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Implications of Constructed Wetlands Wastewater Treatment for Sustainable Planning in Developing World

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Abstract:
Wastewater is a necessary by-product of human activities in his built environment. A sustainable wastewater treatment infrastructure plays a very important role in order to achieve best practices in man's built environment. The paper adopted a qualitative research approach to examine the wastewater planning and treatment facilities in Covenant University, Ota, Ogun State, Nigeria and the implications its processes, products and potentials have for sustainable campus and community planning. It reviewed existing literature providing an overview of wastewater treatment strategies and technologies while highlighting their essential features. Interview of stakeholders responsible for wastewater treatment in the community and on-site case study inspection formed the basis for the result deductions. Physical planning and layout, operation and maintenance cost, infrastructural facilities and equipment to compliment effective functioning of Covenant University Constructed Wetland Wastewater Treatment Plant (CU-CWWTP) were examined. Result showed that the initial cost of erecting a constructed wetland wastewater treatment plant is enormous, but highly cost-effective in terms of operation and maintenance. Furthermore, wastewater is effectively treated and transmitted as dischargeable safe water with advantage of non-toxic fertilizer as an end-product. It is recommended that the CU-CWWTP model should be understudied by community administrators at all governance level with a bid to deploying same for effective wastewater treatment in communities in developing nations.

Keywords: constructed wetland, Covenant University, Nigeria, sustainability, wastewater treatment plant

1.0 Introduction:
Universities can nowadays be regarded as 'small cities' due to their large size, population, and the various complex activities taking place in campuses, which have some serious direct and indirect impacts on the environment (Alshuwaikhat & Abubakar, 2008). The development of the ivory tower as a contributor to pollution and environmental degradation clearly accentuates the need for a balance between human activities and the ability of natural systems to support and nurture life. Alshuwaikhat & Abubakar (2008) noted that the balance between human activities and its diverse impact on the environment such as pollution and environmental degradation as a result of university operations in teaching and research, provision of support services and in residential areas has brought campus sustainability to the fore as an issue of global concern for university policy makers, planners and designers. At the same time, Viebahn (2002) identified that the university not only contributes significantly to the development of our society, it also has special societal responsibility, in particular with regard to youth training and public awareness about sustainability. Velazquez *et al.* (2006) defined a sustainable university as a higher educational institution, as a whole or as a part, that addresses, involves and promotes, on a regional or a global level, the minimization of negative environmental, economic, societal, and health effects generated in the use of their resources in order to fulfil its functions of teaching, research, outreach and partnership, and stewardship in ways to help society make the transition to sustainable lifestyles. Alshuwaikat and Abubakar (2008) opined that a sustainable university campus should be a healthy campus environment, with a prosperous economy through energy and resource conservation, waste reduction and an efficient environmental

management, and promotes equity and social justice in its affairs and export these values at community, national and global levels. Cole and Wright (2005) argued that a sustainable campus community is the one that acts upon its local and global responsibilities to protect and enhance the health and well-being of humans and ecosystems. It actively engages the knowledge of the university community to address the ecological and social challenges that we face now and in the future. While there are several parameters in benchmarking a sustainable university campus, an underlining and recurrent theme was identified in literature. This is that universities are large communities which contribute to pollution and environmental degradation through their domestic and research activities. Furthermore, universities are supposed to enlighten and educate their immediate communities about the protection and improvement of the environment through efficient environmental management practices. Therefore, the environmental policies and practices of the university in effectively managing wastewater of its large size and population could be a model for communities in developing countries.

Wastewater is a necessary consequence of human activities on the campus just like it is in any human environment. The city-like situation on university campuses with the attendant volume of wastewater generated is an issue that must be given adequate attention. To achieve best practices in campus planning and to maintain a sanitary environment, the sewer infrastructure plays a very critical role. This is because untreated wastewater poses a threat to human health and environment thus making the protection of the environment of vital importance. This protection is aimed at the improvement of the quality of life, the protection of the ecosystem and the conservation of the natural resources together with the securing of sustained economic development (Xajipakkos *et al*, 2000). This brings to fore the need for an inclusive sanitation system whose main objective according to Langergraber (2013) is to protect and promote human health by providing a clean environment and breaking the cycle of disease. In addition, Panesar *et al* (2009) submitted that beyond the requirements of protecting the environment and natural resources, a sustainable sanitation system should be economically viable, socially acceptable and technically and institutionally appropriate.

