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Construction Of Subsurface Wetland As An Efficient Method For Black And Gray Water Treatment In IPRC Musanze/Rwanda

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Abstract— Horizontal subsurface flow-built wetlands are used all over the world to treat wastewater from diverse sources. The Rwanda Polytechnic (RP)-Musanze College has a problem of treating wastewater which motivated us to conduct research on constructed wetland. This college utilizes the septic systems in treating the available wastewater volumes. The discharge from these septic tanks is not fully treated to meet the standards of the Environmental Effluent Regulations based on Rwanda Standard Board (RSB), which can pollute the groundwater which is the source of domestic water supply. The aim of this research was to assess the performance of a 250 m^2 constructed wetland model (CWM) for wastewater treatment at the college. To achieve the objective of this study, samples from the inlet and outlet of CWM were taken and various parameters such as: Biological Oxygen Demand after 5 days (BOD5), Total Suspended Solids (TSS), Nitrates (NO_3^-), Total Phosphorus (TP) and Fecal Coliforms (FC) were measured in Water Quality Laboratory of RP-College of Musanze. This CWM showed promising results in removing some pollutants but 80% BOD5, 82.5% TSS, 83.3% NO_3^-, 68.64% TP and 92.8% FC were not permissible based on RSB. With reference to the effluent quality of this CWM system, the outlet water can be used to irrigate non-food crops. In conclusion, it is recommended to use constructed wetlands as a natural and more efficient method of wastewater treatment, but to continue research into how artificial wetlands (1) reduce greenhouse gases emissions, (2) provide environmental protection and (3) mitigate the climate changes are absolutely necessary.

Keywords— Wetland, Wastewater, Water Quality Paremeters, Influent, Effluent.

I. INTRODUCTION

Global supplies of freshwater are diminishing due to overuse and contamination, creating a need for viable water recycling options (Kundzewicz, 2007; Sing, 2024). Three primary direct implications exist in the water industry among the multitude of effects that such increase might have: In order to meet the needs of the growing population, there are three factors that must be taken into account: (i) An increase in fresh water demand and a reduction in the availability of fresh water sources; (ii) An increase in wastewater production and the need for more sanitation technologies; and (iii) A decrease in the amount of green space (Daigger, 2009; Mitchell, 2005; Z.Pereyra, 2015).

Wetlands are intricate ecosystems that act as a transitional zone between terrestrial and aquatic habitats (Ballut-Dajud et al., 2022). These systems typically consist of soil, macrophytes, and various bacteria that work together as a functional unit to improve the quality of ground and surface water (Almuktar et al., 2018; Biswal & Balasubramanian, 2022; Galletti et al., 2010). The influent water to wetlands is cleaned using a range of physical, chemical, and biological techniques. Various pollutants such as heavy metals, suspended solids, and biological contaminants can be removed physically through the settling and sedimentation processes in addition to bio-chemical mechanisms (Kaur et al., 2020; Sharma & Malaviya, 2022; Sheoran & Sheoran, 2006).

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Metal cation and phosphorus adsorption are examples of chemical removal procedures (A Drizo, 1997). Processes for biological elimination commonly depend on the activity of the microorganisms found in the wetland environment (Vymazal, 2007). These procedures are largely in charge of removing organic nitrogen and carbon from waste water (Ilyas & Masih, 2017; Sgroi et al., 2018).

Musanze College of RP is a new constructed college, with a rapid increase in the number of students and staff. It is obvious that this increase in population requires the use of a large quantity of water and then generates a significant quantity of wastewater which requires appropriate treatment. Wastewater treatment available on site relies on septic tanks that receive wastewater from toilets and bathrooms. The effluent from these septic tanks does not comply with the RSB environmental effluent regulations, so additional treatment is required. The effluent wastewaters are directly released into the surrounding environment, reach groundwater and contaminate this precious water resource. In Vunga where the septic tank outlets are located, people use this contaminated water in crop irrigation and can put their lives in danger. This problem can be solved by coupling a sub-surface constructed wetland to the existing septic units and this is the reason for our study.

