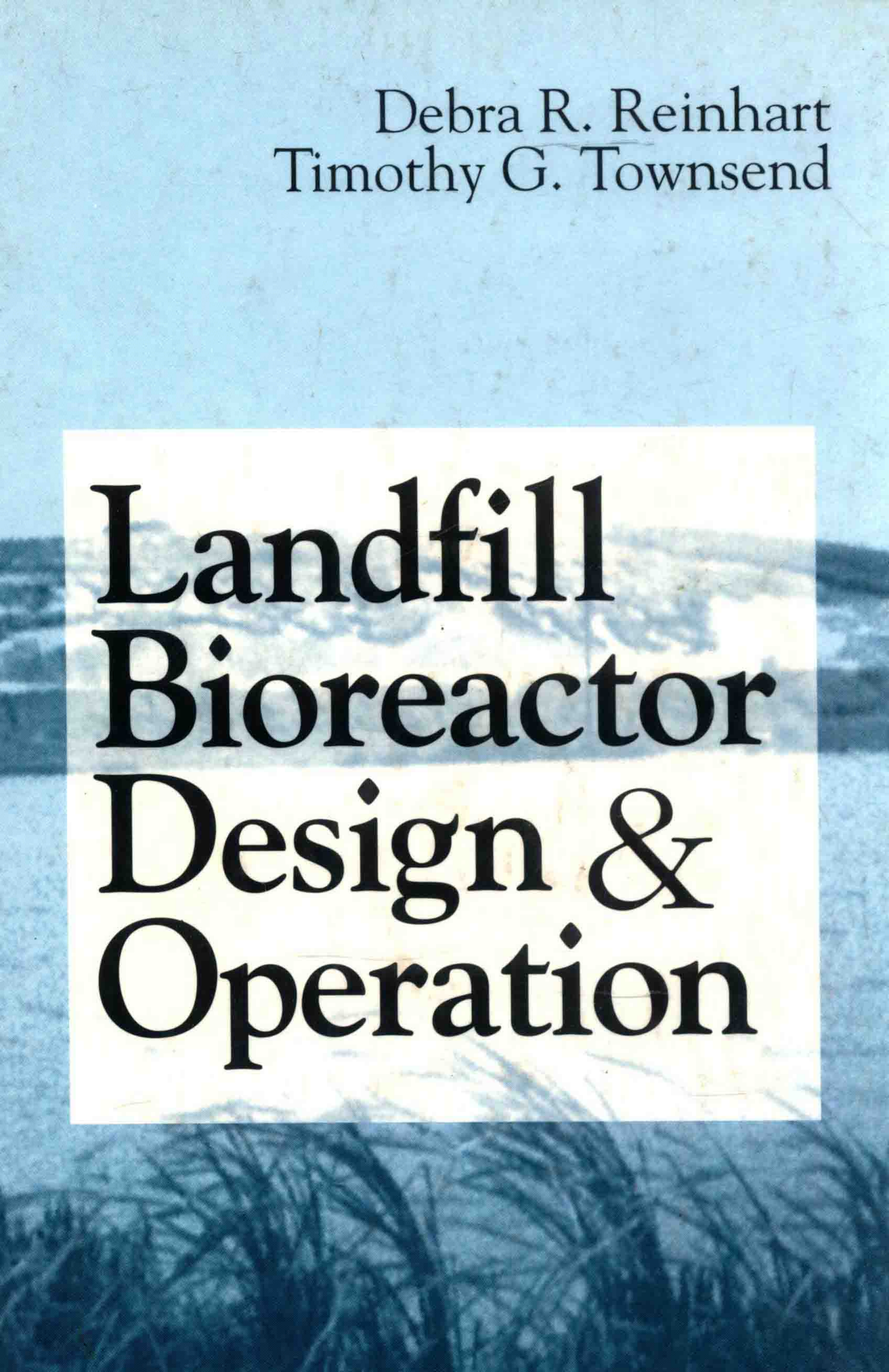

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LANDFILL BIOREACTOR DESIGN AND OPERATION

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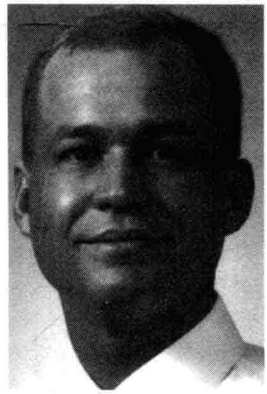
Before joining the University of Central Florida faculty, Dr. Reinhart spent five years in the consulting engineering field serving as a process engineer. She also served for five years with the city of Atlanta's Research and Development Division of the Bureau of Pollution Control.

