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Preliminary Feasibility of Large-Scale Treated Wastewater Re-use for Agriculture in Trinidad and Tobago

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Abstract: *Large expanses of agricultural land in Trinidad and Tobago (T&T) need irrigation during the dry season, but cannot be cultivated during this period because of insufficient water. This study examines the existing difficulties in allocating sufficient water for irrigated agriculture in T&T. The overall status of T&T's water resources and associated current and projected sectoral water demands, as well as the existing operational condition of its wastewater treatment and disposal facilities, were reviewed. This was done to investigate whether a national treated wastewater reuse scheme for agricultural irrigation could be supported based on existing local conditions. The study finds that sufficient quantities of treatable wastewater exist, particularly in North Trinidad, and that these could be used to significantly address the water demand for agricultural lands in T&T. It concludes that although the effluents derivable from wastewater plants could augment irrigation water in T&T more tests should first be carried out to investigate the effect of these effluents on the soils, crops, persons and the environment. Proper legislation, effective treatment of wastewater from treatment plants, and public education to advise on the merits and demerits of using wastewater effluents as irrigation water, are important.*

Keywords: *Water, wastewater, treated, irrigation, Trinidad and Tobago*

1. Introduction

An adequate water supply dedicated to the irrigation of crops is very important in Trinidad and Tobago (T&T), in order to realise a highly productive; intensely managed; and internationally competitive agricultural sector. However, irrigated agriculture is subject to considerable and growing competition for water resources from other sectors of the economy and society.. Singh et al. (2005) stated that agriculture in T&T is mainly rain-fed with only 2% of the irrigable land serviced with irrigation infrastructure: The authors added that access to water resources for agriculture purposes faces extreme competition from the industrial, domestic and service sectors.

Although T&T does not experience water scarcity (Ekwue, 2010), the year-round availability of potable fresh water remains a significant concern, given the increase on demand from industrial, domestic and socioeconomic sectors. This situation is further exacerbated by over-abstraction and by the increased discharge of pollutants into existing sources of potable fresh water namely groundwater resources and surface water resources, which substantially reduce the overall water quality in the country's watersheds and coastal zones.

Many countries around the world (see Table 1) have successfully utilised treated wastewater to augment the water required for irrigating crops. A national treated wastewater reuse scheme in T&T could play a significant role in the improvement of the wastewater and water sectors and the revitalisation of its agricultural sector. Shortage of water for irrigation during the dry season is a major setback to the agricultural sector in T&T. Hence, conservational and pollution mitigation efforts would be realised through reuse of wastewater. The safe use of such water requires along with updated knowledge concerning technical expertise, socioeconomic and environmental considerations (Warrick, 2011).

In the Caribbean, Barbados encourages the reuse and recycling of water by both industries and households (Karanjac, 2003). The use of treated wastewater for agricultural irrigation already exists in Trinidad. Farmers are using river water which is fed by wastewater treatment plants in areas like Caroni (Central Trinidad) and Maloney (East-West Corridor) to irrigate their crops. The effects of these treated wastewater effluents on the crops, soils, humans and the environment have not been determined. The information the present authors received from officials of the Water and Sewerage Authority (WASA) was that the use of these effluents is not authorised but that present laws are not enforced to curb this practice.

Table 1. Examples of the use of recycled wastewater for irrigation in some countries

Country	Brief description of the use of wastewater for irrigation
Kuwait	About 85 per cent of the total population is on a central sewerage system. Kuwait provides tertiary treatment (activated sludge treatment, filtration, and chlorination) for reclamation for agricultural irrigation. Three reclamation plants have a total capacity of more than 300,000 m^3/d, with plans to use all of it for agricultural and landscape irrigation.
Saudi Arabia	In 1978, the amount of reclaimed water used was estimated at 95,000 m^3/d, and the projection for the year 2000 was about 2.0 x 10^6 m^3/d, i.e. almost 10 % of its water demand through reuse. Of special interest are the projects at Riyadh, Jeddah, and Mecca and Jubal Industrial City. At Riyadh, the trickling filter facility treats over120,000 m^3/d. Of this, about 85 % is available for agricultural irrigation on about 3,100 ha.
Tunisia	Currently, the effluent from four treatment plants, with a total flow of about 250,000 m^3/d, is used to irrigate about 4,500 ha of orchards, forage crops, cotton, cereals, golf courses and lawns. About 70 % of the irrigated area around Tunis will use about 60 % of the available wastewater effluent.
Egypt	The reuse of municipal wastewater has been practised in Gabal El Asfar sewage farm near Cairo for more than 60 years. About 1,600 ha of desert land have been reclaimed by surface irrigation of this primary treated sewage. According to the Ministry of Public Works and Water Resources of Egypt, it is planned to reclaim and cultivate a desert area of about 84,000 ha using about 5.08 x 10^6 m^3/day of treated wastewater by year 2020.
United States	The Southeast Farm in Tallahassee, Florida, has been irrigating with reclaimed water since 1966. The farm is a cooperative between the city of Tallahassee, which supplies water, and farmers who contract acreage. Until 1980, the farm was limited to 8 ha of land for hay production, but has expanded since then to 865 ha. The irrigation water receives secondary treatment. The crops grown are corn, soybeans, Bermuda grass and rye.

