Impact of Tsunami On Ground Water, Soil and Vegetation

19 - 23 September 2005

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Registration Form
Impacts of tsunami on groundwater, soils and vegetation in coastal regions of Sri Lanka
Information Exchange Workshops and Conference

First Workshop: September 19, 2005 (Kandy)
Second Workshop: September 22, 2005 (Colombo)
Conference : September 23, 2005 (Colombo)

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Sri Lanka

Information Exchange Workshop on

Impact of Tsunami on Groundwater, Soils and Vegetation in the Coastal Regions of Sri Lanka

19 September 2005

at

Soil Survey Laboratory & SRICANSOL Resource Center

Department of Soil Science
Faculty of Agriculture
University of Peradeniya

Sponsored by

United States National Science Foundation (USNSF)
National Science Foundation of Sri Lanka (NSF)
Soil Science Society of Sri Lanka (SSSSL)

PROGRAMME

9.00 a.m. - Welcome Address
Dr M.C.N. Jayasuriya – Director, NSF
Prof. Ranjith B. Mapa - SSSSL

9.10 a.m. - Address by Prof. K.G.A. Goonasekara
Vice Chancellor, University of Peradeniya

Session I – Chairman: Prof. T. Illangasekara

9.15 a.m. - Project background, goals and planned outcomes
Prof. Tissa Illangasekara
Dr. Jayantha Obeysekara

9.30 a.m. - Overall assessment of spatial distribution of inundation and wave height associated with the Tsunami
Prof. Ananda Gunatilaka

10.00 a.m. - Tea

10.30 a.m. - Pre and post Tsunami salinity effects on agricultural land
Prof. R.B. Mapa, Dr. M.W. Wickramasinghe
D.N. Sirisena and K.M.A. Kendaragama

11.00 a.m. - Findings of the "green" and "brown' reports
Dr. Mahesh Jayaweera

11.30 a.m. - Introduction to the hydrogeology of coastal regions of Sri Lanka
Dr. H.A. Dharmagunawardena

12.00 noon - Lunch

Session II- Chairman: Dr. Jayantha Obeysekara

1.00 p.m.		Pre and post-Tsunami effects on vegetation of coastal areas Dr. S.P. Nissanka
1.30 p.m.	-	Groundwater conditions of the Dry Zone of Sri Lanka with special emphasis on the coastal region Dr.Lasantha Perera and Dr. C.R. Panabokke.
2.00 p.m	-	Pre and post Tsunami findings of the temporal and spatial characteristics of salt water intrusion. Dr. Karen Villholth and Dr. C.R. Panabokke
2.30 p.m.	-	Integrated management of surface water and groundwater – Approaches and system tools Prof. William Yeh
3.00 p.m		Water and solute transport in the unsaturated zone Prof. Rien van Genuchten
3.30 p.m		Tea
4.00 p.m		Geochemistry of coastal aquifers; salt water, -fresh water stability issues: Field Research Prof. Scott Tyler
4.30 p.m.	-	Comments by participants, discussion and conclusions Prof. Tissa Illangasekara Dr. Jayantha Obeysekara
6.00 p.m		Conclusion

Workshop on "Impacts of tsunami on groundwater, soils and vegetation in coastal regions of Sri Lanka"

Date : September 22, 2005
Time : 9.30 a.m.
Venue : Auditorium ITI, Baudhaloka Mw, Colombo 7.

PROGRAMME

Chairperson – Prof Ananda Gunatilaka

09.30 a.m.	**Welcome and expectations of NSF-Sri Lanka and meeting national needs** *Professor Sirimali Fernando, Chairperson, NSF/SL*
09.45 a.m.	**Project Background, Goals and Planned Outcomes** *Professor Tissa Illangasekare and Dr. Jayantha Obeysekera from USA/NSF*
10.00 a.m.	**Current state of water quality monitoring and laboratory facilities in Sri Lanka and expected needs and challenges due to tsunami** *Dr. A. M. Mubarak, Director ITI*
10.30 a.m.	**Coastal Groundwater, Water Supply and Sanitation : A Vicious Cycle?** *Dr Nalin Wikramanayake, Open University*
11.00 a.m.	**TEA BREAK**
11.15 a.m.	**Impact on drinking water supply & sanitation facilities and rebuilding of the water & sanitation infrastructure affected by the Tsunami tidal waves** Mr R.S.C. George, National Water Supply & Drainage Board
11.45 a.m.	**Risk based decision making, Water Resources Management in coastal regions-approaches and tools adaptable to tsunami affected regions** *Prof. Jagath Kaluarachchi, NSF/USA*
12.30 p.m.	**LUNCH**

Chair by *Professor Tissa Illangasekare and Dr. Jayantha Obeysekera from USA/NSF*

01.30 p.m.	**Mangrove systems- identification of science issues** *Prof. David Hydman, NSF/USA*
02.15 p.m.	**Geophysical investigations- approaches and tools adaptable to coastal aquifers affected by tsunami** *Dr. Kevin Cunningham, NSF/USA*
03.00 p.m.	**TEA BREAK**
03.15 p.m.	**Groundwater and transport modeling for use for salt water intrusion analysis and related problems** *Prof. Prabhakar Clement, NSF/USA*
04.00 p.m.	**Facilitated session of future needs** *Facilitators: Prof. Tissa Illangasekare, Dr. Jayantha Obeysekera and Dr. Karen Villhoth*
05.00 p.m.	**Concluding remarks, vote of thanks** *Professor Ananda Gunatilake and Professor Tissa Illangasekare*

Conference on
"Impacts of tsunami on groundwater, soils and vegetation in coastal regions of Sri Lanka"

Date : **September 23, 2005**
Time : **9..15 a.m.**
Venue : **Palm lounge, Galle Face Hotel, Colombo.**

PROGRAMME

09.15 am	**Registration**
09.30 a.m.	**TEA**
10.00 a.m.	**Welcome,** *Prof. Sirimali Fernando, NSF/SL*
10.10 a.m.	**Introduction of USA/NSF team,** Professor Tissa Illangasekare NSF/USA
10.20 a.m.	**Speech by the Chief Guest,** Prof Tissa Vitharana, Hon. Minister of Science and Technology
10.40 a.m.	**Summary of observations, findings, future needs and recommendations for collaborations by NSF/USA delegation** *Prof. Rien van Genutchen, Prof. William Yeh, Prof. Scott Tyler; NSF/USA*
11.30 a.m.	**Comments and possible directions for follow-up** Prof Ananda Gunatilaka NSF/SL
12.00 noon	**Press conference**
12.45 -1.45	**Lunch**

Tissa H. Illangasekare

Dr. Illangasekare is the AMAX distinguished chair of environmental sciences and engineering and a professor of civil engineering at the Colorado School of Mines (CSM). He is also the director of the Center for the Experimental Study of Subsurface Environmental Processes (CESEP) located at CSM. He received BS (honors) in Civil Engineering from University of Ceylon (Peradeniya) in 1971, M.Eng. in Water Resources and Hydrology from the Asian Institute of Technology in 1974 and a PhD in Civil Engineering from Colorado State University (CSU) in 1978. He was a faculty member at CSU, Louisiana State University and the University of Colorado at Boulder, prior to joining CSM. His expertise is in mathematical and numerical modeling of flow and transport in porous and fractured media, unsaturated and saturated zone processes, surface-subsurface interaction, snow hydrology, multiphase flow, aquifer remediation, and physical modeling of flow and transport in laboratory test tanks. He is a registered professional engineer, registered professional hydrologist, a fellow of the American Geophysical Union and a Fellow of the American Society of Civil Engineers. He is the Hydrology editor of Earth Science Review and serves on the editorial boards of Water Resource Research, Journal of Hydrology, Journal of Contaminant Hydrology, and Vadose Zone Journal.