Dr. Reinhart's research interests include solid waste management and groundwater remediation. Currently she is conducting research on leachate recirculation, liner clogging, leachate depth on liner, and waste composition analysis. She also has investigated gas emission measurement and reuse, and yard waste composting. In the groundwater remediation field, she is investigating chlorinated solvent treatment using reactive walls and electrokinetic soil treatment for metals removal. She holds patents in both fields.

Dr. Reinhart is an active member of the Solid Waste Association of North America, Water Environment Federation, Air and Waste Management Association, Association of Environmental Engineering Professors, the International Association of Water Quality, and American Society of Civil Engineers. She served on the boards of directors of the Florida Center for Solid and Hazardous Waste Management and the Florida Air and Waste Management Association. She is a registered professional engineer in Florida and Georgia and a Diplomate of the American Academy of Environmental Engineers. Dr. Reinhart has authored more than 30 publications in journals and proceedings.

Timothy G. Townsend is an Assistant Professor in the Department of Environmental Engineering Sciences at the University of Florida. Dr. Townsend received a Ph.D. from the University of Florida in 1996, after spending six years conducting research at the Alachua County Southwest Landfill on bioreactor landfill operation and engineering.

He currently conducts research in all areas of solid waste management and engineering, and teaches a number of solid and hazardous waste related management and design courses.



PREFACE

Research into the use of the municipal solid waste landfill as a bioreactor has been conducted for more than 20 years. The research has progressed from laboratory-scale reactors to pilot-scale lysimeters to recent full-scale demonstration of landfill bioreactor technology. Studies have shown that bioreactor operation provides an opportunity to control waste decomposition within the landfill environment, minimizing long-term risk to human health and the environment.

Because of the importance of encouraging rapid waste stabilization within a landfill, the bioreactor landfill is central to many waste management plans today. The implementation of bioreactor technology at full-scale landfills to date, however, has been accomplished through application of information gathered anecdotally, to the great frustration of designers and operators. The need for organized and complete data regarding the bioreactor landfill clearly was expressed at a gathering of more than 200 professionals at a bioreactor landfill seminar sponsored by the U.S. Environmental Protection Agency in 1995. This book is the outcome of many years of landfill bioreactor research by the authors both in the laboratory and in the field. It is the result of long discussions with professionals studying, designing, and operating the landfill as a bioreactor. This book is offered as a summary of design and operating experiences of professionals all over the world engaged in the safe disposal of municipal solid waste, while attempting to avoid perpetual storage of that waste.

This book is not a design guide for the complete sanitary landfill. There are many fine and detailed texts available that should be consulted to complement this book. However, Chapter 2 does provide some fundamentals concepts offered to provide a frame of reference to the reader. Some important features of the book include a detailed description of laboratory, pilot, and full-scale bioreactor studies, case studies of full-scale operating landfills with pictures and schematics to aid in design, and a discussion of the current understanding of moisture routing through the landfill. The value of past research efforts is recognized in each and every chapter as the authors attempt to provide design and operational insight gleaned from these studies. Finally, the text provides strategy to design a sustainable waste management plan through recovery of stabilized waste and reuse of the landfill site.

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Much of the information in this text was gathered and adapted from numerous other waste professionals. Unfortunately, there are too many to name all of them here.

We would like to acknowledgment the contributions of a few, however, including Phillip McCreanor, Santosh Agora, Mark James, Basel Al-Yousfi, and David Carson. The guidance from Drs. Fred Pohl and Lamar Miller could never be forgotten. And, of course, we must thank our spouses, Richard Reinhart and Marlene Townsend, for their patience and tolerance over the years.

CONTENTS

1 INTRODUCTION

SCOPE AND OBJECTIVES

While the typical person may think otherwise, the modern municipal solid waste (MSW) landfill has evolved into a sophisticated facility. The state-of-the-art landfill can be loosely categorized into four classes. The *secure landfill* tends to entomb wastes, perhaps postponing any environmental impact to the future when environmental controls and safeguards initially provided fail. The *monofill* accepts waste that cannot be processed otherwise through resource recovery, composting, or incineration. These materials tend to be inert and may be more easily assimilated by the environment. At present, the monofill is used for disposal of combustion ash, construction and demolition debris, and yard waste. The *reusable landfill* permits excavation of the landfill contents to recover metals, glass, plastics, other combustibles, compost and, potentially, the site itself following a lengthy stabilization period. A fourth, emerging landfill type, is the *bioreactor landfill*, which is operated in a manner to minimize environmental impact while optimizing waste degradation processes. It is this type of landfill that is the focus of this book.