Source: Adapted from Warrick (2011)

This paper examines the preliminary feasibility of nation-wide (large-scale) reuse of treated wastewater for augmenting the water required for agricultural irrigation in T&T. In particular, the paper reviews the local conditions in the water/wastewater and agricultural sectors which favour water reuse: These include future water demand projections, existing water resources and needs for proper wastewater treatment; the agricultural activities practiced; and the comparison of current and projected agricultural sector water demand/requirements with current and projected wastewater flows/loads.

2. Overview of the Need for Additional Supply of Water for Irrigation in T&T

Precipitation is the primary source of fresh water in T&T, in terms of the typical water cycle, feeding all sources of surface and ground water. On the average, Trinidad receives 2,200 mm of rainfall annually with 70% to 80% falling in the wet season, while Tobago receives approximately 1,900 mm annually (GENIVAR, 2007a). The major river systems in Trinidad include the Caroni, North Oropouche, South Oroupouche, and Navet Rivers. In Tobago, the major river systems that drain the island include the Hillsborough, Hillsborough West, Louis D'Or and Courland Rivers.

Water in T&T is used in a variety of ways: supplying villages, towns and cities for domestic use; irrigating agricultural crops; manufacturing a variety of products; supporting fish and wildlife; meeting recreation and tourism needs. These uses are legitimate and well established and can and often conflict with one another. The surface water availability as determined by a detailed hydrologic analysis and preparation of a water budget (GENIVAR, 2007b) showed that the average surface water availability for Trinidad is about 3,600 million cubic metres (MCM) for the whole year and 513 MCM for the dry season, which runs from January to May. For Tobago, the surface water availability was estimated at 140 MCM for the whole year and 28 MCM for the dry season. According to GENIVAR (2007c and 2007d), the groundwater aquifer systems in Trinidad supply 65 million m^3/year and those in Tobago supply 0.15 million m^3/year.

The public water supply system, owned and operated by the Government of T&T, is managed by the WASA. Water infrastructure has and continues to be installed throughout both islands to satisfy the potable and industrial water demands of the large majority of the population (Ministry of the Environment, 2001). According to the Ministry's report, the major components of the public water supply system originate from the Caroni-Arena Dam and Water Treatment Plant (WTP); North Oropouche Intake and WTP; the Northern, North-West, and Southern systems, the Navet Dam and isolated South WTP's in Trinidad; and the South-West System and isolated WTP's. Raw water is obtained from various sources throughout T&T and is treated in water treatment plants to produce drinking water, before being distributed to all of the water service areas throughout the country (GENIVAR, 2007b). There are three main sources of raw water in T&T namely surface, groundwater and sea water.

WASA produces approximately 1.02 million cubic metres per day (GENIVAR, 2007b), with the surface water sources providing the largest proportion of the supply volume (62%). However, this source is also subject to the largest variability due to changes in climatic patterns. While the 27% supply of groundwater is more reliable, there is also an upper limit of availability to prevent a long-term decline in aquifer levels. The most reliable and abundant source of supply is sea water: however, this source requires more advanced and expensive treatment techniques to obtain drinking water. WASA currently purchases approximately 113,652 cubic metres per day (i.e., 11%) from the Desalination Company of Trinidad and Tobago (DesalCoTT) which augments WASA's own water supply to the Point Lisas Industrial Estate (GENIVAR, 2007b).

