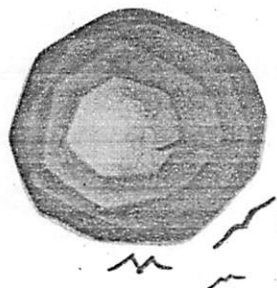


TROPICAL HYDROLOGY

and

CARIBBEAN WATER RESOURCES



Edited By:

J. Hari Krishna, Vicente Quiñones-Aponte,
Fernando Gómez-Gómez and Gregory Morris



AQUATIC WATER RESOURCES ASSOCIATION

TROPICAL HYDROLOGY AND CARIBBEAN WATER RESOURCES

PROCEEDINGS OF THE
INTERNATIONAL SYMPOSIUM ON TROPICAL HYDROLOGY AND
FOURTH CARIBBEAN ISLANDS WATER RESOURCES CONGRESS

Edited by
**J. Hari Krishna,
Vicente Quiñones-Aponte,
Fernando Gómez-Gómez, and
Gregory L. Morris**

Sponsored by the
AMERICAN WATER RESOURCES ASSOCIATION

Co-Sponsored by
U.S. GEOLOGICAL SURVEY, WATER RESOURCES DIVISION

**WATER RESOURCES RESEARCH INSTITUTE
UNIVERSITY OF PUERTO RICO**

**WATER RESOURCES RESEARCH CENTER
UNIVERSITY OF THE VIRGIN ISLANDS**

**UNITED NATIONS EDUCATIONAL SCIENTIFIC
AND CULTURAL ORGANIZATION**

Hosted by
ASOCIACION PUERTORRIQUEÑA DE RECURSOS DE AGUA

**Sands Hotel and Casino Beach Resort
San Juan, Puerto Rico
July 22-27, 1990**



**AMERICAN WATER RESOURCES ASSOCIATION
5410 Grosvenor Lane, Suite 220
Bethesda, Maryland 20814-2192**

PREFACE

The tropics give rise to the world's largest and longest rivers, and span a diversity of climates ranging from the snow cloud Andean peaks to the coastal mangrove forests. Insular areas in the tropics include some of the highest population densities in the world.

Unfortunately, there is a relative paucity of research on water resources in tropical areas. This contrasts with the level of research undertaken in temperate zones, as well as with the urgent economic and environmental concerns of tropical regions of the world. In the absence of adequate research, there is a tendency to make development decisions based on inadequate information, and to extrapolate temperate zone approaches to tropical zone problems where they may not necessarily be applicable. When these concerns are viewed in the context of the absolute size and high growth rate of the human population in tropical areas, their socio-economic needs, and the types and magnitudes of water resource management decisions being made, the need for a substantial increase in research as well as a major effort to disseminate knowledge becomes clear.

The difficulties facing decision makers, researchers, and environmentalists within the tropics and in particular within insular areas are many. Working toward an improvement of the general well being, a symposium was organized to bring together an interdisciplinary group of scientists and managers devoted to the water resources sciences. The "International Symposium on Tropical Hydrology" was organized in conjunction with the Fourth Caribbean Islands Water Resources Congress to: 1) promote technology transfer between the various disciplines; 2) provide a forum for professionals to exchange experiences, ideas, and potential development of new research studies; 3) provide a source for communication with those who are not water scientists; and 4) provide a forum for the discussion of common water resources management problems.

Authors presented studies from about 19 different countries. Over 80 papers were presented orally or by poster. Sixty-six (56) papers were accepted for publication in the *Proceedings* and are arranged in four major sections: 1) Water Resources Management, 2) Surface Water Hydrology, 3) Ground Water Hydrology, and 4) Water Quality. Papers within all four sections range from conceptual descriptive papers to very complex research experiments. These included papers describing: water management problems, strategies, and new techniques for the management of water resources; rainfall runoff modeling in tropical environments; extreme flow forecasting; reservoir operation; erosion, sedimentation, and landslide problems; ground water problems on small tropical islands; geophysical techniques for the study of fresh water lenses; application of numerical techniques to ground water problems; computer developments for the handling of ground water data; baseline water quality data and stable isotopic studies; effects of land development on water quality; tracer techniques, drinking and waste water treatment; and bacteriological water quality studies. Papers included in the *Proceedings* have been reviewed by at least one of the editors and an outside referee.