Bioreactor landfills are constructed in a manner similar to most modern sanitary landfills — they are equipped with liners and leachate collection systems. Bioreactor landfills, however, are operated and controlled to rapidly accelerate the biological stabilization of the landfilled waste. Fig. 1.1 provides a schematic of a typical bioreactor landfill operation. The fundamental process used for waste treatment in a bioreactor landfill is leachate recirculation. Recirculation, or recycle, of leachate back to the landfill creates the environment favorable to rapid microbial decomposition of the biodegradable solid waste. The landfill becomes a treatment system rather than simply a storage facility. Bioreactor operation thus provides additional protection of the environment and may reduce long-term liability and associated monitoring costs. The rapid treatment of the waste also facilitates the operation of a bioreactor landfill as a *reusable landfill*. The combined operation of rapid waste treatment followed by reclamation of the stabilized landfill material results in a system that may dramatically extend the operating life beyond that of a traditional landfill.

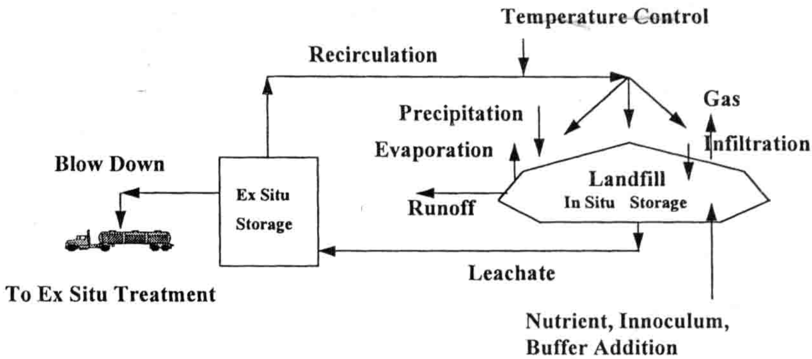

Figure 1.1 Schematic diagram of the landfill bioreactor.

Laboratory and pilot-scale studies have clearly demonstrated that operation of a landfill as a bioreactor accelerates waste degradation, provides *in situ* treatment of leachate, enhances gas production rates, and promotes rapid settlement. Full-scale evidence of bioreactor landfill benefits is rapidly accumulating. However, many challenges still face the implementation of bioreactor technology, including regulator reluctance to permit such facilities, the availability of theoretical design criteria, the ability to uniformly wet the waste, and operator training issues. The objective is to provide the regulator, designer, landfill owner, and operator with information and data that support the utility of the landfill bioreactor and provide design and operating criteria essential for the successful application of this technology.

THE EVOLUTION OF LANDFILLS FOR WASTE MANAGEMENT

The landfill, as we know it, has evolved from a long tradition of land disposal of MSW, dating back to prehistoric times. Problems with land disposal began as society developed and population density increased. Land disposal of waste — often as open dumps — was subject to aesthetic, safety, and health problems that prompted innovations in design and operation. Environmental impacts associated with MSW landfills have complicated siting, construction, and operation of the modern landfill. Production of leachate has lead to documented cases of groundwater and surface water pollution. Landfill gas emissions can lead to malodorous circumstances, adverse health effects, explosive conditions, and global warming. Traffic, dust, animal and insect vectors of disease, and noise often are objectionable to nearby neighbors. These issues have lead to strict regulation of landfill disposal of MSW.

Ideally, land should be a repository exclusively for inert "earthlike" materials that can be assimilated without adverse environmental impact, a conviction held by landfill regulators, designers, and operators throughout the world.[1] However, successful application of this concept requires extensive waste processing to develop an acceptable product for land disposal, and faces challenges related to public opposition, economics, waste handling, and transportation of recovered materials. The most reasonable scenario for success appears to be a MSW management park, where regional facilities for managing waste — from separation to resource recovery/reuse to incineration to landfilling — would be collectively sited.

While disposal solely of inert materials may be an admirable objective, it will be some time, if ever, before this concept can be universally applied. Therefore, it is likely that landfills will continue to receive a variety of materials with potential for environmental impact. A second global consensus is that where leachable materials are land disposed, impenetrable barriers must be provided and waste stabilization must be enhanced and accelerated so as to occur within the life of these barriers. That is, the landfill must be designed and operated as a bioreactor. Additional advantages of the bioreactor landfill include increased gas production rates over a shorter duration, improved leachate quality, and more rapid landfill settlement.

