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Principles of Design and Operations of Wastewater Treatment Pond Systems for Plant Operators, Engineers, and Managers

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Notice

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Foreword

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Sally Gutierrez, Director
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Abstract

Principles of Design and Operations of

Wastewater Treatment Pond Systems for Plant Operators, Engineers, and Managers

Wastewater pond systems provide reliable, low cost, and relatively low maintenance treatment for municipal and industrial discharges. However, they do have certain design, operations, and maintenance requirements. While the basic models have not changed in the 30-odd years since EPA published the last ponds manual, there have been some innovations and improved understanding of the complex biological processes at work in these systems. Additionally, new water quality requirements are either in place or about to be put in place throughout the United States, particularly relating to nutrient concentrations, that were not factored into the design specifications when many of the existing ponds were constructed. This updated version of the wastewater treatment ponds manual includes basic design recommendations, discusses the innovations in design that have been made in new, expanded or modified systems, as well as the additional processes that have been added to address nutrient requirements. An emphasis is placed on the importance of operations and maintenance, which is demonstrated in the troubleshooting section and appendices from several states, directed at providing training for operators.

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Table 1. Metric Conversion Factors (SI to U.S. Customary Units)

Multiply the SI unit		by	To obtain the U.S. unit	
Name	Symbol		Symbol	Name
Area				
hectare (10,000 m^2)	ha	2.4711	ac	acre
square centimeter	cm^2	0.1550	in^2	square inch
square kilometer	km^2	0.3861	mi^2	square mile
square kilometer	km^2	247.1054	ac	acre
square meter	m^2	10.7639	ft^2	square foot
square meter	m^2	1.1960	yd^2	square yard
Energy				
Kilojoule	kJ	0.9478	Btu	British thermal unit
joule	J	2.7778×10^{-7}	kWh	kilowatt-hour
megajoule	MJ	0.3725	hp · h	horsepower-hour
conductance, thermal	$W/m^2 \cdot °C$	0.1761	$Btu/h \cdot ft^2 \cdot °F$	conductance
conductivity, thermal	$W/m \cdot °C$	0.5778	$Btu/h \cdot ft \cdot °F$	conductivity
heat transfer coefficient	$W/m^2 \cdot °C$	0.1761	$Btu/h \cdot ft^2 \cdot °F$	heat transfer coefficient
latent heat of water	344,944 J/kg	—	144 Btu/lb	latent heat of water
specific heat, water	4215 J/kg · °C	—	1.007 Btu/lb · °F	specific heat of water
Flow rate				
cubic meters per day	m^3/d	264.1720	gal/d	gallons per day
cubic meters per day	m^3/d	2.6417×10^{-4}	MGD	million gallons per day
cubic meters per second	m^3/s	35.3157	ft^3/s	cubic feet per second
cubic meters per second	m^3/s	22.8245	MGD	million gallons per day
cubic meters per second	m^3/s	15.8503	gal/min	gallons per minute
liters per second	L/s	22.8245	gal/d	gallons per day
Length				
centimeter	cm	0.3937	in	inch
kilometer	km	0.6214	mi	mile
meter	m	39.3701	in	inch
meter	m	3.2808	ft	foot
meter	m	1.0936	yd	yard
millimeter	mm	0.03937	in	inch
Mass				
gram	g	0.0353	oz	ounce
gram	g	0.0022	lb	pound
kilogram	kg	2.2046	lb	pound
megagram (10^3 kg) (metric ton)	Mg (mt)	1.1023	ton (t)	ton (short: 2000 lb)
megagram	Mg	0.9842	ton	ton (long: 2240 lb)
Power				
kilowatt	kW	0.9478	Btu/s	British thermal units per second
kilowatt	kW	1.3410	hp	horsepower
Pressure				
pascal	Pa(N/m^2)	1.4505×10^{-4}	lb/in^2	pounds per square inch
Temperature				
degree Celsius	°C	1.8(°C) + 32	°F	degree Fahrenheit
kelvin	K	1.8(K) − 459.67	°F	degree Fahrenheit
Velocity				
kilometers per second	km/s	2.2369	mi/h	miles per hour
meters per second	m/s	3.2808	ft/s	feet per second
Volume				
cubic centimeter	cm^3	0.0610	in^3	cubic inch
cubic meter	m^3	35.3147	ft^3	cubic foot
cubic meter	m^3	1.3079	yd^3	cubic yard
cubic meter	m^3	264.1720	gal	gallon
cubic meter	m^3	8.1071×10^{-4}	ac-ft	acre foot
liter	L	0.2642	gal	gallon
liter	L	0.0353	ft^3	cubic foot
liter	L	33.8150	oz	ounce (U.S. fluid)
megaliter (L × 10^6)	ML	0.2642	MG	million gallons

