DESIGN OF CONSTRUCTED WETLANDS FOR WASTEWATER & DRINKING WATER MANAGEMENT A STUDY PROJECTS for the University of Antananarivo Site

Author: FINARCH, Rafatro Tsiambanavalona

"This Fellowship offers a unique opportunity to gain specialized knowledge, explore innovative solutions, and develop practical skills in a field crucial for preserving our environment and the well-being of communities worldwide. Moreover, by working on a concrete project, fellows can have a real and measurable impact, further enhancing the value and relevance of this experience. " - Mr. Finarch

Editorial Notes: A Vision for Sustainable Water Management at the University of Antananarivo

The University of Antananarivo stands at the forefront of sustainable water management and rice research, thanks partially to the innovative research and design efforts of Mr. Finarch Rafatro Tsiambanavalona. As a key member of the 2024 Jacquelyn Sanders Foundation Fellowship team of engineers, Mr. Finarch brings experience and passion for environmental sustainability, specifically in water management, to the project.

Mr. Finarch's academic background in Petroleum Engineering from the Ecole Supérieure Polytechnique d'Antananarivo has equipped him with a profound understanding of water treatment and management processes. His commitment to sustainability is exemplified in his thesis, which focused on enhancing the efficiency of a wastewater treatment plant for an agro-food company. This project required him to conduct thorough diagnostics and formulate strategic recommendations, showcasing his ability to apply theoretical knowledge to practical, real-world challenges.

In the context of the University of Antananarivo, Mr. Finarch has meticulously investigated the campus landscape to design a technical plan that transforms several acres into a constructed wetland system. This system is envisioned not only to serve as an effective water storage area but also to position the university as a premier facility for rice research in Africa. By harnessing the natural processes of wetlands, Mr. Finarch aims to enhance the water management capabilities of the university, thereby contributing to a sustainable and ecologically sound environment.

His role in the design of the ponds is a critical step towards realizing the university's vision of becoming the largest rice permaculture agroforestry facility in Africa. The innovative approach to water sustainability spearheaded by Mr. Finarch promises to offer a blueprint for similar water management across the continent and beyond.

As we embark on this journey towards a more sustainable future, we are grateful for the expertise and dedication of motivated Students like Mr. Finarch, whose work not only supports the technical aspects of the project but also champions a broader commitment to environmental stewardship and resource preservation. His contributions are invaluable in our pursuit of creating a model of excellence in sustainable water management and agricultural research, and in engaged scholarship.

JACQUELYN JESTINE SANDERS FOUNDATION
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Abstract

The University of Antananarivo's "Garden of Eden Constructed Wetlands Rice Permaculture Agroforestry Initiative" aims to integrate innovative ecological solutions for wastewater treatment and water storage on campus. This project seeks to optimize artificial wetlands using vegetative filtration, specific substrates, and appropriate plants, addressing both wastewater treatment and stormwater management while supporting sustainable agriculture. The initiative includes subsurface and surface flow wetlands and a pond, each designed to meet the university's needs for water management and agricultural research. The project plans to implement subsurface flow lagoons for wastewater treatment and surface flow lagoons for water storage and rice cultivation. Key decisions include selecting cost-effective and environmentally beneficial lagoon lining materials. This project not only aims to enhance water management and agricultural practices but also positions the university as a leader in ecological engineering and sustainable development, providing practical research opportunities and contributing to environmental sustainability.

Keywords: Constructed wetlands, rice permaculture, water management, wastewater treatment, sustainable agriculture

Introduction

The University of Antananarivo Garden of Eden Constructed Wetlands Rice Permaculture Agroforestry Initiative aims to implement innovative ecological solutions for water management and pollutant treatment on the university campus. This document explores the concepts of subsurface flow wetlands and rice permaculture in the context of the University of Antananarivo, providing a detailed overview of the methods and systems proposed for optimizing the efficiency of these artificial aquatic environments. By incorporating elements such as vegetative filtration, specific substrates, and suitable plants, the initiative aims to create systems that not only treat wastewater and manage stormwater but also support sustainable agriculture. The following sections will examine the proposed designs for a subsurface flow wetland, a surface flow rice permaculture wetland, and a pond, tailored specifically to the needs and environment of the University of Antananarivo.