It is our hope that these *Proceedings* will serve as an impetus to promote further research and better understanding of the water resources of tropical and insular areas, and that this knowledge can be translated into better water management for the benefit of all.

J. Hari Krishna
Vicente Quiñones-Aponte,
Fernando Gómez-Gómez, and
Gregory L. Morris

Editors

ARTS AND DRAFTING OF COVER ILLUSTRATION BY RAFAEL MEDINA

**AMERICAN WATER RESOURCES ASSOCIATION TECHNICAL PUBLICATION SERIES
TPS-90-2**

LIBRARY OF CONGRESS CATALOG CARD NUMBER: 90-81063

1990 COPYRIGHT BY THE AMERICAN WATER RESOURCES ASSOCIATION

All rights reserved. No part of this book may be reproduced in any form or by any mechanical means without permission by the publisher. These proceedings were published by the American Water Resources Association, 5410 Grosvenor Lane, Suite 220, Bethesda, Maryland 20814-2192. The views and statements advanced in this publication are solely those of the authors and do not represent official views or policies of the editors or of the American Water Resources Association; the U.S. Geological Survey, Water Resources Division; the Water Resources Research Institute, University of Puerto Rico; the Water Resources Research Center, University of the Virgin Islands; or the United Nations Educational Scientific and Cultural Organization. Communications in regard to this publication should be sent to the Circulation Department of the American Water Resources Association, 5410 Grosvenor Lane, Suite 220, Bethesda, Maryland 20814-2192, (301) 493-8600.

ACKNOWLEDGMENTS

The organization of the symposium was possible due to the dedicated effort by many individuals and organizations. We must recognize the support provided by the sponsoring organizations. Special thanks goes to the Caribbean District of the U.S. Geological Survey, WRD, who provided manpower, materials, and use of facilities for most of the organizing committee meetings. Also, the organizing committee is grateful to many other individuals who contributed their time and effort in accomplishment of the symposium.

The editors acknowledge the assistance and cooperation of the following persons in organizing and preparing the *Proceedings*:

Ms. Ana V. Sánchez & Ms. Carmen M. Torrens
U.S. Geological Survey, Water Resources Division

Ms. Ada Sotto
Gregory Morris and Associates

We greatly appreciate the time and effort of many individuals who reviewed the manuscripts which were submitted. Thanks to the authors for their cooperation during the process of revision.

SYMPOSIUM ORGANIZING COMMITTEE

Rafael Muñoz-Candelario, General Chairperson

Water Resources Research Institute
University of Puerto Rico
Mayagüez Campus
P.O. Box 5000
Mayagüez, Puerto Rico 00708

Alton Robertson
Law Environmental Services-Caribe
54-56 Bolivia Street
Hato Rey, Puerto Rico 00917

Vicente Quiñones-Aponte
U.S. Geological Survey, WRD
GPO Box 4424
San Juan, Puerto Rico 00936

SUB-COMMITTEES

FINANCE

Ramón Amador, Chairman
Jorge Martínez
José C. Agrelot

POSTER SESSION

Gregory L. Morris, Chairman

LOCAL ARRANGEMENTS

Ana V. Sánchez, Chairperson

EXHIBITS

Eugenio Ascencio, Chairman

FIELD TRIPS

Matthew C. Larsen, Chairman
Robert A. Renken

SPOUSES EVENTS

Carmen M. Torrens, Chairperson
Ana V. Sánchez

TECHNICAL PROGRAM

J. Hari Krishna, Chairman / Surface Water
Vicente Quiñones-Aponte, Chairman / Ground Water
Fernando Gómez-Gómez, Chairman / Water Quality
Gregory L. Morris, Chairman, Poster Session
Nicolino Liberatore
Ismael Págan-Trinidad
Allen L. Zack
E. J. Wexler