The consuming demand for water in T&T has been quantified under distinct categories by the Ministry of the Environment Report (2001), as domestic (38%), industrial (19%), irrigated agriculture (3%) and water unaccounted for (40%). The same paper projected these water uses as 42%, 26%, 3% and 29% for both 2015 and 2025. Irrigation accounts for a very small part of water demand (presently 3%) in T&T. According to Singh et al. (2005) only 2% of the irrigable lands are serviced with irrigation infrastructure. The Ministry of the Environment (2001), observed that the current irrigated agricultural demand of 10 mcm/year was based on the present 3,040 hectares currently irrigated in T&T and predicted that the agricultural sector may not be allocated more water up to 2015 and 2025, since it was unlikely to expand given the competing economic development of the other business sectors. However, a Ministry of Agriculture, Land and Marine Resources (MALMR) Report, (, 2007) has indicated that there is a substantial amount of irrigable lands, which if developed will require substantial increases in the demand for irrigation water. The MALMR (2007) insists that there are a number of initiatives that may be pursued in the future once irrigation water can be made available.

According to a Ministry of the Environment's Report (2001), water demand estimates have been anticipated to increase significantly should irrigated agriculture become prevalent; and predicted that, if developed, agricultural irrigation could account for as much as 41% of the national water demand. In fact, MALMR (2007) revised current and projected figures for overall agricultural water demand to take into account the agricultural sector as a whole and these showed that the domestic sector would have 32%, industrial (20%) and irrigation (48%) in 2025. However, according to GENIVAR (2008a), the present WASA water supply system is incapable of servicing future larger water demands for agriculture mainly because the envisioned demand for future irrigation water is very sizeable and that according to current proposals by the MALMR (2007), it could exceed future domestic and industrial demands. GENIVAR (2008a) added that the need for irrigation is particularly apparent during the dry season (January to May). Although some dry seasons are wet, steady production of food during the dry season needs stable and reliable irrigation water. Moreover, water distribution for irrigation is typically less efficient and highly subsidised by government. Water needed for irrigation does not need to be treated to drinking water quality standards; and the delivery of irrigation water is scheduled and requires very large quantities (GENIVAR 2008a).

The development of irrigated agriculture, which may be the key to the revitalisation of agriculture in the country, requires a separate supply and distribution system be established to provide more water for agriculture.

3. Wastewater Treatment/Disposal Facilities in T&T

According to the T&T Water and Wastewater Master Plan - Wastewater Condition Assessment Report by GENIVAR (2007e), there are approximately 250 wastewater facilities in T&T. Approximately 30% of the population are sewered while the remaining 70% is serviced by septic tanks and pit latrines. Approximately, two thirds of the sewered population is serviced directly by WASA. The report stated that 70% of the existing facilities are small wastewater treatment facilities that are poorly maintained and have reached their service life, or abandoned, resulting in improperly treated sewerage being discharged into the environment.

GENIVAR (2007e) conducted a national wastewater sector condition assessment, based on a list of existing facilities provided by WASA. A total of 245 facilities were assessed and it was revealed that 40% of the facilities had reached their service life, and needed to be replaced; 20% of the facilities were in need of major structural upgrades while 15% of the facilities were in need of minor structural upgrades. It was also found that 75% of the effluents from these facilities did not meet internationally recognised quality standards for discharg to the environment. Above all, 85% of the facilities presented health and safety concerns to the operators—WASA, and the public. These concerns include uncovered manholes and access hatches, steep staircases, no handrails and corroded metal structures that pose the risk of breaking. According to GENIVAR (2008b), the current situation imposes a strain on the environment as the current rate of production of pollutive wastewater flows is more than what natural systems can handle. Furthermore, increased discharge of wastewater into the environment increases the risk of jeopardising public health and safety as well as the natural environment. A need may then exist to utilise some of these effluents, if properly treated, in irrigating crops.

4. Computation of Annual Irrigation Water Demand and the Flow Rates of Wastewater Effluents

The data for wastewater effluents were derived from the master plan reports developed by GENIVAR (2008b and 2008c) for WASA. The annual irrigation water demand was obtained from the report on the projected agricultural water requirement to the year 2025 done by the Land and Water Development Division of the MALMR (MALMR, 2007). These reports divided the country into three primary regions: (a) North Trinidad, (b) South Trinidad and (c) Tobago with the first two being each subdivided into ten and twelve catchment/agricultural districts, respectively. Tobago was treated as a single catchment/agricultural district for a total of twenty-three (23) catchment/ agricultural districts in T&T (see Table 2). These catchment/agricultural districts can be considered to be hybrids or amalgamations and their formation was deemed necessary in order to provide a common reference between the catchment areas in T&T, defined by GENIVAR (2008b and 2008c) and the agricultural districts in T&T, defined by MALMR (2007). These were differently demarcated to facilitate the necessary quantitative comparisons between the separate data sets provided by these studies for the common time horizons of 2010, 2015, 2020 and 2025.