I. Case Study: University of Antananarivo Facility

The University of Antananarivo, located in Antananarivo, Madagascar, is embarking on a project to rescue its aged water management and to build up mission critical tree conservation & agricultural research capabilities, dependent upon abundant water. The facility requires efficient wastewater treatment solutions and reliable water storage systems for drinking water. To address both of these discrete these needs, the project will implement a series of subsurface flow lagoons for wastewater treatment and free flowing and connected surface flow lagoons for water storage and rice research beds.

I.1 Facility Needs

The primary objectives for the University of Antananarivo's project are:

1. Wastewater Treatment: Efficiently treat wastewater generated by the university to meet environmental standards and reuse the treated water for agricultural purposes.
2. Drinking & Agricultural Water Storage: Ensure a reliable supply of water for drinking and agricultural research, particularly for rice cultivation.
3. Research and Education: Provide practical research opportunities for students and faculty in sustainable agriculture and water management.

The "University of Antananarivo Garden of Eden Constructed Wetlands Rice Permaculture Agroforestry Initiative" represents a groundbreaking opportunity for the university to lead the way in Africa by integrating permaculture principles with traditional rice production. This initiative addresses the pressing need for efficient water use in a region where water scarcity is a critical issue. Conventional rice production is highly water-intensive and often diverts water from essential drinking water needs, leading to inefficiencies and shortages. By implementing this innovative plan, the university can demonstrate that man-made wetlands are precisely what is needed to solve its water demands. The project exemplifies a significant environmental advancement, showcasing that sustainable, constructed wetlands can provide a dual solution: enhancing water management and supporting agricultural productivity. This initiative not only meets immediate water needs but also positions the University of Antananarivo as a leader in sustainable agricultural practices and ecological responsibility.

II. Design and Layout

II.1 Subsurface Flow Lagoons (for Wastewater Treatment)

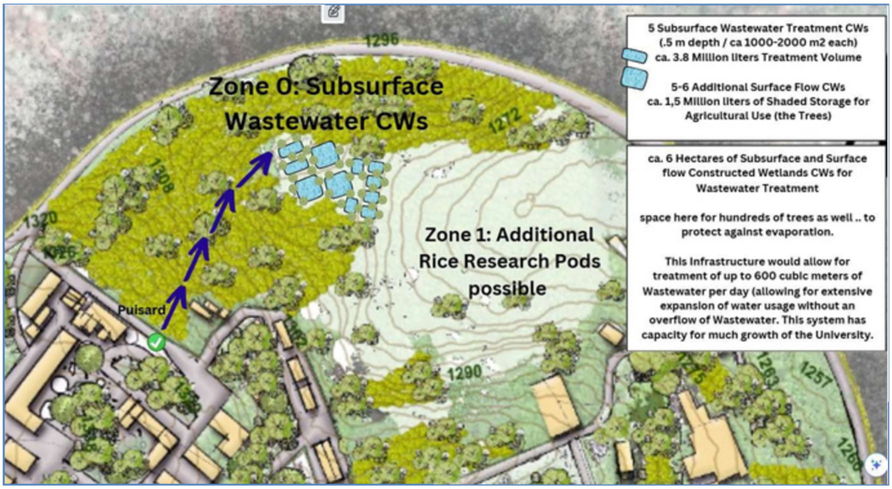

Figure 1 : Zones 0, 1, University of Antananarivo Source: Coman,

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The subsurface flow lagoons are designed to treat wastewater through a natural biological filtration process. These lagoons will be strategically placed to maximize their efficiency and integration with the university's infrastructure.

Key Features for Planning

- Dimensions: Each lagoon will have a depth of 0.3 to 0.9 meters.
- Substrates: Layers of gravel, sand, and soil to facilitate filtration and root growth.
- Plants: Common reed (Phragmites australis) will be used for his pollutant removal capabilities.
- Flow System: Horizontal flow system to maintain a saturated environment for optimal filtration.

Design: The subsurface flow lagoons will be designed with an inlet area of 2 meters, an outlet area of 1 meter, and a central filtration area with specific granulometry as per the Austrian standard ÖNORM B 2505.