Studies have shown that most often in developing countries, wastewaters from small communities are discharged without previous treatment into rivers and lakes (Villalobos *et al,* 2013, Kivaisi, 2001). The indiscriminate discharge of polluted effluents from industrial, agricultural, and domestic/sewage activities have continued to put surface water bodies in developing countries under serious threat (Kambole, 2003). For instance, Teli *et al* (2008) identified that the continued discharge of domestic and industrial wastewater directly into the river is one of the main causes of water pollution in the streams of Nepal. Another consequence of indiscriminate discharge of polluted effluents according to Dallas *et al* (2004) is the deterioration of the quality of available fresh water resulting in intensified shortage of water supply in communities. Consequently, the availability of fresh water for human consumption is being constantly depleted. Bruch *et al* (2011) affirmed that availability of freshwater resources on earth are diminishing rapidly due to less constant water supply and increasing world's population. From the foregoing, it can be deduced that untreated sewage has serious impacts on the quality of an environment and on the health of people. Related to the protection of the environment is the problem of acute water shortage facing many communities. Exploring appropriate utilisation of every water resource locally and globally thus becomes necessary.

An important source of water is the recycled water that originates from the treatment of wastewater, which replaces equal quantities of potable water. It has been reported that close to 90 per cent of wastewater produced globally remains untreated, resulting in widespread water pollution, especially in low-income countries. Untreated waste water leads to serious environmental problems such as pollution of the groundwater and soil, as well as serious odour and vector nuisance to the nearby communities. For instance, WHO (2009) reported that access to safe drinking water is more critical in Africa and South Asia, where more than 80% of children deaths occur due to diarrhoea each year. The report further submitted that 1.5 million children die annually worldwide from water-borne diseases especially diarrhoea caused by lack of proper drinking water service.

Constructed wetlands (CW) have proved useful worldwide in treatment of municipal, industrial, storm water and agricultural wastewater (Bruch *et al*., 2011; Korkusuz *et al*., 2004). CWs are very suitable for small communities and settlements for which there is a big demand for proper wastewater treatment due to their ease of operation and maintenance (Haberl *et al*., 2003). Despite the advantages that CWs poses, studies have focused more on technicalities rather than on simple operational and maintenance strategies of the wastewater treatment plant. Therefore, this paper examined the Covenant University constructed wetland wastewater treatment (CU-CWWTP) plant in Canaanland community which is the home to Covenant University, Ota, Ogun State, Nigeria and the implications its physical planning and layout, operation and maintenance cost and end products have for sustainable campus and community planning. Existing literatures were reviewed to give an overview of CWs wastewater treatment strategies and technologies while highlighting their essential features. It examined the capabilities of the CWs, the functional design approach and the management requirements to ensure performance with a bid to deploy the model for wastewater treatment in communities of developing countries.

2.0 Overview of Waste Water Treatment Strategies and Technologies

2.1 *An overview of wastewater treatment: categorisation and technologies*

Several technologies have been developed over the years for treatment of industrial or domestic wastewater. Outlined in Table 1 is a broad categorization of available technologies for wastewater treatment. CWs could also be classified into three types in terms of the water level in the wetlands and the different pollutants that they can remove (Nilsson *et al.*, 2012). They are surface flow wetlands, often referred to as free water surface constructed wetlands (FWS), subsurface flow constructed wetlands, and hybrid constructed wetlands which are various combinations of each type of systems (Vymazal, 2010a). Free water surface (FWS) wetlands (also known as surface flow wetlands) closely resembles natural wetlands in appearance because they contain aquatic plants that are rooted in a soil layer on the bottom of the wetland and water flows through the leaves and stems of plants.

CWs with subsurface flow {also known as vegetated submerged bed (VSB)} do not resemble natural wetlands because they have no standing water. They contain a bed of media (such as crushed rock, small stones, gravel, sand or soil) which has been planted with aquatic plants. When properly designed and operated, wastewater stays beneath the surface of the media, flows in contact with the roots and rhizomes of the plants, and is not visible or available to wildlife. CWs with subsurface flow may be categorized to horizontal flow (HF) and vertical flow (VF) as shown in Figure a. However, the paper focused on delineating HF constructed wetlands as used in the Covenant University Constructed Wetland Wastewater Treatment Plant (CU-CWWTP).

