WASTE STABILIZATION PONDS

AND

CONSTRUCTED WETLANDS

DESIGN MANUAL

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Acknowledgement

This Design Manual has been prepared through a grant from DANIDA ENRECA. as part of the outcome of research on the application of waste stabilization ponds and constructed wetlands for wastewater treatment in Tanzania. The Constructed Wetlands and Waste Stabilization Ponds (CWWSP) project is a joint research project between The Danish University of Pharmaceutical Sciences, Department of Analytical Chemistry, Section of Environmental Chemistry, Danish Technological University (DTU) and The Prospective College of Engineering and Environmental Technology, University of Dar Es Salaam, Tanzania.

Recognition is extended to the following individuals who provided assistance on the compilation of WSP and CW module incorporated in this manual: Richard Kimwaga - University of Dar es Salaam, Prospective College of Engineering and Technology, WSP & CW Research Project: *Model on total suspended solids removal in a coupled constructed dynamic roughing filters and horizontal subsurface flow constructed wetland;* Athanas Haule, University of Dar es Salaam, Prospective College of Engineering and Technology, WSP & CW Research Project: *Modelling nitrogen removal from domestic wastewater by indigenous macrophytes in Horizontal subsurface flow constructed wetlands in Tanzania;*Charlotte Nielsen, University of Copenhagen, Danish University of Pharmaceutical Sciences: *Model on removal of lead, copper and zinc by subsurface flow constructed wetlands;* Merete Bang Petersen, University of Copenhagen, Danish University of Pharmaceutical Sciences: *Model on removal of phosphorous by subsurface flow constructed wetlands;* Dr. Athuman Masudi Senzia, University of Dar es Salaam, Prospective College of Engineering and Technology, WSP & CW Research Project: *Model on the transformation of nitrogen in waste stabilization ponds and constructed wetlands;* William Mwegoha, University of Dar es Salaam, Prospective College of Engineering and Technology, WSP & CW Research Project: *Model on suspended solids removal by subsurface flow constructed wetlands.* A special thanks also is extended to Esben Bruun and Mikke Poulsen and all who gave liberally of their time and expertise in providing a technical review of this manual.

The present Design Manual on Waste Stabilization Ponds and Constructed Wetlands is a joint publication by UNEP-IETC with the Danish International Development Agency (Danida).

Part One

Chapter One: Introduction

1.1 Importance of Waste Stabilization Ponds and Constructed Wetlands in Wastewater Treatment in Tropical Climates

Waste Stabilization Ponds (WSP) and Constructed Wetlands (CW) have proven to be effective alternatives for treating wastewater, and the construction of low energy-consuming ecosystems that use natural processes, in contrast to complex high-maintenance treatment systems, will hopefully lead to more ecologically-sustainable wastewater treatment in the future. CWs and WSPs also have the capability of meeting the demand for a high percentage removal of pathogenic organisms, compared to conventional technologies. CWs and WSPs combined, and joined with other technologies, may be important for even more improved performance of water cleaning systems. WSP's and CW's are now well-established methods for wastewater treatment in tropical climates. Their many advantages include: simplicity, low cost, low maintenance, low energy consumption, robustness, and sustainability. While WSPs are most commonly used for treating domestic wastewaters, they are also successfully used for treating industrial wastewater, including water that contains agro-industrial wastes. One of the potential advantages of using constructed wetlands is that they do not allow mosquitoes to breed (sub-surface flow wetland). The process of designing WSPs and wetlands, and predicting their performance, is improving rapidly as we gain more experience with these systems.

Many countries in tropical climates use WSPs for wastewater treatment (e.g., Tanzania, Kenya, Malawi, Uganda, Zambia, Botswana, Zimbabwe). Many of these systems have been performing below the required standards, due to lack of proper operation and maintenance (Kayombo *et al*., 1998). Constructed wetlands have not yet received the deserved attention as an alternative method for wastewater treatment.

1.2 Overview

This manual provides comprehensive technical information about the planning, design, construction and operation of WSPs and CWs for a wide range of applications. To understand

and design WSPs and CWs requires the involvement of expertise in a variety of fields, including chemistry, hydrology, soil science, plant biology, natural resources, environmental management, ecology, environmental engineering, surveying, and project management.