II.2 Surface Flow Lagoons for Drinking Water Management

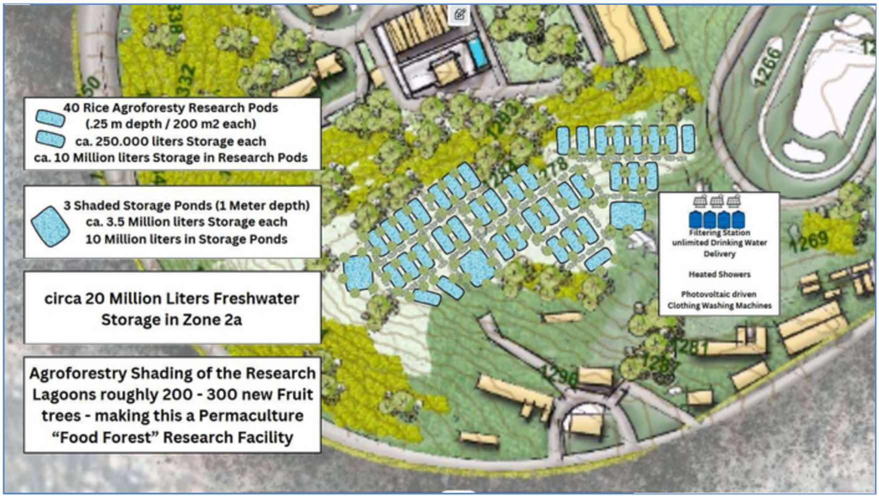

Figure 2: Zone 2A, University of Antananarivo Source: Coman,

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The surface flow lagoons will be utilized for storing drinking water and supporting rice research beds. These lagoons will be designed to ensure minimal evaporation and maximum water retention.

Key Features:

- Dimensions: Maximum depth of 2 meters, with additional depths of 2.5 to 3 meters for winter fish survival.
- Substrates: Layers of gravel, sand, and soil for water storage and rice cultivation.
- Plants: Fruit plant like papaya, citrus and banana around the periphery to provide shade and reduce evaporation.

Design: The surface flow lagoons will include embankments upstream to prevent sediment deposits and downstream for fish management. A synthetic lining will be used to ensure water impermeability, with a geotextile underlayer to protect the liner.

II.3 Integration with the Site

The layout of the lagoons will be designed to harmoniously integrate with the existing university landscape. The placement of lagoons will ensure easy access for maintenance and monitoring while providing an aesthetically pleasing environment for students and staff.

Proposed Layout

- Wastewater Treatment Lagoons: Located near the main wastewater discharge points to minimize the distance for wastewater transport.
- Water Storage and Research Lagoons: Positioned in areas with optimal sunlight for rice cultivation and easy access for research activities.

II.4 Expected Benefits

- Environmental: Significant reduction in pollutants from wastewater, contributing to cleaner local water bodies.
- Agricultural: Enhanced research opportunities in rice cultivation and permaculture techniques, leading to improved agricultural practices.
- Educational: Hands-on learning experiences for students in sustainable water management and ecological engineering.

Case Study – Antananarivo

The University of Antananarivo's project represents a comprehensive approach to integrating wastewater treatment and water storage solutions. By implementing subsurface flow lagoons for wastewater treatment and surface flow lagoons for water storage and rice research, the university will not only address its immediate water management needs but also contribute to the field of sustainable agriculture.

III. Subsurface Flow Constructed Wetland for Wastewater Treatment

Constructed wetlands, with depths ranging from 0.3 to 0.9 meters, immerse substrates and roots, thereby promoting the growth of biofilm and the removal of pollutants. Plants such as bulrush and common reed are commonly used in subsurface drainage systems. Numerous studies have proven the effectiveness of artificial wetlands in treating urban wastewater and removing various pollutants. Horizontal and vertical flow systems operate in different environments, whether aerobic or anaerobic, to degrade pollutants, with hydraulic retention times varying according to studies.

In horizontal subsurface flow systems, wastewater moves horizontally through substrates located in a bed planted beneath the surface of macrophytes. Horizontal filters are uniformly filled with gravel, imported sand, or in-situ soil, in which reeds take root. Water circulates horizontally through the filter, often continuously, thus keeping the filter beds saturated permanently. There is no water surface exposed to the atmosphere, as the water level is maintained 5-10 cm below the surface of the gravel layer. The horizontal filter does not receive raw effluent, as it is pre-treated to reduce suspended solids that could clog the filter.

Horizontal filters are saturated with water thanks to an outlet siphon system that allows adjusting the water height in the basin. Phragmites reeds planted in the horizontal filter effectively reduce many pollutants. The optimal bed depth is 0.6 meters, corresponding to the maximum depth reached by the reeds' rhizomes in a saturated environment. Additionally, the bed slope is 1% to allow the filter to drain. According to the Austrian standard ÖNORM B 2505, it is recommended to use granulometries of 40 to 80 mm for the inlet and outlet areas. The inlet area should be 2 meters long, while the outlet area should be 1 meter long. Finally, the substrate granulometry in the middle should be between 20 and 30 mm.