II. Materials and Methods

2.1. Study area

This research was conducted in RP, at Musanze college which is located in Northern province of Rwanda, Musanze District, Nkotsi sector, Bikara Village along the Road Musanze-Muhanga NR17 (Fig. 1).

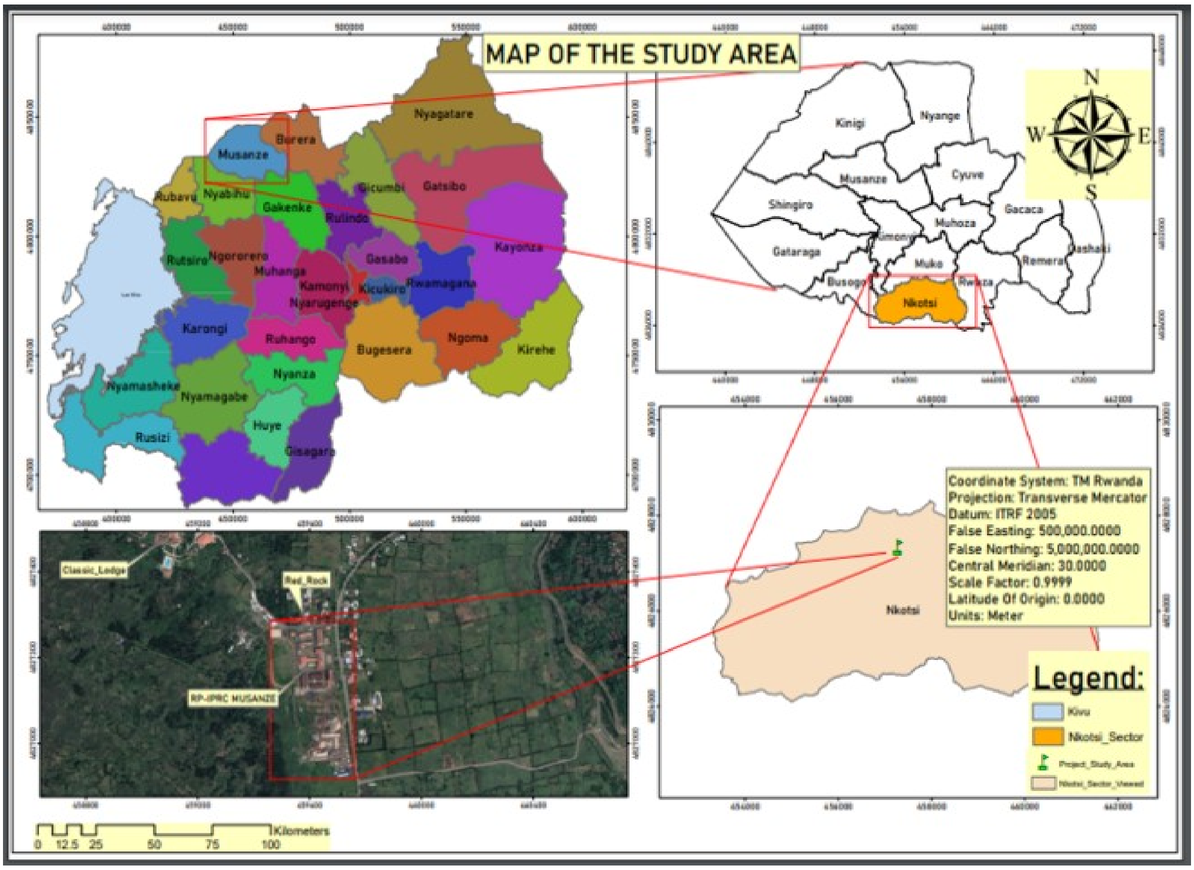

Figure 1: IPRC Musanze Location map (source: Primary Data)

2.2. Methodology

The RP-Musanze College water quality laboratory was used to examine various samples of wastewater taken from the inlet and outlet of the CWM. Various contamination parameters were measured in triplicates for each samples collected; CWM influent, on day 10 at L/3, on day 20 at 2L/3 and on day 30 at L after the commencement of wastewater treatment (L = distance from this CWM inlet). Table 3-1 portrays the wastewater quality components being tested according to the Quality Assurance Project Plan by RSB.

