

Copyright is owned by the Author of the thesis. Permission is given for a copy to be downloaded by an individual for the purpose of research and private study only. The thesis may not be reproduced elsewhere without the permission of the Author.

**TRACER STUDIES OF A SUBSURFACE FLOW
WETLAND**

A thesis submitted in partial fulfilment
of the requirements for the degree
of

MASTER OF TECHNOLOGY

in

ENVIRONMENTAL ENGINEERING

by

JULIUS NARENDRA PRASAD

Department of Process and Environmental Technology

Massey University

1996

628.168

Pra

DC20

ABSTRACT

The use of constructed wetlands represents an innovative approach to wastewater treatment. However, the treatment performance of constructed wetlands has been variable due to an incomplete knowledge of the hydraulic characteristics. Current design methods idealise constructed wetlands as plug flow reactors ignoring the existence of longitudinal dispersion, short-circuiting and stagnant regions. The overall effect will be a reduction of treatment efficiency at the outlet.

This thesis investigates the hydraulic characteristics of a subsurface flow wetland using a fluorescence dye tracer so as to determine the difference between theoretical and actual retention times and their effect on treatment efficiency.

A thorough review of the literature is undertaken, firstly examining wetland systems and their treatment mechanisms, it then reviews their hydraulic characteristics and design considerations while finally discussing dye tracing studies.

A series of dye tracing trials were undertaken on a pilot scale gravel bed wetland with a theoretical retention time of four days. The results from this research are presented as plots of dye concentration versus time at the outlet. These results are analysed in terms of chemical reactor theory and their implications on performance of various treatment mechanisms is discussed.

ACKNOWLEDGMENT

I am indebted to Andrew Shilton, my supervisor, for his patience, support and encouragement during the development and completion of my research.

I wish to thank the Kapiti District Council for the use of their wetland. My sincere thanks to the staff of the Sewage Treatment Plant for their willingness to help at difficult times.

I am grateful to Dr. Kathy Kittson for her help in understanding and operating laboratory equipment.

My deepest appreciation to the staff in the Department of Process and Environmental Technology for their friendly and supportive help throughout the study.

My sincerest thanks to my flatmates, Andrew Slaney and Paul Bickers for their great sense of humor and willingness for a game of golf in any type of weather.

My gratitude to the McMinn family and especially Kiri for being a wonderful and understanding friend whenever I needed her.

I cannot thank my loving mum and sister enough for all their prayers and encouragement during some very difficult times.

This Thesis is dedicated to my best friend, Lord and Savior, Jesus Christ.

TABLE OF CONTENTS

	Page
ABSTRACT	I
ACKNOWLEDGEMENTS	II
TABLE OF CONTENTS	III
LIST OF FIGURES	VII
LIST OF TABLES	IX
CHAPTER 1. INTRODUCTION	1
CHAPTER 2. LITERATURE REVIEW	3
2.1 OVERVIEW OF CONSTRUCTED WETLAND SYSTEMS	3
2.1.1 Development History	3
2.1.2 Constructed Wetlands	4
2.1.2.1 Definition	4
2.1.2.2 Free Water Surface Wetlands	4
2.1.2.3 Subsurface flow Wetlands	5
2.1.2.4 Vertical Flow Wetlands	7
2.1.3 Specific Pollutant Removal Mechanisms	7
2.1.3.1 BOD Removal	7
2.1.3.2 Suspended Solids Removal	12
2.1.3.3 Nitrogen Removal	13
2.1.3.4 Phosphorus Removal	15
2.1.3.5 Pathogen Removal	16
2.1.3.6 Heavy Metal Removal	17

2.2 HYDRAULIC CONSIDERATIONS AND SIZING	18
2.2.1 Hydraulic Retention Time	18
2.2.2 Water Depth	18
2.2.3 Aspect Ratio	19
2.2.4 Area Estimation	19
<i>2.2.4.1 Cross-sectional Area</i>	19
<i>2.2.4.2 Surface area</i>	20
2.2.5 Flow in Subsurface Flow Systems	21
2.2.6 Hydraulic Conductivity	22
2.2.7 Organic Consideration	23
2.2.8 Hydraulic Loading Considerations	25
2.2.9 Actual Hydraulic Retention Time	25
2.3 DYE TRACING	27
2.3.1 Purposes of Tracer Studies	27
2.3.2 General Description of Dye Tracer	27
<i>2.3.2.1 Theory</i>	27
2.3.3 Fluorescent Dyes	29
<i>2.3.3.1 Types recommended for tracing</i>	29
<i>2.3.3.2 Rhodamine WT</i>	31
2.3.4 Factors Which Affect Fluorescence	32
<i>2.3.4.1 Temperature</i>	32
<i>2.3.4.2 Suspended Solids</i>	33
<i>2.3.4.3 Chlorine</i>	33
2.3.5 Stimulus-Response Techniques	34
2.3.6 Calibration Curves	34