Table 1: An Overview of Wastewater treatment Categorization, technologies and outcome

S/N	Categorization	Technologies	Outcome
1.	Secondary Treatment	Stabilization ponds	Restricted agricultural irrigation (i.e. for food crops not consumed uncooked)
2.	Tertiary Treatment	Constructed wetlands	Unrestricted irrigation quality
		Soil Aquifer Treatment (SAT)	-Unrestricted irrigation quality -Drinking water quality
		Coagulation/flocculation, sedimentation, filtration and disinfection train (aka Title 22)	Indirect agricultural reuse
3.	Quaternary Treatment	Microfiltration Reverse osmosis Membrane Bioreactors (MBR)	Drinking water quality

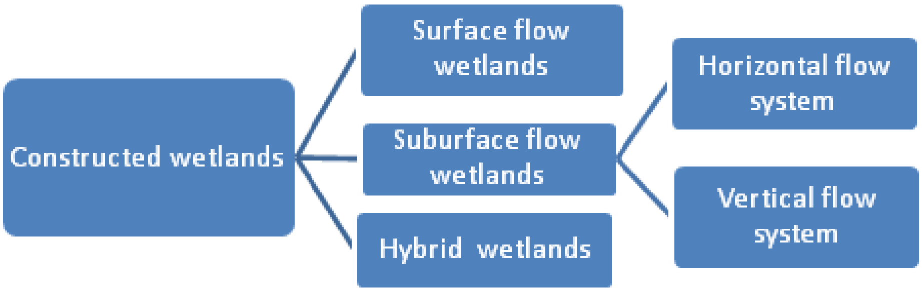

Figure a: Classification of constructed wetlands (Vymazal, 2010a)

2.2 Overview of constructed wetlands

CWs are engineered systems that have been designed and constructed to utilize the natural processes involving wetland vegetation, soils, and the associated microbial assemblages to assist in treating domestic and industrial wastewaters (Langergraber, 2013; Villalobos *et al*, 2013; Vymazal, 2010b). They are also utilized in the treatment of stormwater and different types of wastewater (Nilsson *et al.*, 2012). Treatment takes place through a variety of complex natural, chemical, physical and biological processes, including sedimentation, precipitation, adsorption, assimilation from the plants and microbial activity. The system utilizes aquatic plants, such as phragmites reeds, bulrushes and cattails. Bruch *et al.* (2011) argued that CWs can be applied in both cold and warm climates, and the technology is considered as suitable options for wastewater treatment and reuse in developing countries. Nilsson *et al.* (2012) recognized the usefulness of the application of CWs all over the world and its economic advantages, however noted that their performance level still reduces at cold weather, especially winter. Constructed wetlands are usually designed to work under gravity, thus minimizing any need for pumps or other electrical devices.

They are typically constructed with uniform depths and regular shapes near the source of the wastewater. For some applications, they are an excellent option because they are low in cost and in maintenance requirements, offer good performance, and provide a natural appearance, if not more beneficial ecological benefits. However, because they require large land areas, 4 to 25 acres per million gallons of flow per day, they are not appropriate for some applications. Constructed wetlands are especially well suited for wastewater treatment in small communities where inexpensive land is available and skilled operators are hard to find.

3.0 The Study Area

Covenant University (CU), Ota, Nigeria is a fully residential Christian Mission University, established by the World Mission Agency (WMA), an offshoot of the Living Faith Church Worldwide (LFCW). The University commenced operation on October 21st, 2002. Covenant University is a growing, dynamic vision-birthed, vision driven University, founded on a Christian mission ethos and committed to pioneering excellence at the cutting edge of learning. Covenant University is a part of the bigger Canaanland community, where the 50,000-seat Faith Tabernacle (the largest church auditorium in the world) is sited. Figure b shows the entire Canaanland community which covers a landmass of 387 hectares, while Covenant University covers a larger chunk of 275 hectares. The university has a resident student and staff population of about 10,000. The university campus is home to five academic buildings, a lecture theatre, and university library adjoined by the University chapel, ten student's halls of residence, staff residential accommodation and other support facilities. The campus enjoys a relatively gentle slope that is sufficient enough to allow for flow of run-off water. Wastewater is collected through a central sewer network system. The site gradient provided the basis for the flow of wastewater through a network of pipelines by gravity to the Covenant University Constructed Wetland Wastewater Treatment Plant (CU-CWWTP). The CU-CWWTP serves both the University and the Canaanland community.