William W-G Yeh

Professor Yeh is Distinguished Professor and Chair of the Department of Civil and Environmental Engineering at the University of California, Los Angeles (UCLA). He received his BS in Civil Engineering from the National Chen-Kung University, Taiwan, in 1961; his MS in Civil Engineering from New Mexico State University in 1964; and his PhD from Stanford University in 1967. He has been on the UCLA faculty since 1967. His research interests include groundwater modeling, inverse problems of parameter structure identification, and the development of methodologies and models for optimizing large-scale water resources systems. In 1989, he received the American Geophysical Union's Robert E. Horton Award. In 1993, the AGU elected him a Fellow. In 1994, he received the American Society of Civil Engineers' Julian Hinds Award. In 1996, he was elected an Honorary Member of ASCE. Finally, in 1999, Dr. Yeh was awarded the Warren A. Hall Medal from the Universities Council on Water Resources. In the past, he has served as an Associate Editor of *Water Resources Research* and *Journal of Water Resources Planning and Management* as well as Editor of *JWRPM.*

Prabhakar Clement

Dr. Prabhakar Clement is an associate professor at the Department of Civil Engineering, Auburn University, Auburn, Alabama. Before to joining Auburn University, Dr. Clement worked as a senior research engineer at the Battelle Pacific Northwest National Laboratory, Richland, Washington, for over six years (1994-1999) and later worked as a senior lecturer at the Center for Water Research, The University of Western Australia, Perth, Australia, for three years (1999-2002). Dr. Clement received his BS (1993) and MS (1985) degrees in Physics from Madras University and Madurai University, respectively; M.Tech. degree in Environmental Sciences and Engineering from the Indian Institute of Technology (in 1987), Bombay, India; and PhD in Civil Engineering from Auburn University, USA (in 1993). He is a registered profession civil engineer. His research interests include analysis of flow and reactive transport in groundwater systems, analysis of density coupled flow and variably saturated flow, laboratory-scale visualization of porous media flow, modeling and management of environmental remediation processes mediated by microbial systems, and design of natural attenuation and active bioremediation systems. Dr. Clement has published over 35 peer-reviewed journal articles, 4 book chapters, and over 25 conference papers in the area of environmental engineering. He serves on the editorial board of the ASCE Journal of Hydrologic Engineering and is a member of ASCE's Groundwater Hydrology and Groundwater Quality committees. Dr. Clement is the lead author of the US Department of Energy's public domain bioremediation model RT3D. He is also one of the co-authors of the US EPA's natural attenuation design tool BIOCHLOR. For further details, please visit: http://www.eng.auburn.edu/users/clemept/.

Scott W. Tyler

Scott Tyler is a Professor of Hydrogeology at the University of Nevada, Reno (UNR) and outgoing Director of the University's Graduate Program of Hydrologic Sciences. He received his BS in Mechanical Engineering from the University of Connecticut in 1978, his Masters in Hydrogeology from the New Mexico Institute of Mining and Technology in 1983 and his Ph.D. in Hydrogeology from the University of Nevada, Reno in 1991. He was a research scientist at Battelle Pacific Northwest National Laboratory and the Desert Research Institute prior to joining UNR in 1991. His research expertise ranges from vadose zone hydrology with an emphasis on ground water recharge and paleoclimate reconstruction from soil tracer profiles , experimental, field and numerical simulation of variable density fluid flow in porous media and field and numerical simulation of land surface energy budgets. He also serves as the faculty advisor to UNR's Student Associate for International Water Issues (SAIWI) and has led SAIWI work trips drilling and repairing village level water systems in Ghana, Haiti and Chile. Dr. Tyler is a fellow of Geologic Society of America (GSA) and Soil Science Society of America. He also serves as the incoming Hydrogeology Division chair of the GSA. Dr. Tyler is editor of Water Resources Research and has also served on the editorial boards of Groundwater, Hydrogeology Journal and Soil and Tillage Research.

Kevin J. Cunningham

Dr. Cunningham is a research hydrogeologist at the U.S. Geological Survey's Florida Science Research Center for Water and Restoration Studies in Fort Lauderdale, Florida. He received his BS in Geology from the University of Wisconsin-Oshkosh, MS in Geology from Louisiana State University-Baton Rouge, PhD from the University of Kansas-Lawrence, and performed his post-doctoral study at the University of Miami's Rosenstiel School of Marine and Atmospheric Science in Miami, Florida. His subsurface geologic experience includes eight years as a petroleum exploration geologist with Shell Oil Company in Houston, Texas. His recent research interests include conducting a long-term study to characterize the hydrogeology and hydraulic properties of the karst Biscayne aquifer in southeastern Florida by integrating high-resolution cyclostratigraphic techniques, ground-penetrating radar and seismic methods, and borehole geophysical tools; including borehole-flowmeter measurements and quantification of vuggy porosity using digital borehole images. Other research includes applying a conceptual model of karst porosity he has developed for the southeastern Florida Biscayne aquifer to evaluating core and field-scale microbiological transport in ground water for the assessment of the vulnerability of a major southeastern Florida utility well field to pathogen contamination. He is a registered professional geologist and the member of two technical groups involved in a 30-year plan for the restoration of the Florida everglades.

Rien Van Genuchten

Rien Van Genuchten is a Senior Research Soil Physicist and former Research Leader at the George E. Brown, Jr. Salinity Laboratory of the USDA Agricultural Research Service in Riverside California. He holds an MS degree in irrigation and drainage from Wageningen University in The Netherlands (1971), and a PhD in Soil Physics from New Mexico State University (1975). He has published widely on vadose zone flow and transport processes, numerical and analytical modeling, development of computer software, characterization and measurement of the unsaturated soil hydraulic properties, preferential flow in macroporous soils and unsaturated fractured rock, and root water uptake. Dr. van Genuchten is a Fellow of AAAS, AGU, ASA, and SSSA, and was recognized as one of the original "Highly Cited Researchers" by the Institute of Scientific Information, ISI. He holds an honorary degree from the University of Hannover, Germany, and earlier this year received the Dionys Stur Medal of Honor from the Slovak Academy of Sciences, Bratislava, for outstanding achievements in the natural sciences. He is founding editor of Vadose Zone Journal, an on-line journal published by SSSA in cooperation with GSA.

Jayantha Obeysekera ('Obey')

Jayantha Obeysekera is the Director of the Office of Modeling at the South Florida Water Management District (SFWMD). He holds a B.S. degree in Civil Engineering from University of Sri Lanka, M. Eng. in Hydrology from University of Roorkee, India, and a Ph.D. in Civil Engineering with specialization in water resources from Colorado State University. Prior to joining SFWMD, he worked as an Assistant Professor in the Department of Civil Engineering at Colorado State University where he taught courses in the Hydrology and Water Resources area and conducted research in stochastic hydrology. In addition, he has taught courses in the water resources area at George Washington University, Washington, D.C. and at Florida Atlantic University, Boca Raton, Florida. During his career, Dr. Obeysekera has published numerous research articles in refereed journals in the field of water resources. Dr. Obeysekera has over 20 years of experience practicing water resources engineering with an emphasis on both stochastic and deterministic modeling. He has taught short courses on modeling in the countries of Dominican Republic, Colombia, Spain, Sri Lanka, and U.S. He was a former member of the Surface Runoff Committee of the American Geophysical Union and is currently serving as a member of a Federal Task Group on Hydrologic Modeling.

Karsten H. Jensen

Dr. Karsten H. Jensen is professor in hydrogeology at University of Copenhagen. He holds a MSc degree in civil engineering and a PhD degree in hydrology both from the Technical University of Copenhagen. He was a professor in hydrology at the Technical University of Denmark until 2002. Currently he is director of the International research Scholl of Water Resources (Fiva). In the period 1997-2001 he was president of the International Committee on Atmospheric-Soil-Vegetation Relations under the International Association of Hydrological Sciences (IAHS). He has been co-convenor and co-editor for several international workshops and symposia and currently he serves as associate editor of Water Resources Research and Vadose Zone Journal. He has been involved in several international research and project activities and recently he has been member of missions in Zambia and Botswana regarding research and capacity building

Jagath Kaluarachchi

Prof. Kaluarachchi has been with the Department of Civil and Environmental Engineering and the Utah Water Research Laboratory since 1990 and is current the head of the Water Engineering Program. During this period, his research interests have been groundwater hydrology; analysis and modeling of subsurface contamination due to organic liquids, heavy metals, and agricultural pollutants; analysis of remedial technologies; risk assessment and decision analysis; stochastic subsurface hydrology; aquifer vulnerability assessment; and water resources analysis and management at the basin scale. He has published over 55 manuscripts in reputed scientific journals plus over 100 numerous conference proceedings, participated in scientific presentations, gave invited seminars and short courses in the US, Middle East, and Asia. Prof. Kaluarachchi is an active member of the ASCE and EWRI and currently serving as the Vice-Chair of the Watershed Council.