Table 2. Conversion Factors for Commonly Used Design Parameters

Multiply the SI unit		by	To obtain the U.S. Customary unit	
Parameter	Symbol		Symbol	Parameter
cubic meters per second	m^3/s	22.727	mgd	million gallons per day
cubic meters per day	m^3/d	264.1720	gal/d	gallons per day
kilogram per hectare	kg/ha	0.8922	lb/ac	pounds per acre
metric ton per hectare	Mg/ha	0.4461	ton/ac	tons (short) per acre
cubic meter per hectare per day	$m^3/ha \cdot d$	106.9064	$gal/ac \cdot d$	gallons per acre per day
kilograms per square meter per day	$kg/m^2 \cdot d$	0.2048	$lb/ft^2 \cdot d$	pounds per square foot per day
cubic meter (solids) per 10^3 cubic meters (liquid)	$m^3/10^3\ m^3$	133.681	ft^3/MG	cubic feet per million gallons
cubic meters (liquid) per square meter (area)	m^3/m^2	24.5424	gal/ft^2	gallons per square foot
grams (solids) per cubic meter (liquid)	g/m^3	8.3454	lb/MG	pounds per million gallons
cubic meters (air) per cubic meter (liquid) per minute	$m^3/m^3 \cdot min$	1000.0	$ft^3/10^3 \cdot min$	cubic feet of air per minute per 1000 ft^3
kilowatts per 10^3 cubic meter (tank volume)	$kW/10^3\ m^3$	0.0380	$hp/10^3\ ft^3$	horsepower per 1000 ft^3
kilograms per cubic meter	kg/m^3	62.4280	$lb/10^3\ ft^3$	pounds per 1000 ft^3
cubic meter per capita	$m^3/capita$	35.3147	$ft^3/capita$	cubic feet per capita
bushels per hectare	bu/ha	0.4047	bu/ac	bushels per acre

Temperature (°C)	Density (kg/m^3)	Dynamic viscosity $\times 10^3$ (N $\cdot$ s/m^2)	Kinematic viscoity (γ) $\times 10^6$ (m^2/s)
0	999.8	1.781	1.785
5	1000.0	1.518	1.519
10	999.7	1.307	1.306
15	999.1	1.139	1.139
20	998.2	1.002	1.003
25	997.0	0.890	0.893
30	995.7	0.798	0.800
40	992.2	0.653	0.658
50	988.0	0.547	0.553
60	983.2	0.466	0.474
70	977.8	0.404	0.413
80	971.8	0.354	0.364
90	965.3	0.315	0.326
100	958.4	0.282	0.294

Table 4. Dissolved Oxygen Solubility in Fresh Water*

Temperature (°C)	Dissolved oxygen solubility (mg/L)
0	14.62
1	14.23
2	13.84
3	13.48
4	13.13
5	12.80
6	12.48
7	12.17
8	11.87
9	11.59
10	11.33
11	11.08
12	10.83
13	10.60
14	10.37
15	10.15
16	9.95
17	9.74
18	9.54
19	9.35
20	9.17
21	8.99
22	8.83
23	8.68
24	8.53
25	8.38
26	8.22
27	8.07
28	7.92
29	7.77
30	7.63

*Saturation values of dissolved oxygen when exposed to dry air containing 20.90% oxygen under a total pressure of 760 mmHg.

Glossary

Abate®	larvicide
AFP	advanced facultative pond
AIWPS	Advanced Integrated Wastewater Pond System®
AMTA	Activated Membrane Technology Associations
AMTS	Advanced Microbial Treatment System
ASP	algae settling pond
ATLAS-IS	Advanced Technology Lagoon Aeration System with Internal Separator
AWT	activated waste treatment
BIOLAC® Process	activated sludge in earthen ponds
BOD	biochemical oxygen demand
BOD_5	5 day biochemical oxygen demand
Bti	Bacillus *thuringiensis israelensis* (larvicide)
CAPM	Centre for Aquatic Plant Management
CBOD	carbonaceous biochemical oxygen demand
CFID	continuous feed, intermittent discharge
CLEAR™	Cyclical Lagoon Extended Aeration Reactor
COD	chemical oxygen demand
CWT	Centralized Waste Treatment
DAF	dissolved air flotation
DFR	design flow rate
DMR	discharge monitoring reports
DO	dissolved oxygen
DPMC	Dual-power, multi-cellular system