UNESCO COORDINATOR

Carlos Fernández-Jauregui
ROSTLAC, Montevideo, Uruguay

AMERICAN WATER RESOURCES ASSOCIATION

BOARD OF DIRECTORS

EXECUTIVE COMMITTEE

President.....	Warren Viessman, Jr.
President-Elect.....	Peter E. Black
Vice President	David W. Moody
Secretary	Nancy Lopez
Treasurer	Kenneth J. Lanfear
Director-at-Large	Jeffrey T. Armbruster
Past President	Jerry R. Rogers

DIRECTORS

Pacific Northwest	Charles D. Mosher
Pacific Southwest	Herbert B. Osborn
Mountain	Bruce P. Van Haveren
West North Central	Kenneth N. Brooks
West South Central.....	Donald D. Adrian
East North Central	Vladimir Novotny
East South Central	Ferdinand Quifiones
Mid-Atlantic	Stephan J. Nix
Chesapeake	Jonathan P. Deason
South Atlantic.....	Wade L. Nutter
New England	Milton Potash

STAFF

Executive Director	Kenneth D. Reid, CAE
Meetings Manager	Michael C. Fink
Publications Manager	Charlene E. Young
Membership Services Manager	Judah B. Flum
Finance Manager	Michael J. Kowalski



CONVERSION FACTORS

To Convert	To	Multiple By
acre-foot (acre-ft)	cubic metre (m ³)	1.23 x 10 ³
acre (acre)	hectare (ha)	0.405
pound mass (lbm)	kilogram (kg)	0.454
mile (mile)	kilometer (km)	1.61
pound force per square inch (psi)	kilopascal (kPa)	6.89
U.S. gallon (gal)	liter (L)	3.79
inch (in.)	millimeter (mm)	25.4
kilogram-force (kgf)	newton (N)	9.81
pound force (lbf)	newton (N)	4.45
foot	meter	0.305

TABLE OF CONTENTS

WATER RESOURCES MANAGEMENT

An International Programme for Environmentally Sound Hydrologic and Water Management Strategies in the Humid Tropics — <i>John S. Gladwell and Michael Bonell</i>	1
Preferred Alternative Uses of Water Resources: Views of Environmental Activists in the U.S. Virgin Islands — <i>Dennis L. Soden</i>	11
Ground-Water Management Problems in the North Central Coast of Puerto Rico — <i>Sandra N. Salgado and Felix I. Aponte</i>	19
Significance of Chemical Boundaries to Ground-Water Management of Coastal Aquifers — <i>William Back and Janet S. Herman</i>	31
Development of an Aquifer Management Model: AQMAN3D — <i>Juan C. Puig, Lourdes I. Rolón-Collazo, and Ismael Pagán Trinidad</i>	39
Wellhead Protection: An Approach to Preservation of Public-Water Supplies — <i>John S. Malleck and Myriam Albino</i>	49
Conditions for Successful Irrigation Projects in Africa — <i>Philippe W. Zgheib</i>	61
Using Common Sense to Prevent Soil Erosion From Urban Development Areas — <i>Raúl E. Zapata López</i>	71

SURFACE WATER HYDROLOGY

An ARMA Model for Rainfall-Runoff With Applications — <i>Yun-Sheng Yu and Wang Guang-Te</i>	81
Parameter Estimation in Conceptual Precipitation-Runoff Models With Emphasis on Error Analysis — <i>Jorge Rivera-Santos</i>	91
Automatic Parameters Calibration Technique for Rainfall-Runoff Modelling — <i>Shiang-Kueen Hsu</i>	101
The Study and Application of Rainfall-Runoff Model for Karst Regions — <i>Zhang Jianyun and Zhuang Yiling</i>	111
Rainfall-Soil Moisture Relations in Landslide-Prone Areas of a Tropical Rain Forest, Puerto Rico — <i>Matthew C. Larsen and Angel J. Torres-Sánchez</i>	121
Hydrological Responses to Urbanization in Forested Lanana Creek Watershed, Nacogdoches, Texas — <i>Mingteh Chang and Alexander K. Sayok</i>	131
The Geographic Distribution of Drought on Two Caribbean Islands: Puerto Rico and St. Kitts — <i>Gregory L. Morris and Mali Vázquez</i>	141
Role of Temperature for Drought Study — <i>Tiao J. Chang</i>	151