David W. Hyndman

David Hyndman is an Associate Professor in Hydrogeology and Environmental Geophysics at the Department of Geological Sciences at Michigan State University. He has a Ph.D. and an M.S. degree in the area of hydrogeology from Stanford University. His research explores the physical and chemical processes that influence groundwater flow and solute transport, and the factors that affect seismic and electromagnetic wave propagation. He has combined multiple independent data sets, such as crosswell seismic traveltimes , hydraulic heads and tracer concentrations through three-dimensional numerical simulations, to estimate aquifer properties with high resolution. This provides information about the influence of these properties on groundwater flow, solute transport, and bioremediation of organic contaminants. Research also includes a variety of models to explore processes occurring in natural and anthropogenically altered systems.

Dr. Hyndman has received numerous awards for his work and has authored and/or co-authored many articles in referred journals. He is also a co-author of the book, Natural Hazards and Disasters published in 2005. Presently, he is the Associate Editor for the journals of Ground Water and Water Resources Research. He is co-editor for SEPM Volume on Aquifer Characterization

Integrated Management of Surface Water and Groundwater – Approaches and Systems Tools

William Yeh
Department of Civil and Environmental Engineering
University of California, Los Angeles, California

Abstract: Increasing demands for water by competing users pose new challenges for water resources managers. Decision makers must understand the interactions between surface water, groundwater and the environmental system. Additionally, the decisions made with regard to water transfer and allocation must take into consideration the diverse objectives that include water supply, cost efficiency and ecosystem protection. This paper reviews the concept of multiobjective optimization, and systems analysis approaches and tolls developed for water resources planning and management with particular emphasis on the linking of simulation models to optimization. This paper will also review the integrated management of surface water and groundwater in Southern California as well as the saltwater intrusion barrier projects in the coastal plain in Southern California.

Understanding the Dynamics of Contaminant Transport near a Salt Wedge using Field/ Laboratory Observations and Computer Simulations

T. Prabhakar Clement
Associate Professor
Auburn University

In this presentation, I will discuss multiple laboratory, field, and computer simulation datasets to illustrate the contaminant transport issues associated with saltwater intrusion dynamics. This is a short summary of the projects completed by the members of my research group in the past five years. The field dataset is based on a two-year field investigation of a dissolved hydrocarbon plume flowing towards a tidally- and seasonally-forced estuarine river system (Westbrook et al. 2005). Installation and sampling of several multi-port wells along the saline riverbank and into the river enabled us to map both vertical and horizontal definition of the hydrocarbon plume. Using the field data, a conceptual model was developed to illustrate the hydrodynamic controls of groundwater and contaminant discharge patterns occurring near a groundwater and saltwater interface.

Our laboratory research focused on developing physical models to study the transient migration patterns of contaminants in unconfined aquifers (e.g., Simpson et al. 2003). Observations were made in laboratory-scale tanks to record the salt-wedge intrusion and recession processes occurring in an unconfined aquifer. Later, the effect of basement heterogeneity on accumulating salts within an unconfined aquifer was studied. The salt accumulation processes due to gradual invasion of saltwater (due to natural reduction in aquifer flow), and the salt accumulation processes due to sudden invasion of saltwater (due to catastrophic events such as tsunami) were studied. Finally, experiments were completed to record the migration patterns of anthropogenic contaminants (such as nutrients and other organic contaminants) released just beneath and above the salt water wedge. These laboratory observations provide data to develop conceptual models for modeling various types of transport problems occurring near a salt wedge.

Our modeling efforts focus on benchmarking density coupled codes using various types of theoretical and experimental datasets (Simpson and Clement, 2003 & 2004). Two classes of benchmark problems that involve stable and unstable internal interfaces and their respective role in testing density coupled codes will be presented. Further, a brief introduction to the current version of the reactive transport code RT3D (Clement et al. 2000) and its use in modeling reactive contaminants will also be provided.

References

1) Clement, T.P., C.D., Johnson, Y. Sun, G.M. Klecka, C. Bartlett, Natural attenuation of chlorinated solvent compounds: Model development and field-scale application, *Journal of Contaminant Hydrology*, vol.42, p.113-140, 2000.
2) Simpson, M.J., T.P. Clement, and T.A. Gallop, Laboratory and numerical investigation of flow and transport near a seepageface boundary, *Ground Water*, vol 41(5), p.690-700, 2003.
3) Simpson, M.J., and T.P. Clement, Worthiness of the Henry and Elder problems for validating density-dependent flow models, *Advances in Water Resources*, vol (26) p. 17-31, 2003.
4) Simpson, M.J., and T.P. Clement, Improving the worthiness of the Henry problem as a benchmark for density-dependent groundwater flow models, *Water Resources Research*, vol 40 (1), W01504, doi:10.1029/2003WR002199, 2004.
5) Westbrook S.J., J.L. Rayner, G.B. Davis, T.P. Clement, P.L. Bjerg, and S.J. Fisher, Interaction between shallow groundwater, saline surface water and contaminant discharge at a seasonally- and tidally-forced estuarine boundary, *Journal of Hydrology*, vol (302) p. 255-269, 2005.

Coastal Aquifer chemical mixing: salt-water freshwater stability issues and possible mechanisms for post-tsunami aquifer mixing.

Scott W. Tyler
Professor of Hydrology
Department of Geologic Science and Engineering
University of Nevada, Reno
Reno, NV
tylers@unr.edu
http://equinox.unr.edu/homepage/tylers/

Convective behavior in aquifers and porous media are often overlooked as possible mixing mechanisms of both salinity and contaminants. Vertical or horizontal gradients of fluid density, either from salinity or temperature are quite common in many aquifer systems and can lead to convective fluid motion not easily predicted from water level or peizometric level analysis. The development of convection cells in aquifers is controlled by fluid density contracts, fluid density gradients, and aquifer permeability and the diffusion/dispersion properties of either salinity or heat. System stability can be parameterized through the Rayleigh number, a non-dimensional representation of the ratio of buoyancy forcing to resistive forcing.

Of particular interest to coastal aquifers inundated by tsunami waves may be case of a relatively thin layer of denser seawater infiltrated over a fresher ground water. Such an unstable density contract can lead, depending upon aquifer parameters, to a convective mixing pattern in the aquifer in which the denser seawater descends through the aquifer in plume-like structures. In this lecture, an overview of density driven miscible flows in aquifers will be presented, along with examples of laboratory and field data showing the nature of mixing and stratification that can occur in saline-fresh water aquifer systems. A discussion of the possible application of stability analysis to better understand the salinity distribution in coastal aquifers following the tsunami wave will also be presented.

This discussion will then be followed by an overview of UNR student/faculty international activities in the area of public water supply. To date, UNR students and faculty have led 7 work trips, primarily to developing countries, to transfer technology on drinking water and water resource management and also to provide volunteer labor and training to local water managers. These work trips are completely volunteer driven and funded by local donations, yet provide a tremendously valuable educational experience for American students to learn about other cultures, while also providing a valuable service to the host country. Work trips have included drilling water wells in Kenya, repairing and training Haitian teams to repair village hand pumps in drilled and dug wells, sanitation and water resource education in Panama and measurement of evapotranspiration in Chilean wetlands. It is hoped that through these discussions, appropriate projects for UNR and other US university students can be developed or expanded in Sri Lanka.

Water and Salinity Dynamics in Soils and Groundwater

Rien van Genuchten
George E. Brown, Jr. Salinity Laboratory, USDA, ARS
Riverside, CA

Many of the tsunami-related problems in coastal regions of Sri Lanka involve the salinity of the invading seawater and its effect on local soil and groundwater resources, including agricultural operations. The Salinity Laboratory of the USDA-Agricultural Research Service has a long history of research dealing with water flow and salinity dynamics in the subsurface, especially as related to the unsaturated zone. This presentation reviews some of our basic and applied research that may have direct relevance to the Tsunami-related salinity problems in Sri Lanka. This includes development of user-friendly models for predicting one-and multi-dimensional water and solute transport in soils and groundwater, multicomponent geochemistry, salinity dynamics in irrigated areas, unsaturated soil hydraulic property characterization, the effects of salinity on the soil hydraulic properties, root water uptake and plant salt tolerance, bacteria and virus transport, and instrumental techniques. Some of the modeling tools developed at the Salinity Laboratory (such as especially the HYDRUS and STANMOD codes;
http://www.ussl.ars.usda.gov/models/modelsmenu.htm) should be useful for estimating the general or site-specific effects of salinity (both short- and long-term) on soil and groundwater resources, and for evaluating possible remediation strategies.