3.4.1.5 <i>Tracer Volume Calculations</i>	62
3.4.2 Field Work	62
3.4.2.1 <i>First Run</i>	62
3.4.2.2 <i>Second Run</i>	63
3.4.2.3 <i>Third Run</i>	63
3.4.3 Sample Analysis	64
CHAPTER 4. RESULTS AND DISCUSSIONS	66
4.1 CALIBRATION CURVES	66
4.1.1 Temperature Effect	66
4.1.2 Time Delay Effect	68
4.2 RESIDENCE TIME DISTRIBUTION	68
4.3 HYDRAULIC RETENTION TIMES	71
4.3.1 Inlet Flow Distribution	75
4.3.2 Treatment Efficiency	76
4.4 DEAD VOLUME	80
4.5 DISPERSION NUMBER	81
4.6 DYE RECOVERY	82
4.7 MODELS	83
CHAPTER 5. CONCLUSION	86
BIBLIOGRAPHY	89
APPENDICES	94

LIST OF FIGURES

Figures		Page
2.1	Typical cross-section of a surface flow wetland	6
2.2	Typical cross-section of a subsurface flow wetland	8
2.3	Typical cross-section of a vertical flow wetland	9
2.4	Nitrogen removal in wetlands	14
2.5	Water-level curves for reed-bed treatment systems with different hydraulic conductivity	24
2.6	Mean and theoretical retention times	26
2.7	Lateral mixing and longitudinal patterns and changes in distribution of concentration from a single centre slug injection of tracer	28
2.8	Typical graph for instantaneous dye injection	30
2.9	Stimulus-response techniques commonly used for flow in vessels	35
2.10	Types of calibration curves	36
2.11	Dispersed plug-flow for varying dispersion number	40
2.12	Normalised plot of C-curve called the E-curve	42
2.13	Determining parameters for residence time distribution	43
2.14	One dimensional mass balance for dispersed plug flow model	50
2.15	Open and Closed vessels	52
3.1	Longitudinal cross-section of the subsurface flow wetland	57
3.2	Dimensions of the subsurface flow wetland	59
3.3	Positions of dye injection and collection	65
4.1	Calibration Curves	67
4.2	Linear Calibration Curves	67
4.3	Calibration curves at varying temperatures	69

4.4	Time delay on fluorescence	69
4.5	Retention time comparison of run 1	70
4.6	Retention time comparison of run 2	72
4.7	Retention time comparison of run 3	73
4.8	Dye concentration versus Time	74
4.9	Fit of the dispersed plug flow and the tank-in-series models	85

LIST OF TABLES

Table		Page
1	Recommended design depth for subsurface flow wetland	19
2	Typical media hydraulic conductivity	23
3	Properties of Rhodamine Wt dye tracer	32
4	The effect of free chlorine on Rhodamine	33
5	Summary of Residence Times of the Three Runs	68
6	Summary of Mean Retention Times	75
7	Treatment Efficiency Comparison	79
8	Effective Volume and Dead Space of the Wetland	80
9	Dispersion Number and Coefficient	81
10	Dye Tracer Recovery	82

CHAPTER 1

INTRODUCTION

Natural wetlands have been used for many decades as a discharge site for wastewater. In recent years, their natural treatment processes has been recognised. Today there are numerous wetlands in use for waste treatment with a strong trend towards artificial wetlands specially designed for this application. The use of constructed wetlands which mimic natural marshlands, represents an innovative approach to wastewater treatment (*Bharridimarri et al., 1991*). Constructed wetlands have potential to provide low-cost and low-maintenance biological treatment of wastewater (*Fisher, 1990*). However, the treatment performance of constructed wetlands has been variable. This variability is due to an inadequate understanding of how to optimise the physical, chemical and biological processes providing treatment and an incomplete knowledge of the hydraulic characteristics that typify constructed wetlands (*Fisher, 1990*).

The efficiency of wastewater treatment in constructed wetlands is largely dependent on the effective duration of contact between the pollutants and the microbial populations. This concept is common to any reactor system. The degree of treatment being directly related to the residence time and efficiency of contact. To obtain maximum treatment efficiency, it is necessary to maximise contact between the wastewater contaminants, the wetland media and the plant roots/stems and minimise short circuiting (*Steiner & Freeman, 1989*). Current design methods idealise the constructed wetland as a plug flow reactor and use a "residence time" based solely on the volume of the wetland cell and the flow-rate (*Stairs, 1993*).

This idealisation ignores the existence of longitudinal dispersion, short-circuiting and stagnant regions within the wetland cells. The result of these phenomena is that the fluid elements are not retained in the wetland cell for the theoretical retention time, rather there is a distribution of residence time. If a system is designed as plug-flow ignoring the of distribution of residence time, the overall effect will be a reduction of treatment efficiency at the outlet.

An insufficiently understood aspect of constructed wetlands design is the hydraulic regime. Currently used hydraulic design criteria in the field of constructed wetlands are largely theoretical. An appreciation of the hydraulic regime and actual detention time in a wetland system is a prerequisite to the understanding of the treatment mechanisms and the effectiveness of the purification provided by such systems (*Fisher, 1990*). By injecting a fluorescent tracer into the system, an assessment of the hydraulic regime can be obtained. Tracer methods have been used extensively in chemical reactor analysis and have been employed frequently in more conventional wastewater treatment technologies, such as stabilisation ponds (*Slade, 1992; Stairs, 1993*).

This thesis investigates the hydraulic characteristics of a subsurface flow wetland using Rhodamine WT (fluorescent dye tracer) so as to firstly, determine the difference between theoretical and actual retention times and their effects on treatment efficiency. Secondly, to show through the calculation of the treatment efficiency that the current assumption of wetland being an ideal plug-flow reactor is not valid.