Approximative Techniques in the Operational Optimization of the Mahaweli Reservoir System in Sri Lanka — <i>Janos J. Bogardi, M. D. U. P. Kularathna, and Ricardo Harboe</i>	167	Shr
Real-Time Operation of a Multipurpose Reservoir During Typhoon Occurrence — <i>Janos J. Bogardi, Wen-Cheng Huang, and Ricardo Harboe</i>	177	Hyc
Reservoir Filling Plans for Tropical Reservoirs – A Case Study — <i>James Vearil and James C. Miller</i>	187	App
Effects of Hurricane Storm Flow on Transport of Woody Debris in a Rain Forest Stream (Luquillo Experimental Forest, Puerto Rico) — <i>Alan P. Covich and Todd A. Crowl</i>	197	Labo
Estimation of Total Water Consumption of Selected Vegetable Crops in the Semiarid and Humid Regions of Puerto Rico — <i>Megh R. Goyal</i>	207	Aspe
Economic and Engineering Considerations for Planning Medium Scale Irrigation Systems: A Study From Northeast Thailand — <i>Sam H. Johnson III and Sanguan Patamatamkul</i>	217	Grou
Study and Recommendations on the San German Vaulted Brick Storm Sewer System — <i>Luis Pumárada-O'Neill and Miguel Cruz-Arocho</i>	227	Appli
Culvert Flow in Small Drainages in Montane Tropical Forests: Observations From the Luquillo Experimental Forest of Puerto Rico — <i>F. N. Scatena</i>	237	Artifi
Regional Equations to Determine Peak Stream Discharges in the Santander Region, Colombia — <i>Luis E. Aramburo B. and German E. Gavilán L.</i>	247	A Con
		The In Fi

GROUND WATER HYDROLOGY

Problems of Ground-Water Development in Small Volcanic Islands in the Eastern Caribbean — <i>Nicholas S. Robins, Adrian R. Lawrence, and Alan C. Cripps</i>	257	Chemic
A Ground-Water Supply Study for the Nigua River Basin in the Dominican Republic — <i>Mark D. Taylor, Richard C. Johnson, and José Brea G.</i>	269	Water
A Ground-Water Pollution Risk Assessment for Public Water Supply Sources in Barbados — <i>P. J. Chilton, A. A. Vlugman, and S. S. D. Foster</i>	279	Baselin Pue
Techniques for Appraisal of Ground-Water Resources on Atoll Islands: Case Studies from Micronesia — <i>Stephen S. Anthony</i>	291	Land De
Geophysical Mapping and Hydrogeologic Analysis of Fresh-Water Lenses at Big Pine Key, Florida — <i>Michael J. Wightman, Mark T. Stewart, and H. L. Vacher</i>	301	U.S. Arn
Very Low Frequency Electromagnetics Mapping of a Freshwater Lens at Key West, Florida — <i>James L. Labowski, Donald J. McKenzie, and Aaron L. Higer</i>	311	- F L