DPMC-IS	Dual-power, multi-cellular intermittent sand filter system
e.s.	effective size
EDI	Environmental Dynamics, Inc.
ENRCCI	Engineering News Record Construction Cost Index
FC	fecal coliform(s)
F/M	food/microorganism
FWS	free water surface
GIS	Geographic Information System
gpm	gallons per minute
HCR	hydrogen controlled release
HLT	high level transfer
HPAPS	high-performance aerated pond system
HRP	high rate pond
HRT	hydraulic residence time/hydraulic retention time
IPDs	in-pond digesters
I&I	Inflow & Infiltration
JTU	Jackson Turbidity Unit
Lagoon-ISF	Lagoon Intermittent Sand filter
M	metal ion
MBBR™	Moving Bed Biofilm Reactor
MCRT	mean cell resident time
mgd	million gallons per day
MLSS	mixed liquor suspended solids
MLVSS	mixed liquor volatile suspended solids
MPN	most probable number
MSL	mean sea level

NEIWPCC	New England Interstate Water Pollution Control Commission
NFB	nitrification filter bed
NH_4 - N	ammonia-N, ammonia nitrogen
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NRCS	National Resources Conservation Services
OD	oxygen demand
O&M	operation and maintenance
%	percent
POTWs	publicly owned treatment works
RAS	return activated sludge
RO	reverse osmosis
SAR	sodium adsorption ratio
SBR	sequencing batch reactor
$SCBOD_5$	soluble carbonaceous BOD_5
scfm	standard cubic feet per minute
sf	square foot
SF, SSF	subsurface flow
SFP	secondary facultative pond
SS	suspended solids
STEP	septic tank effluent pumping system
TFCC	total fecal coliform count
TKN	total Kjeldahl nitrogen
TP	total phosphorus
TSS	total suspended solids
TVSS	total volatile suspended solids

U.C., u.c.	uniformity coefficient
UF	ultrafiltration
USGS	U. S. Geological Society
VSS	volatile suspended solids
WAS	waste activated sludge
WHO	World Health Organization
WTCost	a CD-Rom for estimating plant membrane treatment costs

Acknowledgments

This document, an up-to-date revision of the Municipal Wastewater Stabilization Ponds design manual published by USEPA in 1983, is the result of the interest and commitment of many contributors, who are listed below in alphabetical order.

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The authors wish to dedicate this manual to the memory of Dr. William J. Oswald, whose vision of using design principles respecting and modeled after natural processes has come to be understood as basic to our survival as a species: reducing energy consumption, reimagining "waste products" as resources, and building sustainable projects, in order to solve some of civilization's most complicated and persistent problems. Dr. Oswald continues to be an inspiration to generations of his students, in and out of universities, and throughout the world.

*In 2000, USEPA Office of Wastewater Management (OWM) underwrote a needs assessment to determine whether a revised and updated edition of the 1983 Wastewater Stabilization Ponds Design Manual was needed. The answer was affirmative and OWM, working with ORD NRMRL, Cincinnati, hired a consultant, E. Joe Middlebrooks to conduct the work. Several of the Regions contributed funding to complete the project: Regions 5, 8 and 9 applied for Regional Applied Research Effort (RARE) funds; Region 6 contributed funds from its Tribal program; Region 1 funds were from RARE as well as general funding. Gajindar Singh, Office of Water has been a tireless supporter of pond technology. The final product represents the work of the consultant and his subcontractor and many USEPA staff, who share the belief that the benefits of wastewater pond technology should be more widely known and accepted among the community of design engineers, city and community managers, and that information about them should be more readily available, especially to the plant operators, who work with them every day.

Cover Picture is of a modified AIWPS® treating wastewater from Pine Ridge, South Dakota on the Pine Ridge Reservation, home the Oglala Sioux (Lakota) Tribe. Startup was in 2009 treating wastewater from the 5,500 residents of the village. The Treatment works consist of AIWPS® primary Pond with fermentation pits, followed by secondary cells, followed by a wetland for final treatment prior to discharge. The design was based on the Tribe's desire for something other than a conventional lagoon system and the need to keep operation and maintenance to a minimum. The Treatment area is surrounded by pasture lands and can be expected to stay remote for the foreseeable future. Each of the primary ponds will contain two Oswald type fermentation pits that are conservatively designed. The outer pond is oversized to compensate for lack of aerators. The secondary cells have been sized for holding during the winter with a total detention of 150 days. The wetland design is based on 25,000 gpd/ac which was recommended by the State of South Dakota. The facility will discharge 725,000 gallons per day at design capacity. For additional information contact Anthony Kathol, P.E. at Anthony.Kathol@ihs.gov.