Hydrological characterization of the unsaturated zone using cross-borehole radar and resistivity imaging

Karsten H. Jensen
University of Copenhagen

Subsurface heterogeneity complicates a proper field characterization of flow and transport properties using traditional using conventional sampling and monitoring techniques. Data obtained at point locations and in wells may not allow for an accurate representation of subsurface characteristics particularly in the horizontal direction. Recent developments within hydrogeophysics have demonstrated that many hydrogeological studies may benefit from the additional information that cross-borehole electrical resistivity tomography (ERT) and transmission radar tomography can provide. Data on changes in water content and salt concentration can be obtained with an attractive spatial resolution and at a spatial scale suitable for testing and calibrating hydrological models for flow and transport. Such data may underpin predictions of future salinity changes of Tsunami affected soil.

Results will be shown from a site in Denmark located on 20 m unsaturated sandy soil. Two identical field sites have been established each having four ERT and four georadar boreholes. The boreholes are drilled to form a cross consisting of two lines. The two sites are located 8.5 m apart enabling an evaluation of the spatial variability. One of the sites is exposed to natural rainfall and evapotranspiration conditions while at the other one the upper boundary is controlled by irrigation. At both sites tracer in the form of chloride has been added for characterization of transport and dispersion properties. Using resistivity and georadar tomography in combination it is possible to obtain data for the spacio-temporal variations of both water content and tracer concentration. The data will also serve the purpose of estimation large-scale hydraulic parameters for unsaturated flow.

Hydrogeologic and borehole and surface geophysical methods applied to aquifer characterization and water-supply recovery: post-tsunami coastal aquifers, Sri Lanka

Kevin J. Cunningham
U.S. Geological Survey, 3110 SW 9th Avenue, Fort Lauderdale, Florida 33315, USA

The December 26th, 2004, tsunami had a huge impact on fresh ground-water supplies in affected areas due to the rapid degradation of the water quality that resulted from overland saltwater flooding of coastal areas. Important to evaluation of the aquifers and restoration of freshwater supplies will be (1) a reliable characterization of the physical system that composes the coastal aquifers, and (2) numerical hydrologic simulation of the tsunami event and the eventual recovery of the coastal aquifers to normal conditions. Assessment of the geologic, hydrologic, and hydraulic parameters of the aquifer are fundamental information needs for aquifer characterization and revitalization of water-supply needs. Hydrogeologic and geophysical methods are the principal tools in accomplishing this assessment. Characterization of the physical system is also a critical component of numerical hydrologic simulations, which are most reliable using an accurate aquifer framework and description of aquifer ground water.

The U.S. Geological Survey's (USGS) Office of Ground Water—Branch of Geophysics in Storrs, Connecticut, and Center for Water and Restoration Studies in Fort Lauderdale, Florida, have numerous borehole and surface geophysical tools that have relevance to coastal aquifer characterization in Sri Lanka. Specific USGS borehole geophysical tools that could provide important aquifer data include: acoustic televiewer, three-arm caliper, digital borehole imager, electromagnetic induction, flowmeters (heat-pulse, electromagnetic, and spinner), fluid resistivity, fluid temperature, natural gamma ray, spectral gamma ray, single-point resistivity, spontaneous potential, video camera, and borehole water sampler. In addition, surface geophysical instrumentation from the USGS that could produce significant information about the coastal aquifers include: electromagnetic and transient electromagnetic ground conductivity meters, ground-penetrating radar, water-borne continuous resistivity profiling, water-borne seismic reflection profiling, and helicopter electromagnetic surveys. Principal applications of both borehole and surface geophysical methods include: (1) depth to freshwater-saltwater interface(s); (2) measurement of vertical ground-water salinity profiles; (3) determination of depth to bedrock; (4) detection, measurement, and orientation of bedrock fractures; (5) delineation of lithology; (6) mapping of clay (confining) units; (7) detection of porous hydrogeologic units; (8) detection of ground-water flow units or productive fractures; and (9) development of a hydrogeologic framework. Many of these geophysical tools have been practical in characterization of the coastal karst limestone Biscayne aquifer of southern Florida and other aquifers of the United States. Examples of their application will be presented.

Suggested for the characterization of the coastal aquifers and recovery of water supplies in Sri Lanka is a plausible, highly generalized plan for implementation of the use of selected hydrogeologic and geophysical methods. The first step would include drilling monitoring wells and water-supply wells. Geologic core samples recovered from the drilling wells would provide definition of the lithologic composition and hydraulic character of aquifers. Borehole geophysical logs acquired in these wells would produce important information on water-table levels, ground-water salinity, aquifer productivity, and aquifer framework; thus, providing data to map potentiometric surfaces, ground-water quality, trends in productivity, and hydrogeologic framework. These maps could show the location of prospective new water-supply wells for the immediate needs of the impacted population. Geologic contacts, water-table elevations, ground-water salinities, freshwater-saltwater interfaces, and aquifer frameworks would delineate between wells with surface geophysical tools. Hydrogeologic and borehole and surface geophysical data would integrate into conceptual hydrogeologic models that would be functional in numerical hydrologic simulations.

Synopsis of Post-Tsunami Rapid Environmental Assessments in Sri Lanka

Ministry of Environment and Natural Resources

13th June 2005

1. Scope of the assessments

In an immediate response to the tsunami, the Minister of Environment and Natural Resources, Hon. A. H. M. Fowzie, took steps to carry out a Rapid Environmental Assessment (REA) of the tsunami-affected areas, in close cooperation with the Central Environmental Authority (CEA), and with the assistance and support of the United Nations Environment Programme (UNEP). The REA was undertaken by scientists from Amparai, Colombo, Eastern, Ruhuna, Jaffna, Moratuwa and Sri Jayawardenapura Universities. It was in two parts, focussing respectively on the 'green' environment (ecosystems, biodiversity, protected areas and farmlands) and the 'brown' environment (pollution, debris and impacts on human settlements and infrastructure).

The 'green' assessment involved describing, at one-km intervals over more than 800 km of affected coastline, transects perpendicular to the shore and running inland from the high tide line. Data were collected on vulnerability, physical, ecological and social damage, land use, constraints on and options for land use, and on the precise pattern of tsunami inundation. All observations were georeferenced digitally. These profiles provided a significant sample of observation points and a set of locations where the complex interaction of the tsunami with topography, ecosystems and human settlements could be analysed and understood. Each was also an observation point for overlapping descriptions of the surrounding area, yielding continuous coverage of the affected coast.

The 'brown' assessment concentrated on contamination at over 750 sites where particular risks were known to exist because the tsunami affected facilities for storage or processing of potentially hazardous materials. These included both established solid waste dumps and new ones used to dispose of tsunami debris, as well as storage and processing facilities associated with the commercial, health, security, transport, tourism, agriculture, fisheries, mining and other sectors. Each site was assessed for type, scope and intensity of pollution, looking at faecal, oil and toxic contamination, visual, air, odour and thermal pollution, disease risks and salinization. Samples of water and soil were collected wherever necessary and analysed chemically. Sites were scored for the severity of impact and conclusions drawn on the urgency and feasibility of mitigation in terms of either short-term, medium-term or long-term projects.

This document is a synopsis of the main findings of the 'green' and 'brown' assessments, which also takes into account findings by other national institutions (CCD, DWLC. NARA, UDA, etc.) and international agencies (IUCN, IWMI, UNEP/OCHA, ADB, JBIC, JICA, World Bank, FAO, etc.). It reviews the main conclusions, drawing out of them a number of recommendations for action, upon which a portfolio of proposed remediation projects is based (Annex 1). From these, detailed proposals can now be prepared to guide investments by government and potential donors.

2. Summary of assessment findings

a) Variation in depth of penetration.

The tsunami impacted the eastern coastline of Sri Lanka shortly after 08.00 hours and then swept along the southern and south-western shores over the following 90 minutes or so. There were typically three large waves and several lesser ones at each site, with the largest ranging from 3-9 metres high at the shore, and penetrating inland for distances ranging from a few tens of metres to up to 3 km. The median depth of penetration was about 300 m in Trincomalee and Ampara districts, 130 m in Batticaloa, 110 m in Matara, 100 m in Hambantota, 70 m in Galle, and 50 m in Jaffna district. The depth of penetration was influenced by the shape of the sea-bed, which is thought to have funnelled the wave into a higher shape in some areas, and by on-shore terrain and vegetation, being resisted by large sand dunes, absorbed by mangroves and lagoons, and facilitated by inlets and estuaries. Complex coastal environments (e.g. those containing beaches, dunes, lagoons, plantations, mangroves, rivers, home gardens, etc. in the same area) absorbed tsunami energy and provided protection.

b) Debris and solid waste.