2.3. Constructed wetland design

a. Area Calculation

Wastewater treatment wetland design is largely governed by wastewater influent quality and the required treated effluent quality parameters.

The area of constructed wetland is calculated as follow;

$$A_h = \frac{Q_{d}\,(lnC_i - lnC_e)}{K_{BOD}} \qquad \text{(Eq…..1)}$$

According to this formula, we know that the Ci is 46.26mg/l O_2. The required performance of this wetland is expected to be 10mg/l O_2, for the irrigation of no-food crop.

Qd: average daily flow,

The septic tanks of IPRC Musanze are constructed and have the capacity of 120m^3 and the discharge is estimated to take in five months at current situation. And then five months is 150days. It means that the average daily flow is estimated to be 120m^3 /180 day = 0.67m^3/day. It is provided to increase number of Students to 2100Student and add 2 Septic tanks of 80m^3. The average daily flow is 200m3/150days = 1.33m^3/day.

$$A_h = \frac{1.33m3/day(46.25-10)}{0.19m/day}, = 250m^2$$

Formerly proposed value for K_{BoD} of 0.19 m d^{-1} by Kickuth

The A_h = 250 m^2. The required area to accumulate and treat the whole waste from the IPRC Musanze is estimated to be 287m^2. It means that for a rectangular constructed wetland of 10m wide and 25m length. It has the designed inlet and outlet.

b. Porosity of media material

The porosity (n) of the media soil is calculated by the following equation $n = \frac{e}{1+e}$ where e is the void ratio of the soil.

a. The specific gravity (Gs)

It is calculated by the following equation:

$$Gs = \frac{M_d}{M_{d-(M_3-M_4)}} \qquad \text{(Eq…..2)}$$ where ;

M_1: mass of empty bottle

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M_2: Mass of bottle with dry soil

M_3: Mass of bottle with soil and water

M_4: Mass of bottle with water

M_d= Mass of solid, M_2-M_1

Mass of solid, Md=195g

Mass of bottle + soil +water =1584g (M_3)

Mass of bottle + Water = 1465g (M_4)

$$G_s = \frac{M_d}{M_{d-(M_3-M_4)}} = \frac{195g}{195g-(1584g-1465g)} = 2.56$$

b. Calculation of void ratio (e)

The void ration is calculated by the following equation

e = wG_s where w is water content of the media soil.

c. $W = \frac{Mass\ of\ water}{mass\ of\ solid} = \frac{75-61.9}{61.9} * 100 = 21\%$

e=wGs = 23.8%*2.54 = 0.53 and then, the porosity (n) = $\frac{e}{1+e}\ \frac{0.53}{1+0.53} = 0.35$, the porosity is **0.35**

Then we calculate the retention time (Tr) as follow,

$$T_r = \frac{V_{active}}{Q} = \frac{nhA_{active}}{Q} = \frac{0.35*0.5m*250\,m2}{1.33m3/day} = 32days$$

The required time for wetland to treat the waste water is estimated to 32days, or one month. (ten days in each cell).

2.4. Hydraulic design

From the profile drawn, it shows that the mean slope of the conveyance is 2.3% downward. And we know that the average daily flow 1.33m^3/day means that 0.93*$10^{-3}$$m^3$/min. The proposed channel is rectangular coved channel.

According to Manning Formulae, $V = \frac{1}{n} * R^{\frac{2}{3}} * S_0^{\frac{1}{2}}$ (Eq………..3)

Where

R is Hydraulic Radius

S_0 is Bed slope and n is the manning roughness (for Concrete is 0.012). We need a speed of 0.4m/sec into the flow.

0.4m/sec = $\frac{1}{0.012} * R^{\frac{2}{3}} * 0.023^{\frac{1}{2}}$ and this gives $R^{\frac{2}{3}}$= 0.152m and **R= 0.666m**

We know that for rectangular channel, an economic channel have the b = 2y where b is the base and y is the depth. R = $\frac{A}{P} = \frac{b*h}{b+2y}$ $and\ b = 2y$ it means that

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$$0.666m = \frac{y.2y}{2y+2y}$$ then y = 0.33m and then b=0.666m.