1.3 Why Produce a Manual for Waste Stabilization Ponds and Constructed Wetlands?

This manual has been produced to provide necessary information regarding most aspects of the design and implementation of WSPs and CWs. Lack of such information, and an integrated approach, has led to the development of many WSPs and CWs that are inappropriate, under-performing, or poorly designed or maintained. The reasons for these problems include:

- Lack of appreciation by many designers of the complex, physical, biological and chemical processes within WSPs and CWs;
- Lack of consistency in design, construction and operation aimed at optimal performance;
- Lack of appropriate design tools and methodologies suitable for local conditions; and
- Changing nature of rapidly-developed technology

Although WSPs and CWs are often relatively simple in engineering terms, they are extremely complex ecological systems. Performance of WSPs and CWs relies not only on good design, but also good construction and operation. This design manual for WSP and CW has adopted the design approaches detailed by D.D. Mara (WSP design approaches), and the design approach for the constructed wetlands given by Department of Land and Water Conservation, New South Wales (Volume 1 and 2). Part one of this manual provides a description of the design of WSPs, while Part two provides a detailed description on the design of CW's. The management of WSP and CW is discussed in Part three, while Part four focuses on modelling of WSP and CW ecosystems. Specific design examples are given as appendices in the file, "**Design examples.**"

1.4 Design Tools and Rapidly-Developing Technology

WSP and CW designers come from many different backgrounds or disciplines, including civil engineering, environmental engineering, microbiology, chemical engineering, soil science, or natural resources management. Many of the WSP and CW design tools and models have been adopted from countries with temperate climates. Thus, not all models can be transferred and used in tropical climate countries. For example, the hydrology and climate in tropical African is significantly different to that of most States in the United States or Europe. Nutrient removal in these countries has a high priority, whereas the removal of pathogenic organisms has a high priority in tropical countries. Most empirical model or design tools developed and used on-site or regionally-specific WSPs or CWs data. Different characteristics, in terms of climate and hydrology, can lead to problems when models are transferred without appropriate modification for local conditions. Further, using simple tools or "rule of thumb" methods, in lieu of appropriate design techniques, often results in malfunctions or a reduced efficiency in the effect of WSP's and CW's.

1.5 Objectives

The objectives of this waste stabilization and constructed wetland manual are as follows:

- To provide WSP and CW designers, builders and operators with appropriate information to develop, implement and operate WSP and CW for a range of applications and design objectives;
- To provide standard systems approach that can be adopted universally, and which can accommodate a development technology, with changes in information concepts and ideas with time;
- Provide theoretical background on the biological, chemical and physical processes of WSPs and CWs, the current state of the technology and technical knowledge on how to design, operate and maintain the systems; and
- Provide theoretical knowledge on how the models can be used in the best manner to describe the systems.

Chapter Two: Waste Stabilization Ponds

2.1 Application of Waste Stabilization Pond Systems

Waste Stabilization Ponds (WSPs) are large, shallow basins in which raw sewage is treated entirely by natural processes involving both algae and bacteria. They are used for sewage treatment in temperate and tropical climates, and represent one of the most cost-effective, reliable and easily-operated methods for treating domestic and industrial wastewater. Waste stabilization ponds are very effective in the removal of faecal coliform bacteria. Sunlight energy is the only requirement for its operation. Further, it requires minimum supervision for daily operation, by simply cleaning the outlets and inlet works. The temperature and duration of sunlight in tropical countries offer an excellent opportunity for high efficiency and satisfactory performance for this type of water-cleaning system. They are well-suited for low-income tropical countries where conventional wastewater treatment cannot be achieved due to the lack of a reliable energy source. Further, the advantage of these systems, in terms of removal of pathogens, is one of the most important reasons for its use.

2.2 Types of Waste Stabilization Ponds and Their Specific Uses

WSP systems comprise a single string of anaerobic, facultative and maturation ponds in series, or several such series in parallel. In essence, anaerobic and facultative ponds are designed for removal of Biochemical Oxygen Demand (BOD), and maturation ponds for pathogen removal, although some BOD removal also occurs in maturation ponds and some pathogen removal in anaerobic and facultative ponds (Mara, 1987). In most cases, only anaerobic and facultative ponds will be needed for BOD removal when the effluent is to be used for restricted crop irrigation and fish pond fertilization, as well as when weak sewage is to be treated prior to its discharge to surface waters. Maturation ponds are only required when the effluent is to be used for unrestricted irrigation, thereby having to comply with the WHO guideline of >1000 faecal coliform bacteria/100 ml. The WSP does not require mechanical mixing, needing only sunlight to supply most of its oxygenation. Its performance may be measured in terms of its removal of BOD and faecal coliform bacteria.