Gross irrigation was defined by Brouwer et al. (1992) as the irrigation need by a given crop in addition to the water needed to compensate for all losses that occur between the intake and delivery of the irrigation water to the crop and is expressed as continuous volumetric flow. The estimated current land areas (in hectares) as stated in Table 2 were detailed for cultivated and uncultivated land in T&T for the various catchment/agricultural districts within the three regions. The overall cultivated land area consists of land used for particular forms of agriculture, namely vegetable/food crops and sugar cane (wherever grown); tree crops; rice cultivation; and livestock farming. The percentage of land areas projected by MALMR (2007) to be under irrigation over the time horizons 2010, 2015, 2020 and 2025 were presented for the various catchment/agricultural districts and regions in Table 3. This was based on the percentage of the estimated arable land area designated to be satisfied by the provision of agricultural irrigation water for each form of agriculture practised in each catchment/agricultural district. The projected percentages of areas are informed the understanding that irrigation development should be phased for maximum efficiency.

Based on the projected percentage of areas to be irrigated (see Table 3) and the distribution of agricultural land in Table 2, the total area to be irrigated was computed for the various catchment/agricultural districts. Table 4 details the sample calculation for the East-West corridor catchment/agricultural district. Table 5 shows the sample calculation of the annual current and projected agricultural irrigation water requirements in cubic metres (m^3) for the East-West corridor. The calculated values for the other areas shown on a regional and district basis for the projected years are shown in Table 6. Finally, the projected agricultural irrigation water requirement for each catchment/ agricultural district was presented as annual volumetric flow rate values (m^3/s) in Table 7.

Table 2. Distribution of agricultural land and land for livestock farming in T&T

District	**Vegetables /food crops/ sugarcane (ha)**	**Tree crop (ha))**	**Rice (ha)**	**Livestock (ha)**	**Total estimated cultivated land (ha)**	**Total estimated uncultivated land (ha)**
North Trinidad						
East-West Corridor (Aranguez/Tacarigua/Arouca/Tumpuna/Wallerfield/ Cumuto/Valencia) and Talparo	2,837	6,410	---	17,310	9,247	4,665
Guiaco Tamana/Sangre Grande/ North Oropouche/Plum Mitan/ Manzanilla	360	4,285	1,000	---	5,645	3,645
Maracas/Las Cuevas/Blanchisseuse	162	621	---	50	783	1,000
Matura/Salybia/Balandra/Guayamare	500	190	---	---	690	750
Fishing Pond/La Fortune	755	1,200	65	---	2,020	1,500
Chaguaramas/Diego Martin	429	29	---	---	458	84
Toco, Matelot, Sans Souci, Grande Riviere	40	3,760	---	---	3,800	3,000
Port-of-Spain/Santa Cruz/ Maracas, St. Joseph	1,340	1,208	---	---	2,548	761
Chaguanas/Cunupia/Las Lomas/Longdenville	4,450	220	1,735	4,700	6,405	1,770
Couva/Gran Couva/Brasso/Carlsen Field/Freeport	8,130	4,880	10	11,100	13,020	6,325
Pasture	---	---	---	---	1,600	---
South Trinidad						
Claxton Bay/Point-a-Pierre/Bonne Aventure/Guaracara	2,370	20	---	200	2,390	1,200
Moruga	200	1,000	---	250	1,200	1,500
Barrackpore/Debe	4,315	500	485	1,000	5,300	2,190
San Fernando/Princes Town/Piparo/Tableland	6,305	1,500	---	400	7,805	5,025
Mayaro/ Guayaguayare	94	965	---	5,400	1,059	1,380
Union/Rio Claro/Ecclesville/ Poole /Brothers Road	688	2,837	22	1,060	3,547	2,657
Navet/Biche	289	1,016	55	104	1,360	721
Fyzabad/ Penal/Clarke/Rochard/ /Pluck Road	1,668	527	255	474	2,450	4,773
Cedros/Granville	90	3,410	---	5,000	3,500	500
Point Fortin La Brea/Erin/San Francique/Chatham	1,525	1,480	139	11,460	3,144	7,945
Santa Flora/Palo Seco/Beach Camp	200	1,500	---	3,000	1,700	1,500
Siparia/Quinam/Morne Diablo	910	668	29	---	1,607	1,524
Pasture	---	---	---	---	500	---
Tobago						
Tobago	**907**	**1,930**	**----**	**24,175**	**3,037**	**7,485**

Source: Based on MALMR (2007)