Figure b: Google image of Canaan land showing the CU-WWTP

4.0 Findings

Findings from interview with the operator of the CU-CWWTP, the Physical Planning Department (PPD), as it relates to the planning and layout, operation and maintenance cost and end-products of the CU-CWWTP are discussed as follows:

4.1 CU-CWWTP planning and layout

CU-CWWTP occupies an approximate land area of 10,000 square meters. The system consists of six units of four beds (P1-P4, P5-P8, P9-P12, P13-P16, P17-P20 and P21-P24) each. The beds are linked to each other by control valves and small openings to allow for continuous flow through the beds as shown in Figure c. All the beds (twenty-four in all) are seeded with water hyacinth plants previously trained to grow on and withstand the toxicity of raw sewage. The sewage gets progressively purified as it flows from one bed to another through the fast absorptive activities of the water hyacinth. The pathogens in the sewage are filtered off by the roots of the water hyacinth. Raw sewage is discharged through a network of sewer pipes from each building on the campus, into two anaerobic septic tanks at the CU-CWWTP. The sewer pipes were planned and laid out to take due advantage of the gentle topography of the campus. The CU-CWWTP is located at the lowest datum level on the campus. Thus, sewage is transported to the CU-CWWTP through a sewerage network of pipeline by gravity without the use of mechanical transportation either by trucks or any kind of pump system. Raw sewage from all buildings is centrally discharged into the two anaerobic septic tanks that serve as a central collection point. The purification process starts by feeding the raw sewage into the first bed through a central manhole. The cycle goes from each of the beds until it gets to the last bed where purified effluent is discharged into River Ijura from where it finally discharges into the Atlantic Ocean.