This thorough analysis process and various recommendations from literature and standards, such as the Austrian standard ÖNORM B 2505, led me to propose the subsurface flow wetland system described below. By considering the optimal depths of substrates, the types of plants to use, as well as the appropriate dimensions and granulometries for the inlet and outlet areas, I was able to develop a detailed and efficient design proposal. This design, illustrated in the following figure, integrates all these considerations to ensure optimal wastewater treatment while minimizing clogging risks and maximizing pollutant degradation efficiency.

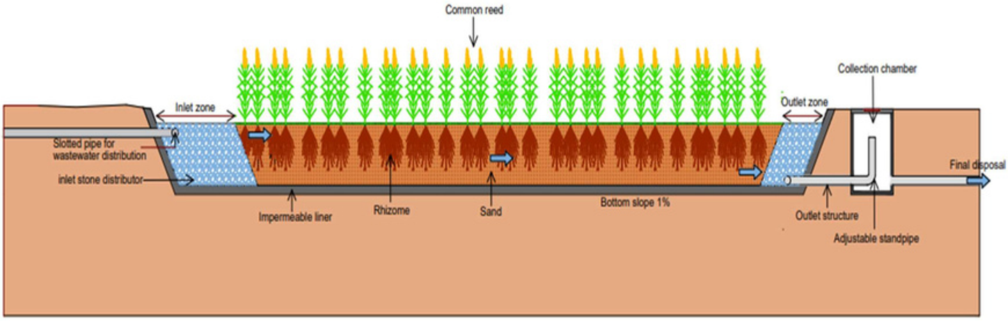

Figure: Subsurface Lagoon Planning: Source: Finarch 2024 (Author)

IV. Freshwater Rice Permaculture Lagoon with Surface Flow

A freshwater rice permaculture lagoon with surface flow is an integrated system that combines permaculture techniques with rice cultivation in an aquatic environment. The constructed wetland for stormwater management is designed to manage stormwater by storing and treating it through vegetative filtration and substrates such as gravel and sand. Subsurface flow occurs in the middle of this system, and aquatic plants can be planted above it.

Research shows that the combined cultivation of rice and citrus on marshy lands greatly benefits from the integration of advanced agricultural technologies and institutional support for farmers. Banana trees, often grown in association with rice and fruit trees like papaya, play an intermediate shading role and provide a food source for households, while the surplus is intended for sale.

By combining these two concepts, it is possible to plant rice above the subsurface flow and position fruit trees around the wetland. The composition of the substrates in the artificial
subsurface flow wetland, made up of soil, sand, and gravel, allows for planting rice above this
soil, as rice paddies are used in managed wetlands in Southeast Asia.

To illustrate the concept of the freshwater rice permaculture lagoon with surface flow and integrate the dimensions of the previously described subsurface flow lagoon, here is a detailed diagram of the proposed design.

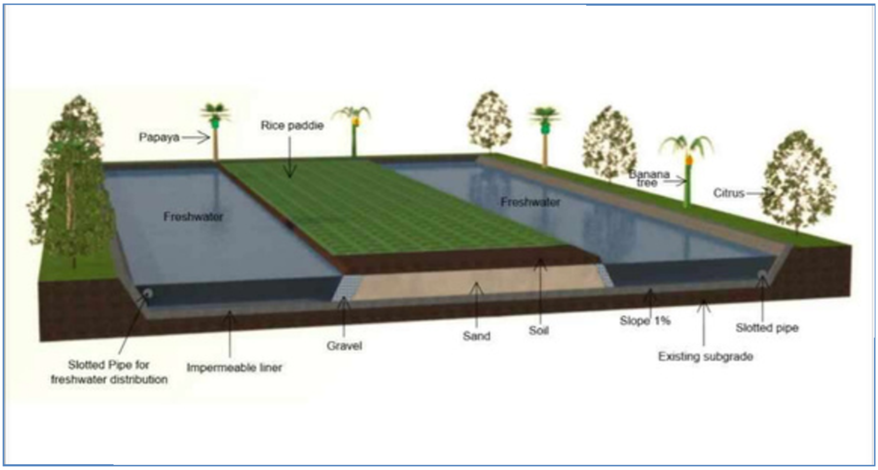

Figure: Proposed freshwater rice permaculture lagoon with Surface Flow design
Source: Finarch – 2024 (Author)

V. General Pond / Lagoon Considerations

A pond is a shallow, generally artificial, stagnant freshwater body that can be drained, resting in a basin with an impermeable bottom. A pond of varied shape is the most suitable. Due to their transitional nature between terrestrial and aquatic environments, ponds can also resemble wetlands.