Well over 500 million kg of rubble were created by the tsunami and are still posing an enormous challenge to the solid waste management system. Debris and marine sand, whether deposited by the tsunami or by subsequent clean-up operations, block drainage channels in many areas, posing an acute risk of water-logging and loss of agricultural land, as well as increased mosquito-borne disease.

c) Salinization of drinking water wells.

This has affected large areas and rendered more than 15,000 wells unusable, greatly reducing water supplies. Over-pumping of wells in an attempt to clean contaminated or saline water and restore fresh-water supplies has often encouraged salt-intrusion, which has done more harm than good. Existing mobile water treatment units in this respect need scrutiny.

d) Contamination of water bodies.

Several coastal water bodies have been contaminated with salt-water, debris, floating material, faecal matter and black sediments, etc. Karagan lewaya, Hambantota, Sastarawila, Panama and Arugam Bay are some sites that need urgent restoration. In these cases, the original ecosystem is completely disrupted, much of the fauna and flora have died, and natural self-purification has ceased, resulting in highly toxic water bodies.

e) Resettlement and reconstruction.

These activities are placing a huge burden on natural resources, especially through the location of new settlements in or near protected areas and other ecologically sensitive locations, and increased demand for sand and wood for reconstruction and firewood for brick-making. Faecal contamination of ground water has become a major issue in some of the tsunami-affected areas, and further resettlements could worsen the situation. Without careful management, these activities have the potential to cause more irreversible damage to Sri Lanka's environment than did the tsunami itself.

f) Damage to marine ecosystems.

These showed a variety of impacts; shallow fringing coral reefs were damaged mechanically, with breakage of branching corals and dislodging of boulder corals, with some smothering by debris carried by backwash; intact coral reefs acted as buffers, but these were few because of pre-tsunami damage from mining, blast-fishing and bleaching.

g) Damage to shoreline ecosystems.

Estuaries often acted as channels of entry for the tsunami, facilitating damage and salt intrusion far inland. Front-line mangroves were badly damaged, while deeper mangroves were left intact and dense mangroves converted the wave into a flood. Lagoons absorbed tsunami energy, but in doing so lost seasonal sand barriers, their banks were scoured, and mangroves at their entrances were dislodged, but they were otherwise little affected and/or recovered quickly (apart from litter and debris pollution, and some cases of blocked water flow causing stagnation). Large, vegetated sand dunes stopped tsunami intrusion. Beaches were eroded and scoured, losing width and height, mainly from tsunami back-wash. There is much debris on most beaches, including unexploded ordnance in some areas.

h) Damage to inland ecosystems.

There was severe damage in near-shore areas, including to seashore *Pandanus* and creeper vegetation, and inland palmyra trees, with near-shore coconuts less affected as were inland economic trees. *Casuarina* plantations proved vulnerable to tsunami damage and by themselves had little protective value, though in places they helped stabilise sand dunes which themselves moderated the tsunami. Alien invasive species have been spread by the tsunami into new areas.

3. Summary of recommendations

a) Urgent interventions in particular sectors.

- *Debris management* - mobilise local government and communities to undertake immediate sorting and safe and environmentally-responsible disposal of debris on a 'cash-for-work' basis at the local level under the direction and guidance of the CEA.
- *Environmental contamination* - manage pollution hotspots associated with solid waste dumping and sludge disposal; sample and test marine sludge deposits for possible heavy metals and other persistent pollutants, and remove and safely dispose as appropriate.
- *Rehabilitation of natural water bodies* - remove debris and sludge, release stagnant, anoxic and contaminated water, and restore pre-tsunami ecological conditions to the extent possible.
- *Restoration of land drainage* - clear sand and debris from drainage channels, in order to prevent the loss of productive land by water-logging, and the increased transmission of mosquito-borne diseases.
- *Sustainable recovery and reconstruction of water supplies* - train all staff who manage water treatment and pumping units to maximise the sustainable rate of recovery of safe water supplies and to prevent over-pumping and irreversible salinisation of wells and ground water; invest in the provision of drinking water supply in many affected areas.
- *Sand mining and nourishment*- identify areas where the landward sides of large sand dunes could be harvested for sand, or wind-blown sand trapped in commercial quantities, without affecting the dunes' ability to protect the coast; areas that need nourishment must also be identified and sand pumping carried out as needed.
- *Ecosystem management* – work with NGOs, local community and other responsible elements to rehabilitate damaged ecosystems with priority to Special Area Management (SAM) sites.

b) Urgent interventions at specific sites.

- Clearing debris, and in places unexploded ordnance from beaches, seashores, near-shore sea beds and coral reefs.
- Restoring access channels for fishing boats.
- Replacing and/or relocating safe anchorages.
- Identifying sites for properly-regulated sand mining.
- Identifying sites that need proper water supply and sanitation facilities.

- Regenerating and stabilizing sand dunes and the banks of drainage channels.
- Removing sand and debris from drainage pathways and farmland.
- Assessing and restoring ground-water quality.
- Identifying land suitable for resettlement, with special attention to freshwater supply, drainage, fishery livelihoods and tenure/resource conflicts.
- Restoring original ecosystems in water bodies and SAM sites.

c) **Urgent strategic interventions.**

- *Coordinating post-tsunami investment* through a standing committee co-chaired by MENR, CEA and TAFREN, and expert/donor round-tables as needed, to ensure that environmental concerns are fully integrated in all decisions on national reconstruction, and to coordinate country-driven implementation of all relevant government recommendations.
- *Strengthening national policy* on the management of critical environmental issues through joint MENR-CEA-TAFREN leadership, including policy on the environmentally-responsible disposal of debris and solid wastes, the extraction and sustainable supply of safe drinking water, the restoration of effective drainage to farmlands and urban areas, and the prevention of deforestation resulting from construction and resettlement. The policy framework should be used to develop mandatory guidelines to ensure uniform practice.
- *Enhancing the role of MENR in national reconstruction planning*, by resourcing it to allow the participation of its officials and/or consultants in all relevant decisions.
- *Building institutional capacity for environmental management* through an appropriate combination of training, addition of expert staff, resourcing to allow the use of national consultants, provision of appropriate equipment, hardware and software, and resourcing to support field work, data and sample analysis and reporting.
- *Building capacity for public participation in ecosystem restoration* by encouraging and enabling local authorities to develop and implement integrated local plans at the community, divisional and provincial levels that incorporate options for restoring ecosystems known to help protect against environmental shocks (e.g. mangroves, dunes, reefs and wetlands) as well restoring home gardens, plantations, bunds, banks, channels and other features of livelihood significance that also help protect the environments where people live.
- *Disseminating information* by producing and distributing clear, simple, illustrated guidelines in appropriate languages, on how safely to classify, separate, compost, re-use, recycle and dispose of solid waste and debris, how to design and construct improved housing and sanitation using safe materials, and how to identify and correct environmental problems such as blocked land drainage, salinisation, and the spread of alien invasive species.

- *Mapping of coastal zone terrain* up to the 10 m contour, to support priority setting for coastal defence investments.
- *Encouraging and enabling regional collaboration*, by ensuring that Sri Lanka participates fully in regional partnerships for information sharing, technical support and capacity building.
- *Building consensus on national priorities* through a national round-table discussion on lessons learned from the tsunami, and national priorities for restoration and development in the coastal zone.

4. The path ahead

The above-mentioned body of recommendations and potential projects has emerged based on the findings of the REA. A Development Forum held in Kandy during May also highlighted the need to address environmental concerns in the government's Post-tsunami Recovery and Reconstruction (PTRR) strategy. There is now an urgent need to begin aligning the recommendations of the REA with those of the Development Forum, and to engage the UN family and potential donors in their coordinated implementation in line with the PTRR process. To this end, the Development Forum recommended the following steps:

- **Establish a high-level Multi-stakeholder Platform**, comprising .MENR, TAFREN, CEA, UDA and other key institutions, to coordinate and direct environmental inputs to the implementation of the PTRR strategy.
- **Establish a Helpdesk in Colombo and a network of District Environmental Helpdesks**, to facilitate rapid responses to problems experienced at the local level in the implementation of the environmental component of the PTRR strategy.
- **Hold meetings of national, provincial and local governmental and non-governmental institutions**:
    - to develop a comprehensive plan of action for environmental remediation and integration of environmental considerations in the implementation of the national reconstruction and development programme;
    - to align environmental needs with donor assistance; and
    - to make institutional arrangements to prevent the duplication of effort, ensure coordinated environmental action at all levels, and arrange for monitoring and further support for implementation.