III. Results and discussion

3.1. Inflow Results

It was found that the inflow concentration load had five parameters exceeding the permissible limits based on Rwanda Standard board. The table 1 shows the results of inflow concentration and method used.

Table 2: Results of different parameters at Day 1, Day 10, Day 20 and Day 30 with Permissible limits to environment and Testing Methods

	Parameter tested	Permissible limits to environment	Results of tested sample				Test method/SOP
			Day 1	Day 10	Day 20	Day 30	
1	pH	5-9	8.93 ± 0.05	WPL	WPL	WPL	RS ISO 10523:2008
2	Color	200	90.33 ± 0.88	WPL	WPL	WPL	RS ISO 7887
3	Total Dissolved solid mg/L	1500	998.67 ± 2.03	WPL	WPL	WPL	ASTM D 5907
4	NO_3^- (mg/l)	20	5.37 ± 0.41	WPL	WPL	WPL	Spectrophotometric
5	Total suspended solid (mg/l)	50	259.00 ± 2.65	169.67 ± 0.88	110.33 ± 0.88	45.33 ± 0.88	ISO 11923:1997
6	Chlorine (mg/l)	2	0	WPL	WPL	WPL	ISO 7393
7	Sulfate (mg/l)	500	66.18 ± 0.18	WPL	WPL	WPL	US EPA Method
8	BOD_5 (mg/l O_2)	50	46.09 ± 1.02	40.20 ± 0.65	20.85 ± 0.70	9.56 ± 0.33	Dilution Method
9	Total Phosphorus (mg/l)	5	6.00 ± 0.03	5.92 ± 0.02	3.93 ± 0.02	1.96 ± 0.01	Spectrophotometric
10	Total Nitrogen (mg/l)	30	5.63 ± 0.09	WPL	WPL	WPL	Kidjeldar Method
11	Nitrite (mg/l)	2	2.05 ± 0.05	1.02 ± 0.02	0.65 ± 0.01	0.35 ± 0.01	Spectrophotometric
12	COD (mg/l)	250	52	WPL	WPL	WPL	ISO 6060:1989
13	*Fecal Coliforms in 100ml	CCA <400	2780.33 ± 0.33	1780.33 ± 0.33	748.33 ± 7.27	203.00 ± 5.86	ISO 9308-1

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All tested parameter are physico-chemical parameters except for * which is biological parameter. The values in the table are mean ± Standard Error (SE) with n=3 and WPL= within permissible limits.

It was found that; Total Suspended Solid (260 mg/l) while the limit is (50 mg/l), Total Phosphorus of (6.06mg/l) instead of 5mg/l as the permissible limit. Nitrite was 2.1mg/l while the permissible limit was 2mgl/l and Fecal Coliforms in 100ml was found $2.78*10^3$ CCA but the permissible limit is 400CCA for discharging it into environment.

i. TSS

Total Suspended Solids (TSS) is classified as weak if TSS is less the 100ml/l, Medium if it between 200mg/l and 350mg/l and strong when is greater than 350mg/l. (Ghernaout, 2020) The current research was found to be medium because the total suspended solid is found 255mg/l as an average at two different points.

Table 1:Typical Composition of Untreated Domestic Wastewater

SN	Wastewater Characteristics	Weak	Medium	Strong
1	Chloride	30	50	100
2	Alkalinity as CaCO3	50	100	200
3	Total Phosphorus (TP)	5	10	20
4	Total Organic Carbon (TOC)	75	150	300
5	Total Dissolved Solids	200	500	1000
6	Total Kjeldshl Nitrogen (TKN)	20	40	80
7	Total Suspended solid (TSS)	100	200	350
8	Chemical Oxygen Demand (CoD)	250	500	1000
9	Biochemical Oxygen Demand (BoD)	100	200	300

Source: (Ghernaout, 2020) and (1992); (Fujii et al., 2013)

ii. BoD5

According to table 2, Biochemical Oxygen Demand (BoD) is said weak when it is less than 100. It is said that here it weak because it is 46.25

iii. Total Phosphorus

The total phosphorus was 6.06mg/l which is greater than 5mg/l. It means that the TP was at high level to be discharged into environment. Here it is classified as medium range.

iv. Nitrites

Typically, this is referred to as total nitrogen. Nitrogen released during the breakdown process as ammonia (NH3) or N2 is typically not detected. Nitrates (NO2 & NO3) and nitrites (NO2 & NO3) are additional nitrogen species that are formed in wetlands. NH3 or N2 are reported by some authors. Typically, a calorimeter or chromatograph is used for measurement. Once more, this is often stated in mg/l.