Shape of Freshwater Lens in Small Carbonate Islands: Great Exuma vs. Bermuda and the Effect of Climate - <i>Thomas N. Wallis and H. L. Vacher</i>	317
Hydrogeology and Tidal Analysis Along the Western North Coast of the Yucatan Peninsula, Mexico - <i>Andrew Reeve and Eugene C. Perry, Jr.</i>	327
Application of the Boundary Element Method to Some Problems in Water Resources - <i>Rajesh Srivastava and Dinshaw N. Contractor</i>	339
Laboratory Simulation of the Effects of Overburden Stress on the Specific Storage of Shallow Artesian Aquifers - <i>Nicasio Sepulveda and Allen L. Zack</i>	349
Aspects of the Hydrogeology of the Northwest Region, Yucatan Peninsula, Mexico - <i>E. C. Perry, Jr.</i>	357
Ground Water Seepage in the Indian River Lagoon, Florida - <i>Thomas V. Belanger and Robert B. Walker</i>	367
Application of Ground-Water Artificial Recharge in a Brackish/Saltwater Environment - <i>Albert Muñiz, Sean Skehan, and Peter J. Kwiatkowski</i>	377
Artificial Ground-Water Recharge, Ventura County, California - <i>Bryant R. Rose</i>	387
A Computer Program for GEOphysical Log Data MANagement and Plotting (GEOMAN) - <i>Ileana E. Arroyo, Sigfredo Torres-Gonzalez, and Ramón A. Carrasquillo</i>	395
The Interactive Computer Program MODUMANAG, A Data Management Tool for the Modular Finite-Difference Ground-Water Flow Model - <i>Sigfredo Torres-Gonzalez and Lourdes I. Rolón-Collazo</i>	403

WATER QUALITY

Chemical and Stable Isotopic Characteristics of Ground Water on Grand Cayman - <i>Kwok-Choi Ng and Brian Jones</i>	411
Water Quality of a Carbonate Island Karst Aquifer, San Salvador Island, Bahamas - <i>William Balcerzak, John Mylroie, and Gerald S. Pabst</i>	421
Baseline Water-Quality Evaluation of Three Basins in the Upper Rio Grande de Arecibo Basin, Puerto Rico - <i>Patrick William McKinley</i>	433
Land Development and Water Quality: The Cayman Islands Study - <i>George E. Bowen and Timothy R. Gangaware</i>	443
U.S. Army Land Condition/Trend Analysis of the Pohakuloa Training Area, Hawaii - <i>Robert B. Shaw, Christine M. Bern, Keith A. Schulz, Victor E. Diersing, and David J. Tazik</i>	455

Siltation of Reservoirs in Agricultural Watersheds Determined Using Radioisotope Techniques – <i>James W. Naney and Sherwood C. McIntyre</i>	465
The Fate of Mevinphos Spill and Water Quality: A Case Study From Lakes Pen Municipal Dump – <i>Peter Lamm</i>	475
Use of Adsorbed and Non-Adsorbed Tracers to Study the Transport of Agricultural Chemicals to Shallow Groundwater – <i>Rameshwar S. Kanwar, Christopher J. Everts, and George F. Czapar</i>	485
Utilization of Intracellular Granules of INT-Formazan and Gene Probes for Tracing Microorganisms in Ground Water – <i>Abdiel J. Alvarez, Sylvia I. Davila, and Gary A. Toranzos</i>	495
Optimization of Drinking Water Chlorination Practices for Minimization of Trihalomethanes Formation – <i>Concepción N. Burgos, Jaime Benítez, and Lorenzo Saliceti</i>	505
The Use of a Remote Operated Vehicle (ROV) to Evaluate Marine Discharges of Treated Wastewater – <i>Robert J. Reimold, W. Kevin Scott, Maria Margarita Irizárry, Raúl Gayá-Nigaglioni, and Stephen J. Cibik</i>	515
Management of Sludge From Puerto Rico's Regional Industrial Wastewater Treatment Plant: Phase 2-Dewatering – <i>Guido Peña, Jaime Benítez, Abraham Rodríguez, and Rafael Muñoz</i>	525
Removal of <i>Giardia</i> spp. by Conventional Water and Sewage Treatment Processes and Presence of Cysts in Surface Waters of Puerto Rico – <i>Ivan E. Correa, Gladys M. Yumet, and Gary A. Toranzos</i>	535
Isolation of Bacteriophages From Large Volumes of Pristine Tropical Water and Their Correlation to Fecal Contamination – <i>Edwin A. Hernández Delgado and Gary A. Toranzos</i>	543
Water Quality Problems of Rural Communities in Puerto Rico: A Case Study – <i>Roque A. Román-Seda, Ismael Pagán-Trinidad, Robert Williams, Susan Shaw, and Jorge Martínez</i>	553
Paper Title Index	567-568
Author Index	569-570