Annex 1: Summary of proposed urgent interventions			
Project theme	**Target**	**Proposed intervention and location**	**Indicative budget (US$)**
1. Managing debris and waste	Tsunami-affected areas	Mobilise local government and communities to undertake immediate sorting and safe and environmentally-responsible disposal of debris and solid wastes on a 'cash-for-work' basis at the local level with the direction and guidance of CEA.	2,000,000
2. Assessing and remediating environmental contamination	**Component 1**: Tsunami-affected water bodies in Sri Lanka	**Component 1**: Restore affected lagoons and estuaries (e.g. Karagan lewaya, Hambantota, Sastarawila, Panama, Arugam Bay). Sample and test marine sludge introduced to water bodies by the tsunami for heavy metals and other persistent pollutants; remove and dispose of safely as appropriate.	2,000,000
	Component 2: Abandoned and active mineral pits.	**Component 2**: Remedy pollution hotspots associated with solid waste dumping and sludge disposal (e.g. at Thelwatta, Akurala, Habaraduwa and Ambalangoda).	500,000
	Component 3: Tsunami-affected areas in Indian Ocean	**Component 3**: Share information among countries concerning the sampling and testing of marine sludge for persistent pollutants, and its removal and safe disposal.	75,000
	Component 4: Tsunami-affected fishery harbours	**Component 4**: Clean, rehabilitate, restore or reconstruct fishery harbours as needed (e.g. Panadura, Beruwela, Hikkaduwa, Tangalle, Hambantota, Kirinda harbours and Arugam Bay, Kalladi Beach, Vallachchanai lagoon anchorages); correct sanitation and waste management issues.	2,500,000
3. Rehabilitating ecosystems	**Component 1**: Rehabilitation of SAM sites	**Component 1**: Rehabilitate SAM sites	

Pre and Post Tsunami Effects on Vegetation of Coastal Areas

S.P. Nissanka

Department of Crop Science
Faculty of Agriculture
University of Peradeniya

Abstract

The devastation and destruction caused by the tsunami disaster is not only restricted to damaging human lives and livelihoods but also collapsed the entire environmental, agricultural and social setup of the coastal area of Sri Lanka. In order to provide the relief for the victims of the disaster, the Government has implemented a massive relief programme, with the assistance of international agencies. Related government and nongovernmental organizations have also been attempting to assess tsunami impacts on agricultural and natural environments. Results of a situation assessment study carried out by a group of scientists at the University of Peradeniya and some already available related information are reviewed in here.

Situation assessment results reveled that 82% and 62% of the displaced people are in favor of moving out of the proposed 100 m buffer zone in Hambantota and Amapara districts respectively. Furthermore, most of the people who wish to move away from the buffer zone wanted to continue their authenticity in the former lands. Regarding future expectations of the affected community both at Hambantota (85%) and Ampara (95%) districts, permanent residence appeared to be the top priority. The job priority (livelihood) seems secondary. It highlights the affected people's desires on the rehabilitation programs.

Large stretches of coastal region inundated with saline seawater body up to a few kilometer to heights of about 10-30 m at certain places. Severity and the extent of the damages varied with the force of the tsunami waves, topography, land use pattern, vegetation types and the extent of damages caused to sand dunes and corral reef. In addition to the loss of thousands of human lives and properties, inundation of coast and deposition of saline sediments caused severe damages to natural habitats of terrestrial and wetlands, agricultural fields and plantations, and to soil and water bodies etc. Major terrestrial vegetation types come under the tsunami-affected regions are thorny forest/scrublands, sand dune vegetation, arid zone maritime grasslands/pasture, riverine forests, and semi evergreen forests. The major wetland types are the salt marsh, mangrove, brackish water lagoons, seashore, water hole/tanks, and streams.

It is estimated that the number of farming families affected by the Tsunami was 9048 and the total extent of damage to agricultural land is around 4200 -6000 ha. In most environmental surveys to date, damage to the natural ecosystems was categorized as slight or negligible in most instances except for few cases. Among the different land use systems, paddy farming was the hardest hit mono-crop, next to fruits and vegetables grown in home gardens. The total number of home garden units affected is estimated as 27,710. However, over 50% of the

agricultural lands have been successfully replanted several weeks or months after the tsunami.

Study carryout by our team to investigate the impact of tsunami on vegetation and soil salinity developments (over 500 soil sampling sites) in the southern region of different land use types namely; urban and rural home-gardens, rice fields, coconut fields, and plantation and natural forest, revealed that salinity development is not a major problem across all land use types. Majority of the sites are having EC values lower than 4 dS/m. Few areas developed salinity, they are mostly sites where sea water was accumulated for longer period due to topographical setup. These sites may need restoration and recovery attention. However, these sites could be recovered faster if the drainage is improved. As an immediate measure especially for rice cultivation use of salinity tolerant varieties, irrigation and improved drainage facilities together with site-specific fertilization and organic matter may improve the productivity.

Mostly affected species in urban and rural home-gardens are the mango, banana, breadfruit, palmyrah, some citrus spp, sesbania etc. Coconut, woodapple, pomegranate, neem, casuarinas, gansuriya (*Thespesia populnea*), palu (*Manilkara nhexandra*) were some species that were not or least affected. Most of the species that were defoliated are recovering. Some species have shown bud breaking and production of fruits with high salt contents (Guava) showing stress adaptation mechanisms. Forested lands and Coconut fields are also having a similar trend. There were a few sites where salinity levels are higher than 4 dS/m (range of 4-10). The trend has been to have slightly higher EC near seashore and decline when moves towards countryside. Urban-homegardens were having soil EC levels well below 4 dS/m casing no real impact on vegetation.

Most of the pandanus and mangrove stands in beachfronts and lagoons were severely affected because these species were the first line of defense in many areas, which took over the full force of the waves. Seashore vegetation cover that consists of mainly creepers is reduced by about 75% in some locations. Debris, sands and sea mud deposited on maritime grasslands, salt marsh and agricultural lands and other land use types. Land use setups such as bunds, irrigation channels, and drainage systems have been badly blocked and destroyed. Massive erosion has occurred and debris left on agricultural fields especially on rice fields pose a problem as the large areas of land need to be cleaned which can be time consuming.

Tsunami waves have pushed seeds of alien invasive species from their coasts farther inland especially in southern region. In some areas, including important national parks, the wave has encouraged the spread of alien invasive species, such as prickly pears (type of cactus) and salt-tolerant mesquite (*Prosopis*), which have become an invasive and severe threat to the natural vegetation in the Bundala national park. They will definitely spread in an unprecedented rate and become dominant posing a severe threat to our natural ecosystems reducing faunal and floral diversity. In some areas species like *Trianthema (sarana)*, *Solunum xanthocapum(ela batu)*, *Avera spp (pala types)* are thriving well and spreading very rapidly.

Several studies confirm of many signs of satisfactory recovery; trees knocked over by the wave's impact and inundated vegetations are regenerating, wildlife including those of elephants and leopards is returning to damaged areas and beginning to drink from ponds that had been contaminated with saltwater but are returning to fresh water.

We learned that the natural ecosystems and barriers such as coral reefs, mangroves, other coastal vegetation and sea-grasses, and sand dunes which we have so casually destroyed were the lifesavers capable of helping to defend our homes, our loved ones and our livelihoods from this nature's more aggressive acts. Several studies also confirm that in those areas with healthy coral reefs and mangroves, the impacts of the devastating tsunami were significantly reduced. Mangrove forests along shorelines are considered critical to halting erosion, but much of growth has fallen victim in recent years to intense coastal development.

Resettlement and reconstruction are now placing a huge burden on natural resources, specially through the location of new settlements in or near ecologically sensitive areas, and increased demand for sand and wood for reconstruction and firewood for brick-making etc. It is therefore vital, that during the reconstruction of shattered coastlines and settlements, the environment is taken into account along with the economic and social factors. If ad-hock, unplanned decisions are taken, it may cause more irreversible damages to the environment than did the tsunami itself.

Tsunami affected many of natural and agro-ecosystems by destroying natural habitats, vegetations in home gardens, plantation crops and forest species and farm fields causing salinization of soil, wells, ponds etc. So far, much of what is known about the environmental damage of the tsunami comes from anecdotal or local reports. Therefore, clear understanding on the nature, severity, dynamics and diversity changes etc, due to the tsunami impacts especially on natural and agro-ecosystems is essential to identify systems that are capable of recover naturally with time and systems that need long-term management strategies to speedy recovery and restoration.