Table 3. Designated percentages of arable land area to be supplied with water from agricultural irrigation with respect to different forms of agricultural activity

Agricultural Activity	Year			
	2010	2015	2020	2025
	Percentage of arable land area to be supplied with water from agricultural irrigation			
Vegetables/Food Crops/Sugar Cane	50%	60%	80%	100%
Tree Crops	27.5%	35%	42.5%	50%
Pasture	75%	100%	100%	100%
Uncultivated	20%	30%	40%	50%
Livestock	100%	100%	100%	100%

Source: MALMR (2007)

Table 4. Sample calculations to determine land area to be put under irrigation based on agricultural activity for the catchment/agricultural district of East-West Corridor up to the year 2025

District	Agricultural activity	Estimated present acreage (ha)	Area to be irrigated (ha)			
			2010	2015	2020	2025
East-West Corridor	Vegetable/Food/ Sugar Cane	**2,837**	2,837 x 0.5 = **1,418.5**	2,837 x 0.6 = **1,702.2**	2,837x 0.8 = **2,269.6**	2,837 x 1.0 = **2837**
	Tree Crop	**6,410**	6410 x 0.275 = **1,762.75**	6,410 x 0.35 = **2,243.5**	6,410x 0.425 = **2,724.25**	6,410 x 0.5 = **3205**
	Pasture	**1,000**	1,000 x 0.75 = **750**	1,000 x 1.0 = **1,000**	1,000 x 1.0 = **1,000**	1,000 x 1. 0 = **1000**
	Uncultivated	**4,665**	4,665 x 0.2 = **933**	4,665 x 0.3 = **1,399.5**	4,665 x 0.4 = **1,866**	4,665 x 0.5 = **2,332.5**
	Livestock	**17,310** (Dairy- 870; Pig /Goat-16,440)	(870x 1.0) + (16,440x 1.0) = **17,310**	(870x 1.0) + (16,440x 1.0) = **17,310**	(870x 1.0) + (16,440x 1.0) = **17,310**	(870x 1.0) + (16,440x 1.0) = **17,310**

Table 5. Sample calculations to determine estimated agricultural irrigation demand for the catchment/agricultural district of East-West Corridor up to the year 2025

District	Agricultural Activity	Year #			
		2010	2015	2020	2025
East-West Corridor	Vegetable/Food / Sugar Cane *	1,418.5 ha x 6,000 m^3/ha = **8,511,000 m^3**	1,702.2 ha x 6,000 m^3/ha = **10,213,200 m^3**	2,269.6 ha x 6,000 m^3/ha = **13,617,600 m^3**	2,837 ha x 6,000 m^3/ha = **17,022,000 m^3**
	Tree Crop *	1,762.75 ha x 3,000 m^3/ha = **5,288,250 m^3**	2,243.5 ha x 3,000 m^3/ha = **6,730,500 m^3**	2,724.25 ha x 3,000 m^3/ha = **8,172,750 m^3**	3,205 ha x 3,000 m^3/ha = **9,615,000 m^3**
	Pasture *	750 ha x 6,000 m^3/ha = **4,500,000 m^3**	1,000 ha x 6,000 m^3/ha = **6,000,000 m^3**	1,000 ha x 6,000 m^3/ha = **6,000,000 m^3**	1,000 ha x 6,000 m^3/ha = **6,000,000 m^3**
	Uncultivated *	933 ha x 3,000 m^3/ha = **2,799,000 m^3**	1,399.5 ha x 3,000 m^3/ha = **4,198,500 m^3**	1,866 ha x 3,000 m^3/ha = **5,598,000 m^3**	2,332.5 ha x 3,000 m^3/ha = **6,997,500 m^3**
	Livestock *	[(870ha x 0.2 m^3/ha/day) + (16,440ha x 0.1 m^3/ha/day)] x 365.25 days = **664,024.5 m^3**	[(870ha x 0.2 m^3/ha/day) + (16,440ha x 0.1 m^3/ha/day)] x 365.25 days = **664,024.5 m^3**	[(870ha x 0.2 m^3/ha/day) + (1,6440ha x 0.1 m^3/ha/day)] x 365.25 days = **664,024.5 m^3**	[(870ha x 0.2 m^3/ha/day) + (16,440ha x 0.1 m^3/ha/day)] x 365.25 days = **664,024.5 m^3**
District Total		**21,762,274.5 m^3**	**27,806,224.5 m^3**	**34,052,374.5 m^3**	**40,298,524.5 m^3**

- Agricultural irrigation water demand considered during the minimum three (3) months dry season (February - April)