4.2 CU-WWTP operation and maintenance cost

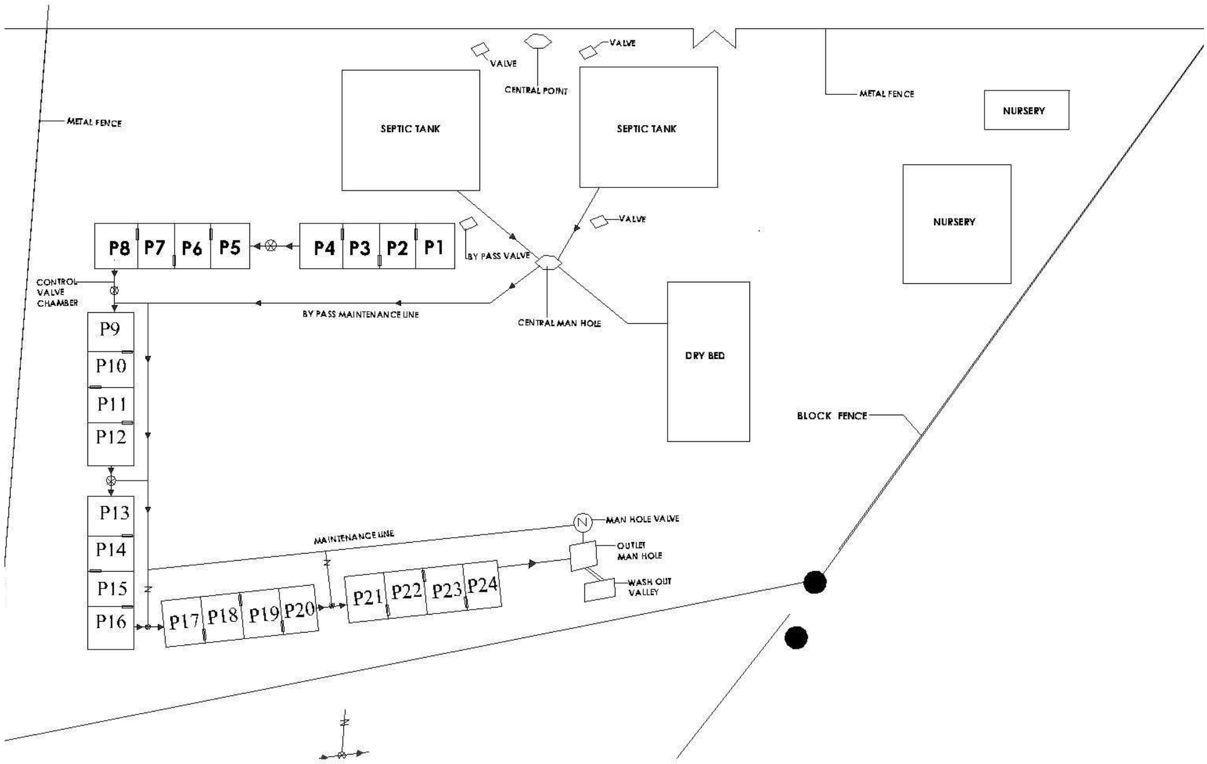

Figure c: Site Layout/ Process Diagram

The CU-CWWTP was constructed in 2003 at a cost of fourteen million, eight hundred and nine thousand, four hundred and seventy naira (eighty seven thousand, one hundred and fourteen dollars) through direct labour by the University's Physical Planning and Development unit (PPD). This is exclusive of cost of pipeline network, which is usually a function of the proximity of the respective buildings to the nearest inspection chamber which is then linked to the network of pipelines (and man-holes) leading to the CU-CWWTP. It is important to note that CU-CWWTP requires little or no maintenance as revealed by the PPD except for the need to keep the area well-trimmed by ensuring that weeds do not overgrow the area. Also the need to avoid environmental pollution through possible odour that may arise as a result of the plant has also necessitated the periodical application of a patented biotechnology called OBD-Plus (Oso Biodegrader-plus) developed by Prof. B. A. Oso. OBD-Plus is a biological agent consisting of a specially formulated consortium of non-pathogenic microbes borne on a specially prepared dry powdery medium of plant origin. The OBD-Plus is an excellent odour remover from sewage. It combines chemically with heavy metals and renders them innocuous and also bio-remediates oil-polluted environments. Between 2003 and 2012, only a single turnaround maintenance was carried out on the CU-CWWTP which has been in active use since it was constructed. This was done in 2012. This once in ten years maintenance frequency as confirmed by the PPD unit of the university is a critical empirical validation of the reliability and cost effectiveness of constructed wetlands in wastewater treatment as modelled by the CU-CWWTP.

4.3 CU-WWTP End-Products

The major output from the last bed is clean, odourless water, safe for discharge into the environment as pointed out by the PPD. It is important to note that the design of the CU-CWWTP has an inherent mechanism for collection of settled sludge. As the sewage flows from the first bed to the last, it is progressively purified by the absorptive activities of the water hyacinth. The particles in the sewage also progressively settles and cakes over a long period of time. This sludge has been found to contain nutrients that are useful as fertilizers for plants.

5.0 Discussion

The critical implications and learning points of the CU-CWWTP for sustainable campus and community planning include the following:

5.1 Cost effectiveness

The CU-CWWTP as currently deployed has proven to be a cost effective technology in several respects. Though the initial cost of construction cost of fourteen million, eight hundred and nine thousand, four hundred and seventy naira (eighty seven thousand, one hundred and fourteen dollars) seems enormous particularly in communities of developing countries, it is relatively low as compared to other treatment plant technologies to serve the population size of ten thousand (10,000) of the coverage area. Also pivotal to the cost-effectiveness of the CU-CWWTP is the simplicity of the plant operations and processes which inadvertently results in simple and easy maintenance procedures. The simplicity of the maintenance procedures has consequently resulted in low maintenance cost. It is important to note that information gathered from the PPD indicates that only one major maintenance of the CU-CWWTP. The maintenance was carried out in 2012, a decade after it was constructed. The uniqueness of the CU-CWWTP is inherent in the fact that the plant procedure is non-mechanical and non-labour intensive, thus non-capital intensive. In fact, it is actually operated almost at a zero-cost. The plant procedure is essentially an adaptation and simulation of nature which essentially is nature-made and nature sustained.