Hillside reservoirs are ponds fed by runoff and precipitation, but not by rivers. A wetland naturally develops around these ponds. They serve as water reservoirs during heavy rainfall and can be connected in succession, requiring embankments upstream to prevent sediment deposits and downstream for fish management. A pond should not be too deep to promote the development of aquatic and amphibious vegetation and to limit thermal stratification. A pond can have a maximum depth ranging from 1.5 to 2 meters. For the survival of fish during winter, an additional depth of 2.5 to 3 meters is necessary.

Water is the structuring and driving element of ponds. Each pond is characterized by the balance between water inflows and outflows. In our case, embankments upstream and downstream of the pond are used since the pond is fed only by runoff and rainwater. The size of the structure is limited to reduce the evaporation of stored water.

After a thorough analysis of the different options, it appears that a synthetic liner, combined with a geotextile underlay, is often preferred due to its cost and durability.

For instance, although natural liners are an option, they can be more expensive. Additionally, among the various synthetic materials, an EPDM rubber liner is considered a better alternative to PVC, particularly for its longevity and lower environmental impact during disposal. Planting trees and hedges is also recommended to provide shade and reduce evaporation.

Building on this foundation, it's important to carefully consider the subsequent steps in the pond's development to ensure its ecological balance and sustainability. It is recommended to cover this layer with 20 cm of soil. The vegetation associated with stagnant water should be suited to the pond's mode of operation, with limited plant introduction. Common reed, for example, is advised for its purifying properties. Similarly, the introduction of fauna should be limited, with only a few small fish in very small quantities.

Considering these essential characteristics and requirements of ponds and hillside reservoirs, I have proposed a layout that harmoniously and effectively integrates these elements.

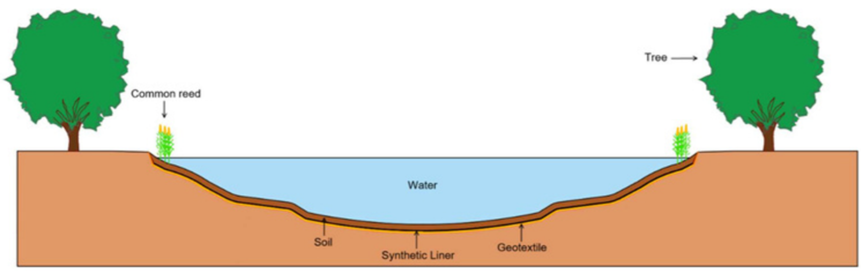

Figure: Freshwater Storage Concept Source: Finarch – 2024 (Author)

Conclusion

The University of Antananarivo's "Garden of Eden Constructed Rice Permaculture Wetlands" project represents a visionary approach to integrating wastewater treatment and water storage solutions, serving as a model for sustainable water management and agricultural research. The proposed design at this stage underscores the technical vision for the project, setting the foundation for detailed planning and site-specific analysis, in cooperation with constructed wetlands experts. The next steps will involve conducting a comprehensive on-site survey of the site to inform the precise placement and dimensions of the subsurface and surface flow lagoons. Additionally, a critical decision remains regarding the lining materials for the lagoons. While a strictly synthetic liner is the most cost-effective option, the potential use of bentonite provides a more natural solution, albeit at a significantly higher cost. This choice will require careful consideration of both budgetary constraints and environmental benefits. The environmental benefits for the university should not be underestimated. The proposed functional landscape will support the local ecosystem and substantially improve water management at the university. Unlike traditional solutions, such as water tanks, which have been tried and found wanting, this project offers a renewable, natural solution. By implementing constructed wetlands, the University of Antananarivo positions itself at the forefront of utilizing green infrastructure for comprehensive and environmentally responsible water management. This project will create a beautiful and sustainable landscape, enhancing the university's role as a leader in ecological engineering and sustainable practices. The holistic approach demonstrated here has the potential to address current and future environmental challenges, ensuring that the University of Antananarivo not only meets its immediate water management needs but also contributes positively to the environment and community.

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