Preface

Eugenia McNaughton (U.S. EPA Region 9), James E. Smith, Jr. (U.S. EPA ORD NRMRL, retired), Sally Stoll (ORD NRMRL)

January 21, 2011

Stabilization ponds have been used for treatment of wastewater for over 3,000 years. The first recorded construction of a pond system in the U.S. was at San Antonio, Texas, in 1901. Today, over 8,000 wastewater treatment ponds are in place, involving more than 50% of the wastewater treatment facilities in the U.S. (CWNS, 2000). Facultative ponds account for 62%, aerated ponds 25%, anaerobic 0.04% and total containment 12% of the pond treatment systems. They treat a variety of wastewaters from domestic wastewater to complex industrial wastes, and they function under a wide range of weather conditions, from tropical to arctic. Ponds can be used alone or in combination with other wastewater treatment processes. As our understanding of pond operating mechanisms has increased, different types of ponds have been developed for application in specific types of wastewater under local environmental conditions. This manual focuses on municipal wastewater treatment pond systems.

We should note here that we will use the word “treatment” in place of “stabilization,” which has come to have a much more specific meaning since the first manual was published. We will also refer to “ponds” versus “lagoons,” for consistency in the manual, though we recognize that in this case either term is acceptable.

The U.S. Environmental Protection Agency (EPA) last published a Wastewater Stabilization Ponds Design Manual in 1983 under the Technology Transfer Program, which was developed “to describe technological advances and present new information.” EPA support for pond systems as options for municipal wastewater treatment was most welcome, particularly for small communities that could not afford to match even the generous construction grants that were offered at that time to bring communities of all sizes some level of wastewater treatment.

While the tendency in the U.S. has been for smaller communities to build ponds, in other parts of the world, including Australia, New Zealand, Mexico and Latin America, Asia and Africa, treatment ponds have been built for large cities. As a result, our understanding of the biological, biochemical, physical and climatic factors that interact to transform the organic compounds, nutrients and pathogenic organisms found in sewage into less harmful chemicals and unviable organisms (i.e., dead or sterile) has grown since 1983. A wealth of experience has been built up as civil, sanitary or environmental engineers, operators, public works managers and public health and environmental agencies have gained more experience with these systems. While some of this information makes its way into technical journals and text books, there is a need for a less formal presentation of the subject for those working in the field every day.

In gathering the information for this revision, we interviewed state regulators, local operators, engineers, consultants, and academics. We read as much of the literature as we could find, always searching for case histories illustrating new performance achievements and associated design details that might be employed in other systems. We found that there has been some evolution of design, such as in the AIWPS™, but many improvements have included, for example, the addition of more aerators, moving the systems closer to activated sludge with the attendant high energy and sludge removal costs. Much recent work has focused on pond hydraulics and we understand now that for consistent performance, the design and placement of inlet and outlet structures to avoid short circuiting and loss of solids is critical, and that redundancy must be built into the system to allow for flexibility in operation and maintenance. Some additions have been necessary to meet nutrient requirements that were not in place when the systems were built. Overall, however, pond systems still offer an alternative that is lower in capital outlay, operations, and maintenance costs. Appropriately designed ponds are capable of meeting strict environmental standards with minimal biosolids management requirements and reasonable energy costs.

Looking to the future, what has been the most problematic element for stabilization ponds, the growth and persistence of algae throughout the system, is lately coming to be seen as a potential asset. It may soon be time to talk about enhancing the growth of algae for use as biofuel or livestock food supplements to replace irrigated feed crops and conventional energy sources. Opportunities to install solar power collectors, either to supply the entire system's energy needs or to run aerators, may make an already low energy use system effectively carbon neutral or net-energy positive. The cost to add elements that treat wastewater to reduce nutrient discharge would be less challenging for a community that has a system that is already a low energy consumer.

In the spirit of the times, we acknowledge that another book isn't necessarily the way to get information out these days. This version of the manual is instead a compendium organized around the topics related to design, operation, and maintenance of wastewater stabilization ponds that must meet ever more stringent discharge requirements. It will be available on the web in its entirety chapter by chapter. It is our hope that this will be a resource to which you will return many times over the course of your involvement with wastewater ponds. And we look forward to hearing from you about improvements to existing text or other information that we might include to make the manual an evolving and dynamic document, attesting to the importance of this wastewater treatment process and to the continued enthusiasm for it that inspired us to make this effort to bring it to you.