Impact on drinking water supply & sanitation facilities and rebuilding of the water & sanitation infrastructure affected by the Tsunami tidal waves

Presented by
R. S. C. George
Deputy General Manager (Corporate Planning)
National Water Supply & Drainage Board

Abstract

The Tsunami tidal waves caused damage mainly to exposed parts of water supply systems. Water supply services were disrupted in the affected coastal areas owing to this. Quick remedial action was necessary to resume supply.

Most of the toilet structures were damaged in the affected areas. Septic tanks in the flooded areas were full. Again immediate action was necessary to repair the toilets and empty the septic tanks.

Immediate relief activities had to be provided in the affected areas. This included water supply using bowsers; construction of temporary toilet facilities or repair of existing toilets; enhancement of facilities in temporary/ transit camps; emptying and cleaning of wells etc.

Some people went back to their damaged houses and their water supply facility had to be restored. Some of our customers were provided with alternate land and they had to be provided with new connections free of charge.

The land use planners identified resettlement areas for the affected people. Water supply facilities had to be extended to those areas. In certain areas this requires the augmentation of the treatment works.

Meanwhile several donors pledged their support to assist Sri Lanka in its rebuilding efforts. The needs had to be matched with the donor assistance. Arrangements are under way to sign Memoranda of understanding to finance these works.

This presentation covers important aspects of the above mentioned activities carried out by the National Water Supply & Drainage Board.

Pre and Post Tsunami Effects on Agricultural Lands of Sri Lanka

Ranjith. B. Mapa,
Faculty of Agriculture, University of Peradeniya

W.M.A.D.B. Wickramasinghe, D.N. Sirisena
Rice Research and Development Center, Bathalagoda

K.M.A. Kendaragama
Natural Resource Management Center, Department of Agriculture, Peradeniya

ABSTRACT

Due to the Tsunami disaster, which took place on 26th December 2004, lands along about 1200 km of the costal belt of Sri Lanka were damaged. In some places sea waves came into about 3 to 5 km from the coast damaging the crops grown in these areas. With the action of sea waves, the lands were physically damaged by removal of soil by erosion and deposition of large amounts of sand and other debris. As sea water contains considerable quantities of sodium bearing salts, its intrusion creates soil salinity and dispersion of soil particles destroying the soil structure. According to estimates by FAO, about 4500 ha of agricultural lands were damaged along the coastal belt of Sri Lanka. Therefore, there is a need of rehabilitating the agricultural lands affected by the Tsunami disaster. The objective of this paper is to assess the damages to agricultural lands from salinity due to Tsunami in selected locations in Sri Lanka and to propose methodology to reclaim them.

For this study, Amapara district in the East of Sri Lanka which was extensively damaged by the Tsunami was selected. This area is called the rice bowl of the country giving high yields amounting to 6 tons per ha. Electrical conductivity, which is an indicator of soil salinity, was measured in effected lowland rice fields as well as in cultivated highlands. Salinity of adjacent unaffected areas were measured and taken as pre-Tsunami values. Nindavur area was selected to assess the damage to rice fields while Vinaygapurum in Thrukkovil where tomato, chillies, cowpea and eggplants were grown extensively was selected to assess the damage to the highlands. Electrical conductivity (EC) was measured in the saturated soil paste from 0-5, 5-15 and 15-30 cm depths at 200, 400 and 900 meters from the sea after 18 days of the disaster. This was followed by measurements after 4.5 months and 8 months at the same sites in the rice fields in Nindavur.

The measurements after 18 days of Tsunami showed that the EC values of the saturated paste of the effected areas were highest in the rice fields nearest to sea (200 m), showing 6.12 and 2.94 dS/m respectively at surface and subsurface depths. At a distance of 900m the EC values decreased to 0.85 and 1.28 dS/m in surface and subsurface respectively. The standing water in some depressions in the rice fields showed an EC value high as 11.46 and 5.84 dS/m at 200 and 400 m away from the sea. In the unaffected rice lands the EC was low as 0.07 dS/m.

The next crop of rice was sawn after 4 months of Tsunami. In the same area where the sea water was stagnant EC values decreased only to 3.2 dS/m and the seed germination was very low resulting in a poor stand of crop. Even if rice varieties

resistant to salinity can tolerate EC values higher than 4 dS/m the variety grown (BG 94-2) can withstand only lower salinity levels. Due to ploughing at the same depth repeatedly and puddling, a hard pan is formed in lowland rice fields around 15 to 20 cm depth, which restrict deep percolation. In fields where surface drainage was satisfactory, most of the salts got washed way reclaiming the land naturally. The EC values of these lands decreased to 1.7 dS/m after 4 months of Tsunami and a satisfactory stand of crop was observed. The rice crop is irrigated from Senanayaka tank and the irrigation water showed an EC value of 0.18 dS/m. The drainage facilities of some rice fields were improved with the assistance provided by a private company and the drainage water showed an EC value of 2.84 dS/m. At the same time well water in the same area showed a higher EC value of 3.63 dS/m.

At the harvesting time of the crop (8 months after Tsunami) the EC values of the same field with stagnant water showed an EC of 1.06 dS/m in surface soil which increased to 1.85 dS/m at 15/30 cm depth. This indicates that salinity increased with depth due to leaching but stopped at the hard pan. In this land, a thin hard crust was formed upon drying during harvest time indicating soil dispersion due to higher Na content. Where surface drainage was satisfactory the EC values were low as 0.02 dS/m in the surface and to 0.03 dS/m in the subsurface. In the unaffected areas (control) EC values were low as 0.03 and 0.04 dS/m respectively in surface and subsurface soils.

In the highlands the highest EC value measured after 18 days of Tsunami was 0.60 dS/m in the sub soil at 400 m away from sea. Even in the highlands, where water logged conditions prevailed the EC was higher as 3.5 dS/m and the well water showed an EC values of 3.14 dS/m. The highlands are well drained and therefore salinity is easily leached to deeper layers.

These data clearly demonstrate that in certain pockets of land, especially in rice fields where the drainage is poor, the salinity still prevails at high levels affecting the rice crop, even after 8 months of Tsunami. There is a need to identify the land areas where salinity still remains at high levels and improve surface drainage for the farmers to cultivate them even in future seasons. In this exercise priority should be given to lowland rice lands than for highlands.

POST-TSUNAMI RESEARCH INITIATIVES IN THE COASTAL ZONE OF SRI LANKA

Ana Gunatilaka

Geological Consultant, National Science Foundation of Sri Lanka

The 2004 December megatsunami that originated in the Sunda Trench region is probably the greatest ever in modern human history. In Sri Lanka, the loss of life is now well over 35,000 and the cost of material damage to inhabitants of the coastal zone has still not been assessed, but will probably exceed several billion dollars.

During the past three months, several Sri Lankan research teams have been gathering data around the coast on various aspects of this tsunami, based on the guidelines given by the Intergovernmental Oceanographic Union (IOU). Data on inundation distances, maximum run-up heights, maximum tsunami heights, standing water levels, eye-witness accounts etc. have been collected from over 200 localities and is still continuing. The initial inundation mapping surveys indicate quite dramatically that the above tsunami parameters are highly variable even within very short distances (<100 m), indicating that several variable factors have contributed to the inundation pattern at a given locality. The presence or absence of mangroves, fringing coral reefs, nearshore bathymetry, angle and direction of wave approach, shape of the coastline, artificial coastal boulder barriers, coastal dune complexes, topographic profiles and gradients from coast to inland are among them. Such detail is required by the government of Sri Lanka for its relief and rehabilitation efforts, relocation programs, tsunami mitigation and management planning and to evaluate the overall impact of the tsunami on the social and economic life of all the stakeholders in the coastal zone.

Perhaps the most damaging impact of the tsunami is on the groundwater table in the coastal zone. Over 50,000 drinking water wells abandoned, sewerage systems damaged, with cross contamination of the water table. Presently, almost a million people in the coastal areas are being supplied with drinking water on a daily basis, at tremendous cost to the state, NGOs and local authorities. Water quality was already poor even before the tsunami. Now it is critical. Further, unscientific cleaning activity by continuous pumping by individuals is only exacerbating the situation, with further salt intrusion into the wells. The groundwater problem will be the most challenging aspect to the authorities and it may take a very long time to restore normalcy. The most highly focused research efforts are on groundwater, with three teams operating in different areas of the coastal zone. Hopefully, the data gathered will lead to a permanent groundwater monitoring and Integrated Water Management Plan for the affected zone. The opportunities for research on groundwater modeling will be an added bonus. Water that was freely available by nature has now become a very precious commodity.