* - Vegetable/Food Crop/Sugar Crop – 6,000 m^3/ha (Sprinkler Irrigation); Tree Crop – 3,000 m^3/ha (Micro Sprinkler/Drip Irrigation); Pasture – 6,000 m^3/ha; Rice - Nil (Rainy Season Production); Uncultivated Land - 3 000 m^3/ha; Livestock: (a) Dairy - 0.2 m^3/ha/day x 365.25 days (b) Pig/Goat - 0.1 m^3/ha/day x 365.25 days

Table 6. Estimated agricultural irrigation water demand (m^3) projections to year 2025 in the catchments/agricultural districts of T&T

Districts	Year			
	2010	2015	2020	2025
North Trinidad				
East-West Corridor[+]	21,762,274	27,806,224	34,052,374	40,298,524
Guiaco Tamana	6,802,125	9,075,750	11,565,375	14,055,000
Maracas	1,600,151	2,137,076	2,771,201	3,405,326
Matura	2,106,750	2,674,500	3,542,250	4,410,000
Fishing Pond	4,155,000	5,328,000	6,954,000	8,580,000
Chaguaramas	1,346,325	1,650,450	2,196,975	2,743,500
Toco	5,022,000	6,792,000	8,586,000	10,380,000
Port-of-Spain	5,473,200	6,777,300	8,885,400	10,993,500
Chaguanas	14,909,441	18,159,941	24,080,441	30,000,941
Couva	35,721,855	44,495,355	57,246,855	69,998,355
South Trinidad				
Claxton Bay	7,853,805	9,640,305	12,848,805	16,057,305
Moruga	2,334,131	3,129,131	4,044,131	4,959,131
Barrackpore	14,708,025	18,066,525	24,014,025	2,9961,525
San Fernando	23,182,110	28,810,110	38,221,100	47,632,110
Mayaro	2,103,360	2,790,885	3,534,810	4,278,735
Union	6,937,441	9,085,666	11,346,691	136,077,165
Navet	2,141,598	2,759,898	3,551,598	4,343,298
Fyzabad	8,319,887	10,871,162	14,423,237	17,975,312
Cedros	3,565,875	4,537,125	5,562,375	6,587,625
Point Fortin	12,331,576	16,413,076	20,959,576	25,506,076
Santa Flora	2,847,075	3,754,575	4,782,075	5,809,575
Siparia	4,195,500	5,349,000	7,048,500	8,748,000
Tobago				
Tobago	10,587,241	14,111,191	17,879,341	216,474,918

* - See Tables 4 and 5 for sample computations for the East-West Corridor catchment.
[+] - A complete list of district names can be referred to column 1 of Tables 2.

The population for each catchment/agricultural district as determined by GENIVAR (2008d and 2008e) is shown in Table 8. The most current population statistics were utilised, and multiple projections were performed to forecast the population until 2025, i.e. over the 2010, 2015, 2020 and 2025 time horizons. Based on the population data, the following formula was used to calculate the annual volumetric flow rate values (m^3/s) for wastewater over the 2010, 2015, 2020 and 2025 time horizons as:

Population x 0.5 m^3/capita/day ÷ 86400 seconds
(where 1 day = 86400 seconds) ..... (Equation 1)

These values were taken as quantities of annual projected wastewater flow. The rate of 0.5 m^3/capita/day (GENIVAR, 2008b) was used for dry weather flow. This value took into account residential, industrial, commercial and institutional water consumption; and infiltration. Table 7 details the values of the current and projected values of the wastewater flows for the various regions and districts.

5. Comparison of Annual Irrigation Water Demand and the Flow Rates of Wastewater Effluents

The values of the current and predicted values of the annual irrigation water demand and the wastewater effluent flows for the various regions and catchment/agricultural districts in T&T are presented in Table 7. The values are also illustrated for North Trinidad, South Trinidad, and Tobago in Figure 1.

For the time horizons of 2010, 2015, 2020 and 2025, the annual agricultural water demand flow was shown to markedly increase for all the regions and districts, whereas a comparatively moderate increase was displayed for the annual projected wastewater flow. In the Northern Trinidad, as a whole, the annual projected wastewater flow was shown to be visibly greater than the annual agricultural water demand flow for 2010, 2015, and 2020: whereas for the subsequent time horizon of 2025, the latter was shown to be slightly greater than the former.