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v. Fecal Coliforms

E. coli and coliform counts, the typical characteristics that are tested in bathing water, are detected using standardized detection techniques. The majority of regulations call for coliform levels of less than 2000 colonies per 100 ml The use of standardized testing is widely accepted in the scientific community. It found that the Fecal coliforms are higher in IPRC Musanze wastewater.

3.2. Designed constructed wetland

The designed Constructed Wetland is 250m^2.plan area divided into two parts of three cells each. The calculated retention time is 32 days and wetland media of 0.35 as porosity. The conveyance of wastewater is found to be the rectangular channel of 0.33m height and 0.66m wide. The figure 3 illustrate the wetland detail and Figure 4 is the conveyance section.

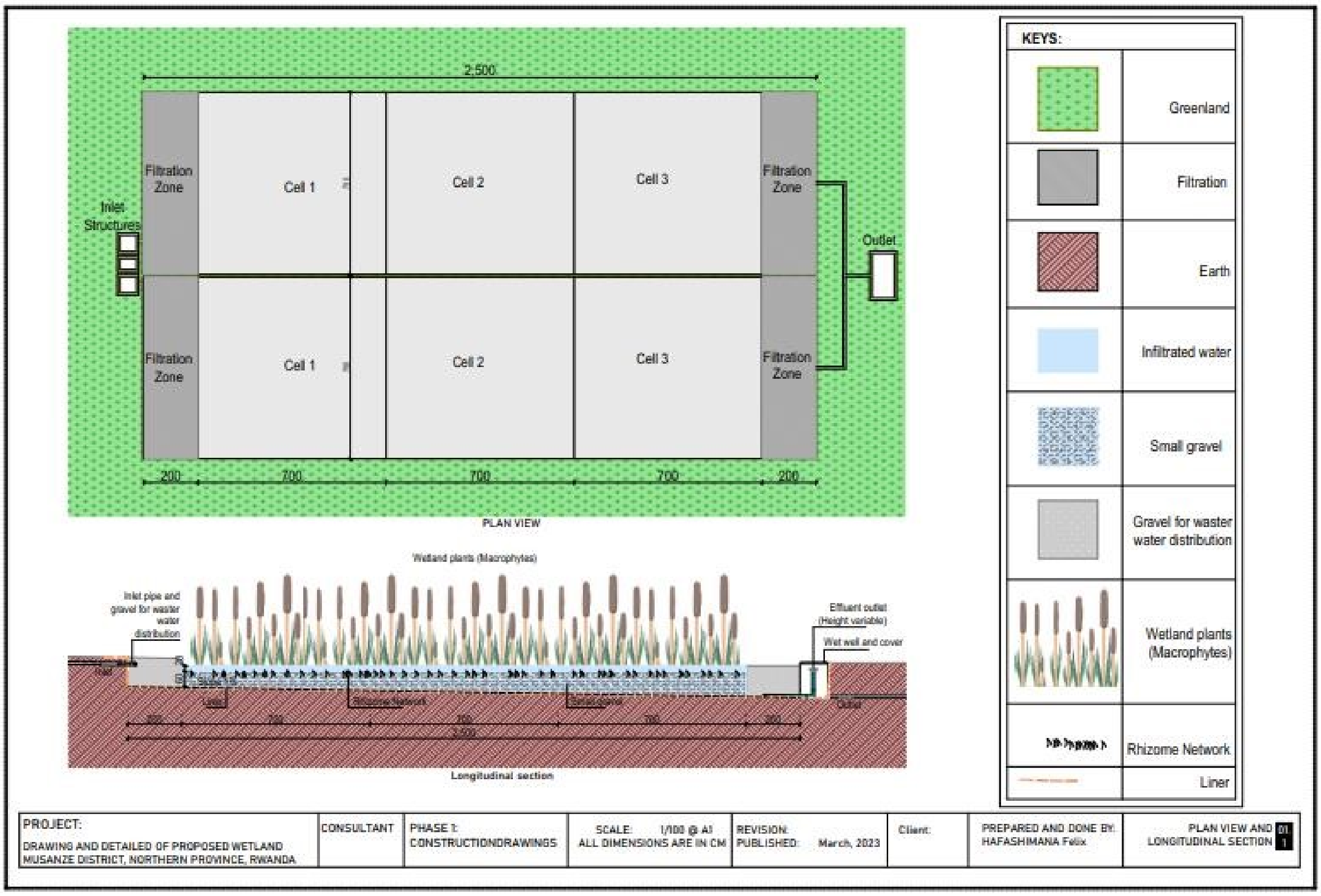

Figure 2: Designed Wetland detail

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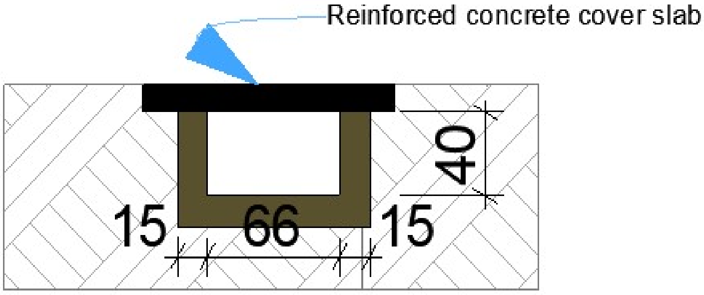

Figure 3: Conveyance section

3.3. Constructed Wetland Performance Evaluation

The assessment is done for the identified parameters in the influent. The variation of those parameters is studied as the following. This performance assessment was done by using a constructed physical model of 5m long and 1m wide. It has one meter length for filtration at the entrance and outflow.

Figure 4: Physical Constructed wetland

3.4 Discussion

a. TSS

It is found that in the raw wastewater 259 mg/l and is classified as medium as indicated in table 2. The removal of TTS by this constructed Wetland was from 259 mg/l to 45 mg/l. it estimated to 82.7%. It is efficient to use this structure for wastewater treatment.

b. BoD$_5$

The Biochemical Oxygen Demand reduced from 46.5 to 9.5 during 32 days into the constructed wetland. The removal is estimated to 79.5%.

c. Phosphorus