LANDFILLS AS BIOREACTORS

Under proper conditions, the rate of MSW biodegradation can be stimulated and enhanced. Environmental conditions that most significantly impact biodegradation include pH, temperature, nutrients, absence of toxins, moisture content, particle size, and oxidation-reduction potential. One of the most critical parameters affecting MSW biodegradation has been found to be moisture content. Moisture content can be most practically controlled via leachate recirculation. Leachate recirculation provides a means of optimizing environmental conditions within the landfill to provide enhanced stabilization of landfill contents as well as treatment of moisture moving through the fill. The numerous advantages of leachate recirculation include distribution of nutrients and enzymes, pH buffering, dilution of inhibitory compounds, recycling and distribution of methanogens, liquid storage, and evaporation opportunities at low additional construction and operating cost. It has been suggested that leachate recirculation can reduce the time required for landfill stabilization from several decades to two to three years.[2]

Implementation of bioreactor technology requires modification of design and operational criteria normally associated with traditional landfilling. For example, the bottom liner system must be designed to accommodate the additional flows contributed by leachate recirculation. The gas management facilities must be operated to control amplified gas production, particularly during the active landfill phase. Overcompaction of waste during placement may adversely impact leachate routing and prevent even moisture distribution. Use of permeable alternative daily cover is recommended for similar reasons. Leachate recirculation devices must be employed which are compatible with daily operation and closure requirements. Monitoring of leachate and gas quality and quantity becomes critical to operational decision making. Even waste pretreatment, such as shredding or screening, may be desirable to promote biological and chemical landfill processes. Leachate management must be carefully planned to ensure adequate supply for recirculation during dry weather conditions, and on the other extreme, to prevent saturation of waste during wet weather periods. Chronological changes in leachate characteristics will impact *ex situ* treatment and disposal requirements as a result of *in situ* treatment of degradable organics, as well as many hazardous leachate constituents.

REGULATORY STATUS

Regulations promulgated under Subtitle D of the Resources Conservation and Recovery Act (RCRA) allow leachate recirculation, provided a composite liner and leachate collection system are included in the design. In the preamble to Subtitle D regulations, implemented in 1991,[3] EPA commented that:

> ... EPA recognizes that landfills are, in effect, biological systems that require moisture for decomposition to occur and that this moisture promotes decomposition of the wastes and stabilization of the landfill. Therefore, adding liquids may promote stabilization of the unit...

Specifically, Section 258.28(b) (2) of CFR Part 258, "Criteria for Municipal Solid Waste Landfills" states the following:

> Bulk or noncontainerized liquid waste may not be placed in a municipal solid waste landfill unit unless ... the waste is leachate or gas condensate derived from the municipal solid waste landfill unit and the landfill unit is equipped with a composite liner and a leachate collection system that is designed and constructed to maintain less than a 30-cm depth of leachate over the liner.

A telephone poll of U.S. state regulatory agencies conducted in late 1992 and early 1993 found that full-scale operation of leachate recirculation was practiced (or would be soon) in 12 states and was permissible in all but seven states. Recirculation facilities were in place at landfills in eight states, under construction at landfills in four states, and planned at landfills in several other states. For the most part, states merely adopted RCRA criteria regarding leachate recirculation, requiring a composite liner in order to implement leachate recirculation.

A few states identified additional, more stringent criteria for leachate recirculation. For example, Florida, Georgia, Pennsylvania, and Virginia specifically address odor prevention. Florida requires that gas management facilities be in place prior to commencement of leachate recirculation. New York requires a double composite liner for all MSW landfills. Pennsylvania and Georgia require that the leachate recirculation piping system be installed under a permeable intermediate cover. Virginia, New York, Georgia, and Florida require control of runoff and prohibit ponding. Georgia also requires that sufficient waste be in place to provide sufficient moisture absorption prior to initiating recirculation.

Those states that prohibited leachate recirculation did so for several reasons. Regulators cited a lack of confidence in the method, interference with the leachate collection system, geological and climate concerns, freezing problems, leachate seepage, lack of waste absorptive capacity, and exacerbated gas and odor production.

ORGANIZATION OF THE BOOK

The long term acceptance of bioreactor landfills as tools in integrated solid waste management systems requires that such facilities be designed and operated in a safe and effective manner. Numerous studies have been performed investigating this technology, and this text serves to bring this information together, so that future bioreactor systems may benefit from the lessons gained from previous work. This text summarizes existing information available regarding the design and operation of bioreactor landfills and should serve as a resource to engineers, regulators, and all parties interested in the technology. The content and organization of the book are indicated in Fig. 1.2. In addition to a review of modern sanitary landfill fundamentals, sections cover the results of previous bioreactor landfill operations experiments, including a series of case studies; describe design and operation issues; and discuss the potential of landfill mining as a method to recover treated waste materials and to reuse the bioreactor cells.