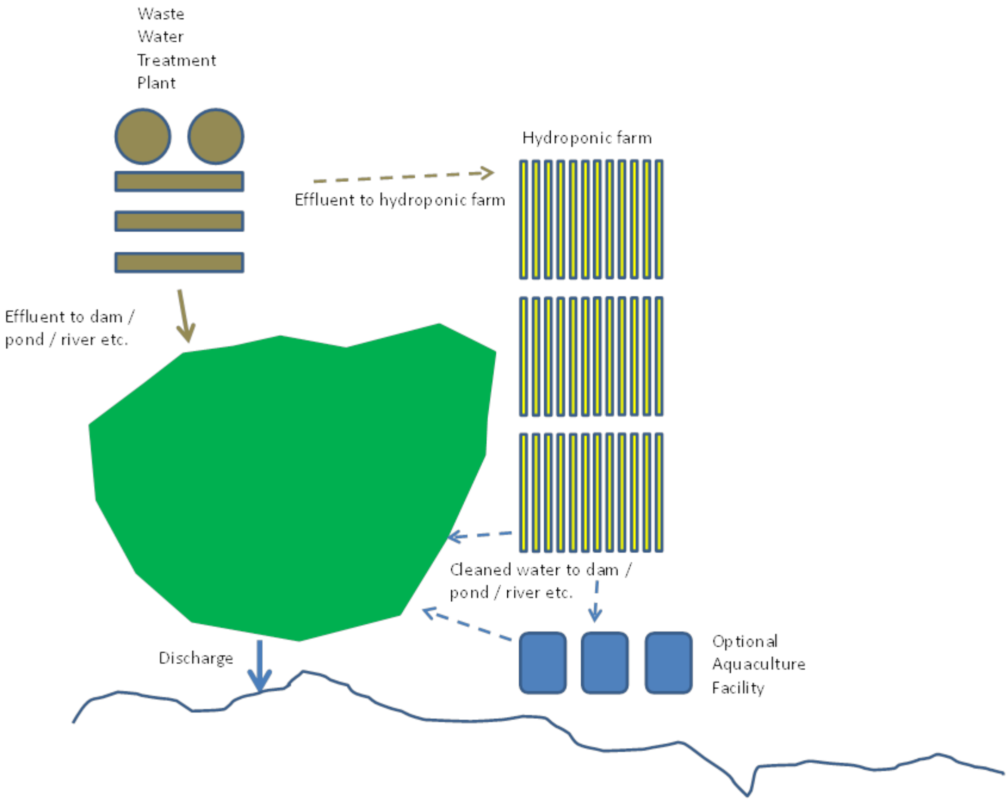

Figure 1: Conceptual Project Components

5. AQUAPONICS PILOT RESEARCH FACILITY

AECOM is currently engaged in an aquaponics (combination of hydroponics and aquaculture, i.e. farming with aquatic species) research pilot programme at the Agricultural Research Council (ARC) Vegetable and Ornamental Plants Institute in Roodeplaat, to develop urban and rural hydroponic and aquaculture systems. The ARC is tasked with developing agricultural potential, agri-processing and food security. AECOM is interested in the use of hydroponics to treat high nutrient water, and to maximise the use of water through integrating fish farming with crop production.

a. Fish Production

Aquaponics is the integration of aquaculture with hydroponic vegetable, flower, and/or herb production. Although still in its infancy in South Africa, it is consistent with the principles of maximising resource efficiency, minimising costs and maximising output. Aquaponics is garnering growing attention internationally because of its efficient use of natural resources and has a major potential in South Africa to address the challenges of sustainable food production and smallholder farming in urban and rural settings:

The pilot plant is farming with tilapia, specifically Tilapia rendalli. There are many common names for this species, in various languages. Common names include Red-Breasted Tilapia, Northern Red-Breasted Tilapia, Red-Breasted Bream, Blue Tilapia and Congo Tilapia (Awaiss et al, 2010). The natural range of T. rendalli is the Senegal and Niger Rivers, south through the Congo and to Kenya on the east of the continent, and much of southern Africa. This species of tilapia is indigenous to South Africa (Awaiss et al, 2010).

The system has been set up inside a plastic greenhouse tunnel structure, alongside an existing hydroponic drip bag system.The purpose of the pilot plant is to investigate the beneficial re-use of aquaculture wastewater in aquaponic plant production.

The production of Tilapia in the pilot plantfor Trial 1 is based on bundles of 4 tanks (each 3.75 m^3 volume) in which fingerlingswere brought in at approximately 20g size and grown out to 90g over 3 months.

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Table 6: Trial 1Production of tilapia rendalli in aquaponics pilot plant

Tank	AvgStart Weight	Avg Weight Month 1	Avg Weight Month 2	Avg Weight End	Percent increase	Fold increase
2a	25	44	76	89	353	4
2b	21	35	51	72	343	3
3a	18	49	56	91	510	5
3b	16	45	66	86	548	5

There was an average fourfold increase in weight over the 4 months. An initial 418 fish were stocked which was a total weight of 8 kg of fish and at the end of the trial (3 months) this had increased to 35 kg of fish. A total of 8 kg of feed was fed to the fish, resulting in a feed conversion rate of 0.32.

The projected increase in fish weight at the same growth rate for a 12 month period would yield 100kg.

Figure 2 shows the monthly increase in average fish weight for Trial 1.