By filtration, plants absorption and settling of phosphorus, it was eliminated at a level of 68.7%. This wetland is efficient to eliminate the phosphorus.

d. Nitrite

The elimination of Nitrite was estimated to 83.3%

e. Fecal coliforms

The Fecal coliforms in wastewater is eliminated by filtration, killing of microbe by sun rays and is estimated to 92.4%. The level of microbes is at high level. The wetland was found to be the good technique of microbe removal.

IV. Conclusion and Recommendations

4.1 Conclusion

This study of Subsurface Wetland as an efficient method for black and gray water treatment in IPRC Musanze/Rwanda was successfully removed organic matter (BOD5 and COD), TSS, total phosphorus, Nitrites and Fecal Coliforms from wastewater during secondary treatment (The first treatment is made by pre-treatment unit and septic tanks) and release usable water. At a relatively short retention time of a one month is wetland of 3Cells, the effluent complied with the permissible local limits for release into surface water courses/ground water or taken for irrigation of no-food crop.

4.2 Recommendation

- The research showed that, the constructed wetland is an effective method for the domestic wastewater, the recommendation is addressed to Administration of University of Rwanda and Rwanda Polytechnic to mobile funds for the implementation of these constructed wetland for their colleges.
- Instead of using a rectangular shape for constructed wetland, more studies are needed to determine the most effective engineering shape. In order to minimize dead zones and water stagnation, the chosen shape must rely on the optimum pollution removal.
- Studying the use of mixed media in the same basin on treatment of pollutants either in sequence or in overlapping layers. Also, the use of different plants in the same cell on treatment performance.

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