2.3 Processes in Waste Stabilization Ponds

2.3.1 Anaerobic ponds

Anaerobic ponds are commonly 2 – 5 m deep and receive wastewater with high organic loads (i.e., usually greater than 100 g BOD/m^3.day, equivalent to more than 3000 kg/ha.day for a depth of 3 m). They normally do not contain dissolved oxygen or algae. In anaerobic ponds, BOD removal is achieved by sedimentation of solids, and subsequent anaerobic digestion in the resulting sludge. The process of anaerobic digestion is more intense at temperatures above 15^o C. The anaerobic bacteria are usually sensitive to pH <6.2. Thus, acidic wastewater must be neutralized prior to its treatment in anaerobic ponds. A properly-designed anaerobic pond will achieve about a 40% removal of BOD at 10^o C, and more than 60% at 20^o C. A shorter retention time of 1.0 - 1.5 days is commonly used.

2.3.2 Facultative ponds

Facultative ponds (1-2 m deep) are of two types: Primary facultative ponds that receive raw wastewater, and secondary facultative ponds that receive particle-free wastewater (usually from anaerobic ponds, septic tanks, primary facultative ponds, and shallow sewerage systems). The process of oxidation of organic matter by aerobic bacteria is usually dominant in primary facultative ponds or secondary facultative ponds.

The processes in anaerobic and secondary facultative ponds occur simultaneously in primary facultative ponds, as shown in Figure 2.1. It is estimated that about 30% of the influent BOD leaves the primary facultative pond in the form of methane (Marais 1970). A high proportion of the BOD that does not leave the pond as methane ends up in algae. This process requires more time, more land area, and possibly 2 -3 weeks water retention time, rather than 2 -3 days in the anaerobic pond. In the secondary facultative pond (and the upper layers of primary facultative ponds), sewage BOD is converted into "Algal BOD," and has implications for effluent quality requirements. About 70 – 90% of the BOD of the final effluent from a series of well-designed WSPs is related to the algae they contain.

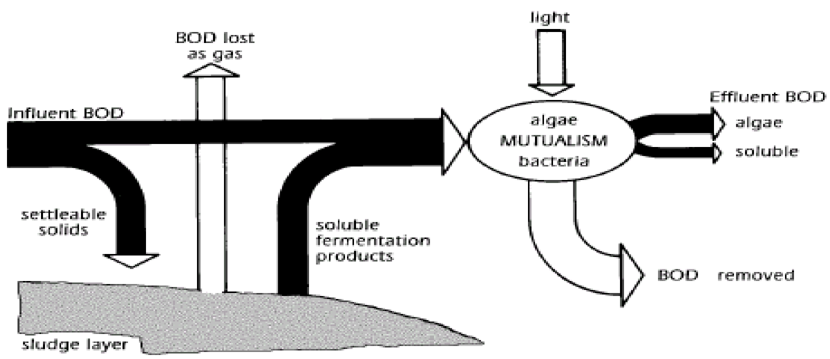

Fig. 2.1 Pathways of BOD removal in primary facultative ponds (After Marais, 1970)

In secondary facultative ponds that receive particle-free sewage (anaerobic effluent), the remaining non-settleable BOD is oxidised by heterotrophic bacteria (*Pseudomonas, Flavobacterium, Archromobacter and Alcaligenes* spp). The oxygen required for oxidation of BOD is obtained from photosynthetic activity of the micro-algae that grow naturally and profusely in facultative ponds

Facultative ponds are designed for BOD removal on the basis of a relatively low surface loading (100 – 400 kg BOD/ha.day), in order to allow for the development of a healthy algal population, since the oxygen for BOD removal by the pond bacteria is generated primarily via algal photosynthesis. The facultative pond relies on naturally-growing algae. The facultative ponds are usually dark-green in colour because of the algae they contain. Motile algae (*Chlamydomonas* and *Euglena*) tend to predominate the turbid water in facultative ponds, compared to none-motile algae (*Chlorella*).

The algal concentration in the pond depends on nutrient loading, temperature and sunlight, but is