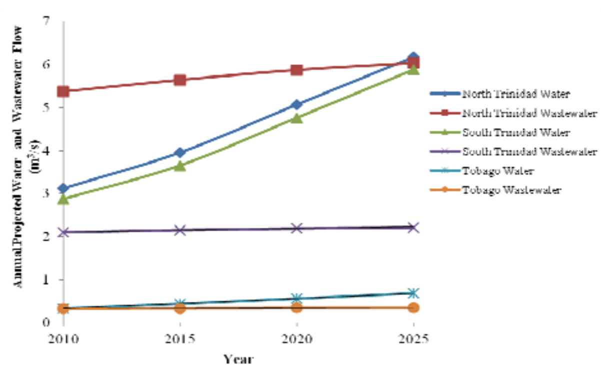

Figure 1. Annual projected wastewater flow compared to the annual projected agricultural water demand flow in the three regions of T&T

Table 7. Projected annual agricultural water demand and wastewater flows in T&T

Region/District	Year 2010		Year 2015		Year 2020		Year 2025	
	*A	B**	A	B	A	B	A	B
North Trinidad	3.13	5.37	3.96	5.64	5.07	5.87	6.17	6.03
East-West Corridor[+]	0.69	1.62	0.88	1.67	1.08	1.70	1.28	1.71
Guiaco	0.22	0.37	0.29	0.46	0.37	0.55	0.45	0.64
Maracas	0.05	0.02	0.07	0.02	0.09	0.02	0.11	0.02
Matura	0.07	0.17	0.08	0.17	0.11	0.18	0.14	0.18
Fishing Pond	0.13	0.46	0.17	0.47	0.22	0.48	0.27	0.48
Chaguaramas	0.04	0.01	0.05	0.01	0.07	0.01	0.09	0.01
Toco	0.16	0.02	0.22	0.02	0.27	0.02	0.33	0.02
Port-of-Spain	0.17	1.65	0.21	1.73	0.28	1.80	0.35	1.85
Chaguanas	0.47	0.49	0.58	0.51	0.76	0.52	0.95	0.52
Couva	1.31	0.54	1.41	0.56	1.81	0.57	2.22	0.58
South Trinidad	2.87	2.10	3.65	2.16	4.76	2.20	5.88	2.22
Claxton Bay	0.25	0.36	0.31	0.37	0.41	0.38	0.51	0.38
Moruga	0.07	0.04	0.10	0.05	0.13	0.05	0.16	0.05
Barrackpore	0.47	0.21	0.57	0.21	0.76	0.22	0.95	0.22
San Fernando	0.73	0.57	0.91	0.58	1.21	0.60	1.51	0.61
Mayaro	0.07	0.04	0.09	0.05	0.11	0.05	0.14	0.05
Union	0.22	0.21	0.20	0.21	0.36	0.21	0.43	0.21
Navet	0.07	0.08	0.09	0.08	0.11	0.09	0.14	0.09
Fyzabad	0.26	0.17	0.34	0.18	0.46	0.18	0.57	0.18
Cedros	0.11	0.05	0.14	0.05	0.18	0.05	0.21	0.05
Point Fortin	0.39	0.30	0.52	0.31	0.66	0.31	0.81	0.31
Santa Flora	0.09	0.05	0.12	0.05	0.15	0.05	0.18	0.06
Siparia	0.13	0.01	0.17	0.01	0.22	0.01	0.28	0.01
Tobago	0.34	0.33	0.45	0.34	0.57	0.35	0.69	0.35
Trinidad & Tobago	**6.34**	**7.80**	**8.06**	**8.14**	**10.40**	**8.42**	**12.74**	**8.60**

* - A is projected annual agricultural water demand flow (m^3/s); ** - B is projected annual wastewater flow (m^3/s)
[+] - A complete list of district names can be referred to column 1 of Tables 2.

Table 8. Summary of current and projected population distribution for all the major catchment/agricultural districts up to 2025

District	Year			
	2010	2015	2020	2025
North Trinidad				
East-West Corridor	280,360	288,314	293,814	295,843
Guiaco Tamana	64,156	79,980	95,340	110,044
Maracas	3,761	3,869	3,944	3,971
Matura	29,874	30,722	31,311	31,526
Fishing Pond	78,858	81,094	82,650	83,208
Chaguaramas	1,004	1,033	1,052	1,059
Toco/Matelot	3,410	3,507	3,572	3,600
Port-of-Spain	285,453	299,773	311,639	320,034
Chaguanas	85,502	87,930	89,609	90,223
Couva	96,363	99,109	101,004	101,669
South Trinidad				
Claxton Bay	62,612	64,392	65,615	66,069
Moruga	7,689	7,906	8,057	8,114
Barrackpore	36,045	37,070	37,776	38,039
San Fernando	100,518	103,378	105,344	106,080
Mayaro	7,752	7,971	8,124	8,181
Union	34,683	35,668	36,346	36,596
Navet	14,048	14,449	14,728	14,829
Fyzabad	29,456	30,291	30,868	31,082
Cedros	8,103	8,331	8,491	8,550
La Brea	51,316	52,772	53,780	54,155
Santa Flora	9,016	9,273	9,447	9,513
Siparia	1,791	1,841	1,876	1,889
Total - Trinidad	**1,294,816**	**1,351,808**	**1,397,568**	**1,427,489**
Total - Tobago	**57,394**	**59,024**	**60159**	**60,565**