5.3 Functional effectiveness

The CU-CWWTP has been in continuous usage since it was built in 2003. A decade after, there has not been any reported case of water or environmental pollution arising from its use. This proves the efficiency of the CU-CWWTP. Isiorho and Oginni (2013) noted that results of bacteriological analysis of the CU-CWWTP indicated that the plant is able to remove the contaminants efficiently, thus, providing empirical validation that the output of the CU-CWWTP is safe for discharge into the environment.

5.4 Potentials and Possibilities

Universities are cities within a city. They are learning grounds for current and future leaders. They offer an environment for research and development with local, national and global interest. They have the potential to offer innovative solutions to some of our greatest global challenges through their research activities. According to Cole and Wright (2005), universities have immense spending power, and shifts in university operations offer many opportunities to improve human and ecosystem well-being, locally and globally. The CU-CWWTP has inherent potentials and possibilities to offer. Exploring these potentials and possibilities provides critical pathways needed for campuses and communities to develop integrated approaches to community sustainability especially with an emphasis on holistic wastewater treatment technologies. A critical core of the potentials and possibilities the CU-CWWTP offers include:

5.4.1 Reuse/Reclamation

Large water stressed regions exist today in the world. That a great percentage of the world's population do not have access to safe, clean water cannot be overemphasized. A vital source of water is the recycled water that originates from the treatment of wastewater, which replaces equal quantities of potable water (Xajipakkos et al 2000). Recycled water essentially implies water from treated wastewater. There are different levels of wastewater treatment ranging from secondary, tertiary to quaternary treatment with different level of water quality from restricted irrigation/agricultural use, non-restricted irrigation/agricultural use to potable drinking water (see Table 1). Presently the treated wastewater from CU-CWWTP is discharged into River Atura and then consequently into the Atlantic Ocean. It suffices to say that this water can be stored in an artificial lagoon and used for large irrigation purpose. A typical example is the Central Wastewater Treatment Plant at Vathia Gonia in Cyprus. The water, which results from the treatment of the wastewater, is stored in a 284,000 cubic metre lagoon. From there, it is distributed via a pumping main, break pressure tank and irrigation network to 50 hectares of land for the irrigation mainly of fodder crops (Xajipakkos et al 2000). The CU-CWWTP has such enormous potential for water storage and supply rather than just discharging treated water into River Atura. Though the CU-CWWTP does not exist in a water stressed area, optimizing her treated wastewater provides a lot of benefits in the area of irrigation, industrial cooling and possibly source of drinking water if so treated to such purity level.

5.4.2 Soil Conditioner (Fertilizer)

The design and mode of operation of the constructed wetland as deployed in the CU-CWWTP enables the settlement of sludge as the wastewater is purified as it flows from one bed to another across twenty-four beds. During this treatment process across several beds, particles in the waste water are screened through screening grits and settled at the bottom of each bed. Over a long period of time, the settled sludge is thickened and can be evacuated to a drying bed on site periodically or during maintenance session. The drying bed is an open suspended concrete structure that allows the thickened sludge to be sun-dried. Again this aspect of the operations of the CU-CWWTP is at minimal or near zero-cost. The dry and thickened sludge is useful and can then be transferred and spread onto land soil conditioner/ fertilizers. This is another viable nature treated and produced resource for agricultural purposes. Fertilizers are biological rather than chemical in nature, thus a viable delineator for sustainability. The CU-CWWTP simply converts waste into another useful commodity. Such a practice minimizes cost of production by eliminating or reducing to a critical minimum cost of raw materials. Beyond the environmentally friendly benefit that accrues from this kind of practice, it is also a sustainable practice in terms of offering reduction in cost of production for agricultural products.

5.4.3 Ancillary Uses

Beyond providing advanced treatment to wastewater, the CU-CWWTP can also be beneficial in nitrogen and saltwater filtering, supply of water and nutrients, production of food and support of endangered species. It can also provide wildlife habitat and recreational uses (also known as enhancement wetlands).

6.0 Conclusion:

The CU-CWWTP can be seen as a viable model in sustainable campus and community planning. The design, construction and operation of the plant is an exemplar in campus sustainability and provide a proven template and framework for sustainable practices in wastewater management. It is recommended that the CU-CWWTP model should be understudied by community administrators at all governance level with a bid to deploying same for effective wastewater treatment in emerging campuses and communities in developing nations. This model may also find suitability for water-stressed regions across and beyond the developing world.

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