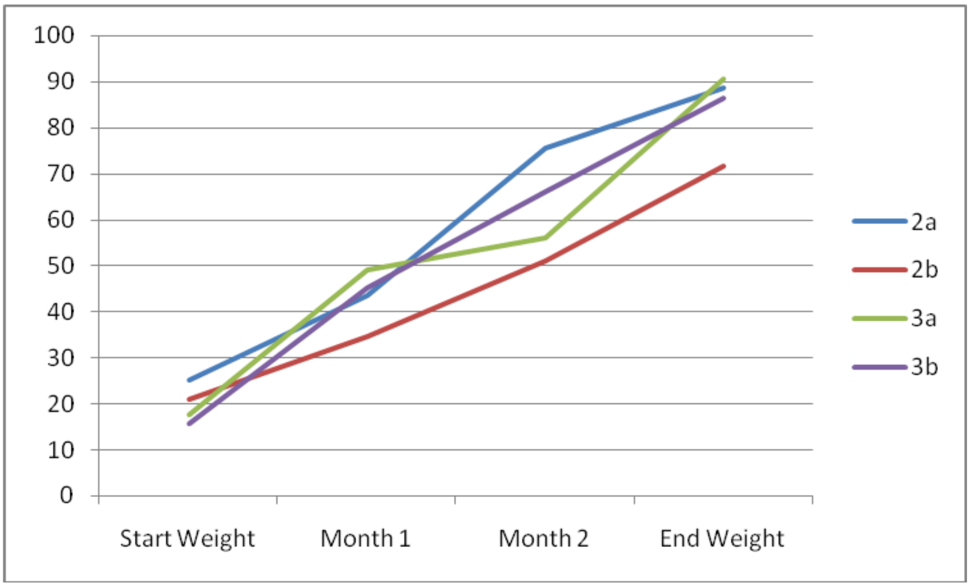

Figure 2: Average increase in fish weight for Trial 1.

The number of bundles of tanks is dependent on the area available. For the unnamed WWTW, it is calculated that up to 1 ha is available. Each bundle of tanks (3 full tanks) occupies 45m^2, thus 100 bundles can be accommodated, resulting in a total of 300 tanks.

Total annual harvest for 100 bundles is calculated at 37.5 tons / annum (125 kg for each tank), requiring 11.25 tons of feed for fingerlings and harvest fish (at 0.32 FCR).

b. Plant Production

The plant production aspect of the project involves the application of aquaponic nutrient solutions in combination with foliar fertiliser on various crops, the first of which is leafy lettuce (Lactucasativa), to assess yield and quality. The lettuce plants will be placed in 10-litre planting bags in a sawdust growth medium, 2 plants per bag. The plants will be fed by means of drip irrigation.
The objectives of the leafy lettuce trial are to:

- Evaluate the performance of lettuce in terms of growth, yield and quality on aquaponic and hydroponic nutrient solution.
- Determine the effect of foliar fertiliser application on growth, yield and quality of lettuce grown from aquaponic solution.
- Determine the effect of aquaponics nutrient concentration in combination with foliar fertiliser on nutrient uptake.

Data will be collected on the following plant growth parameters: Leaf area, leaf number, fresh leaf mass, dry leaf mass, leaf chlorophyll content, leaf mineral content (N, P, K, Ca, S, Mn, Mg, Zn, Fe, Mo, B), and leaf colour (L, a, b) (CR400 Chromameter).

c. Options for Further Investigation

The pre-feasibility desktop study referred to earlier, assessed the possibilities for cultivation of Amaranth; a plant with a high yield and high quality leaves and grains. Various Amaranth species are an important food resource (both the leaves and seeds),and the unprocessed biomass is used as a leafy vegetablein the same way that spinach is. Amaranth is widespread in South Africa during the wet season (Maboko and du Plooy, 2012) and is a widely consumed African leafy vegetable amongSouth Africans. Its leaves are usually harvested in the wild and cooked and eaten with starchy foods such as maize meal. Amaranth leaves are rich in calcium, fibre, ascorbic acid, protein, iron and minerals (Abbot and Campbell, 1982).

Plant biomass can be an excellent and prospective biofuel. Current knowledge of the physical properties of biomass, especially of new energy crops or plants cultivated in polluted fields, is not sufficient for further optimization of industrial energy plants or domestic bio-energy units. Amaranth has been presented as an option with good potential for investigation as a biofuel (Viglasky et al, 2009).

No data exists on nutrient removal efficiency rates for Amaranth, but it has been grown successfully under hydroponic conditions at the Agricultural Research Council, Roodeplaat. The key attributes for Amaranth are:

- The leaves are palatable and highly nutritious;
- The grains are highly nutritious and have a high commercial value;
- The stems and roots are potentially high in calorific value and could be used as a biofuel.

Other produce that can be considered in water polishing hydroponic systemsincludes Swiss chard (Beta vulgaris L.), Kale (Brassica oleracea var. Viridis), Rape (Brassica napus), tomatoes (Solanum lycopersicum L.) and jute (Corchorus).

6. CONCLUSION

Hydroponics and aquaponics present a novel means of maximising the use and treatment of the water at various points to reduce the overall cost and capitalise on the value of water resources. Hydroponics presents an option to bridge WWTW maintenance gaps while enhancing employment / livelihood creation, food security and even renewable energy, particularly when paired with a complementary system such as aquaponics.

Research at AECOM and the Agricultural Research Council's Pilot Facility is underway to assess the potential for use of partially treated WWTW effluent for hydroponic crop production. The pilot plant is focused on two main aspects: One, use of effluent water to grow plants hydroponically, and two, farming of fish in the treated (i.e. due to nutrient uptake by the plants) water to produce protein, after which, secondary treatment by removal of nitrates and phosphates prior to discharge to the river system. Polishing of effluent by using plants decreases the risk of eutrophication and consequent damage to the riverine ecosystems.

7. REFERENCES

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