Sources: Based on GENIVAR (2008d and 2008e)

However, the net difference between these two sets of flow was shown to increase over the stated time horizons due to a significant increase in annual agricultural water demand flow from 3.13 m^3/s in 2010 to 6.17 m^3/s in 2025 (increase in magnitude of 3.04 m^3/s), as opposed to the comparatively steady increase in annual projected wastewater flow from 5.37 m^3/s in 2010 to 6.03 m^3/s in 2025 (increase in magnitude of 0.66 m^3/s). These results indicate a potential intensification of agricultural activity within this region of Trinidad, especially for the time interval of 2010 - 2025; and that the heightened and increasing projected generation of wastewater load displayed (from 2010 to 2025) points to substantially increasing activity in the domestic/ residential, commercial and industrial sectors and by extension a projected substantial increase in human population.

In South T&T, for the time horizons of 2010, 2015, 2020 and 2025, the annual agricultural water demand flow is projected to considerably increase, whereas a comparatively marginal increase is forecast for annual projected wastewater flow; the former was shown to become much greater than the latter in terms of magnitude. However, the nominal difference between these two sets of flow markedly increase over the stated time horizons due to a sizeable increase in annual agricultural water demand flow as opposed to the relatively smaller increase in annual projected wastewater flows. These results indicate a potential intensification of agricultural activity within the South region of Trinidad as well as Tobago, especially for the time interval of 2015-2025, since the wastewater effluents would be able to meet substantial irrigation demand.

Additionally, the generation of wastewater load has been projected to increase slightly from 2010 to 2025 indicative of slightly increasing activity in the domestic/residential, commercial and industrial sectors and by extension a slight increase in human population, which would be less than what exists in and what would be projected for North Trinidad.

In general, the increased magnitudes observed for these quantitative parameters analysed in this study highlight the existence of sufficient quantities of treatable wastewater that can be used to significantly address the agricultural water demand for arable land designated for irrigation in T&T. In six (6) out of the 23 catchment and/or agricultural districts analysed, there were actually surpluses of treatable wastewater effluent when compared to the irrigation water demand. The use of sewage water to augment irrigation water would seem to be more feasible in North Trinidad because of the same surplus of wastewater effluent being greater than the agricultural irrigation demand.

6. Conclusion

From the result of the assessments of the relevant parameters for the different regions and catchment/ agricultural districts throughout T&T, it is evident that engaging in the reuse of treated wastewater for agricultural irrigation would be feasible. This wastewater would otherwise be discharged into the environment in an untreated or insufficiently treated state, given the current state of the wastewater sector: This is a continuing threat to fresh water resources and coastal zones and public health. It would be to put these effluents to constructive use, while at the same time meeting or supplementing the projected irrigation water demand of the agriculture sector. Agriculture, would otherwise continue to struggle in terms of having to be served by scarce potable fresh water supplies.A wide-ranging improvement and revitalisation of this country's wastewater sector is required. This would form the basis of a national treated wastewater reuse scheme for agricultural irrigation.

Given that the data in this study were quantitative in nature, future approaches would be to undertake schemes or projects for wastewater reuse for agricultural irrigation based upon different categories of scale and location, and in consideration of the various catchment/agricultural districts. Work is currently on-going by the present authors to examine the effect of irrigating with treated wastewater effluents on the soil, crops and the environment. Until this is completed, it may be advisable to be cautious until all the effects of treated wastewater effluents are known.

According to Warrick (2011), WASA would have to ensure that the treated wastewater is at an acceptable quality within specified parameters. This would entail testing and monitoring the influent (raw wastewater coming into plants) and effluent (treated wastewater leaving plants). Legislation with respect to restricting industrial wastewater from entering public sewer systems would have to be enforced. Lastly, public education is needed to inform the public of the use, benefits and hazards of using treated wastewater for agriculture.

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