Two research teams are studying sediment profiles along selected traverses (initially 20 traverses are envisaged) and encompassing the wide inundation variability seen. The purpose of this study is to correlate the sediment sequences and their depositional features with the combined flow characteristics of a tsunami wave as it moves inland and withdraws – data that will be useful in studying paleo- megatsunamis. Initial coastal modeling studies indicate that a bay and headland or promontory is the most devastating geomorphic combination during a tsunami. The bay creating a funnellike effect and the headland a wrap-around effect for the tsunami wave, as happened in the port city of Galle. The location of the greatest ever train disaster in history (almost 1500 casualties), occurred in a straight stretch of coastline with a well developed fringing reef. Generally, the coral reef had hardly any major effect as a protective barrier against the waves and may even have aided the wave train to gain height. More important was the landward topographic gradient from the coastal highway to the rail track (~ 300m away), an elevation difference of about 1 m, when the 8-9m high second wave generated sufficient momentum and energy to topple over the crowded train and the heavy engine power unit, which rolled over almost 50m further. Further north, along a straight stretch, a large and extensive boulder barrier built to prevent severe coastal erosion was broken through, with boulders strewn over 50m inland and the wave inundating 800m. The high (15m) coastal dune complexes in Hamabantota and thick/wide mangrove belts were the most effective barriers, with little damage to show.

It became quite obvious that construction quality in the coastal zone is much to be desired. Foundations were not deep or reinforced and were on loose sand. Houses toppled as the debris-charged wave created a path of destruction inland. There are some indications that the geotechnical properties of the soils in the coastal zones may have been altered. This is also being investigated. Obviously, a new building code needs to be strictly enforced. Much of this research initiative has been generously funded by the National Science Foundation of Sri Lanka.

Generally, the east coast of Sri Lanka was the worst affected as it faced the maximum and direct impact of the waves. Even in areas where the run-up heights were around 4-5m (as in Trincomalee), the damage was high. These initial investigations have given a good insight as to the behavior of tsunami waves. Hazardous and safe coastal areas have been recognized and the people made aware. The government has now enforced a coastal restriction or buffer zone, (of 100 and 200 m width for the west and east coasts), where no new construction activity will be permitted barring a few exceptions. Surveys indicate that ~65 per cent of the coastal inhabitants would opt for alternate land inland. This is another big task for the government. The required land may not be available. Also, people may not want to go too far from their ancestral villages, which gives them social cohesion and psychological sustenance. The government is bound to be flexible in this matter, yet enforcing strict guidelines for future activity.

Another major quake may not necessarily generate another megatsunami (as was proven on March 28th 2005). However, disaster mitigation and management planning, early warnings, education and awareness programs will be all the more important in the future. The tsunami was a wake up call. Disaster awareness has become a new element in Sri Lanka. Efficient and reliable communications will be the key to mitigation efforts.

Ana Gunatilaka Ph.D.
National Science Foundation,
47/5, Maitland Place,
Colombo 7
Sri Lanka.
gunat@asianet.lk

HYDROGEOLOGY OF THE COASTAL AREAS OF SRI LANKA

H.A.Dharmagunawardhane, Department of Geology, University of Peradeniya, Sri Lanka

Occurrence and distribution of ground water in the coastal areas of Sri Lanka mainly depend on geology, geomorphology and litho-stratigraphy of the areas concerned. Sri Lankan coast line which extends over a 1700km long and generally low-lying stretch and shows considerable diversity in geology and landforms. Geologically, about 90percent of the country's landmass is underlain by Precambrian basement rocks and the remaining area (10percent) by sedimentary rocks (limestone and sandstone) of Miocene age. The sedimentary rocks are found in the northern and north eastern part of the country as a 20 to 40Km wide belt extending from south of Puttalam through Jafna peninsula to Mullativu. The above two main geological units along the coast have been modified by the Pleistocene and Holocene sea level fluctuations and climatic changes causing deposition of sand, clay, gravel and peat deposits along low-lying coastal areas. These geological proceses resulted in the formation of a multitude of complex and discontinuous aquifers along the coastal areas as observed today.

Although there are complex geological and hydrogeological conditions, prevailing locally, the coastal belt can broadly be divided into three aquifer regimes,

a) Northern and north western limestone aquifers
b) Quaternary unconsolidated sandy aquifers
c) Combined rigolith and fissured crystalline aquifers

Northern and north western limestone aquifers

Highly Karstic and permeable Miocene limestone aquifers are present along the Northern and North western coastal belt from Puttalam through Jaffna peninsula to Mullativu. In this belt from Mannar to Jaffna the limestone aquifer is overlain at many places by permeable and comparatively thin Quaternary (and recent) sand and silty clay deposits. The aquifer possesses mostly unconfined conditions with a ground water level at a depth of between 5 to 15m from surface. The transmissivity of the aquifer varies between 500 to 2000m^2/day and the productive aquifer extends down to more than 100m below the surface. Towards Mullativu in the north east, the limestone is confined between upper quaterny deposits and lower sandstone bed with a sedimentary sequence exceeding 300m in thickness. These conditions have created a multi aquifer system consisting of shallow unconfined and deep confined aquifers. In the North western coastal belt extending from Puttalam to Mannar, the limestone aquifer is overlain by a 60 to 100m thick Quaternary sand and clay sequence The lime stone aquifer is dissected and vertically displaced by asystem of faults creating confined aquifer conditions at many locations. The transmissivity of the aquifer ranges between 500 to 1200m^2/day with a thickness ranging between 100 to 200m. Artesian flowing wells can be seen at several places in this area close to the coast.

High nitrate in groundwater in unconfined aquifer areas arising from intense agricultural practices and High chloride associated with saline water intrusion due to uncontrolled groundwater abstraction are common water quality problems in the sedimentary aquifer system.

Quaternary unconsolidated sandy aquifers

Wind blown accumulations of recent sands forming dunes occur along almost one fifth of the coast line of Sri Lanka These together with Pleistocene and Holocene deposits of sand has created sufficiently thick (up to 25m) local and discontinuous highly productive aquifers in certain areas. This type of aquifers are found along most parts of the eastern coast from Hambanthota to Mullathivu and in the western coast from Negombo to Palavi. The transmissivites of these aquifers are in the order of 2500m^2/day.Good quality groundwater occurs in these aquifers and the groundwater table is present at a depth between 2 to 6m from the surface. In these aquifers, fresh water floats on the saline water at fresh water saline water interface on the seaward side of the aquifers. Excessive pumping often causes saline water intrusion. These unconfined (and occasionally semiconfined) aquifers are highly vulnerable to contamination where direct infiltration of contaminants is common from agricultural activities and onsite waste disposal in these areas.

Combined residual/rigolith and fissured crystalline aquifers

The slightly elevated coastal area from Mount Lavinia in the west to Hambanthota, in the south is dominantly underlayn by laterite and residual weathering products of crystalline rocks. This 2 to 20m thick weathered overburden is underlain by crystalline basement rocks which are also exposed at the surface at some locations. Narrow discontinuous sand dunes and some alluvial deposits are also present at some low lying locations along this coastal belt. Marshes and wetlands are a common feature in the western and south western parts, specially in association with estuaries Groundwater found in the weathered zone (rigolith) is heavily used in this area mainly through traditional dug wells. Water level is found at depths between 2 to 6m from the surface The transmissivity of the regolith aquifer is generally low and varies between 2 to 80m2/day. The Most productive part of the aquifer is the moderately weathered transition zone or the lower part of the regolith which is more sandy than clayey. Water quality is generally good and is slightly acidic specially when found in laterite. The underlying hard rocks form less productive discontinuous and local aquifers only where fissures are developed due to fracturing and weathering. Often the fissured/fractured rock is hydraulically connected with the overburden. Thus it can receive recharge from the water bearing overburden. Fracture zones in the rock extend down to more than100m but majority of the productive ones are situated at depths less than 45m. Groundwater in the hard rock aquifer is mainly extracted by water supply bore holes. Substantial yields have been encountered where such boreholes are located on regional fracture zones.

Alluvial formations that occur in the low lying marshy lands, wetlands and estuaries have very shallow groundwater levels but often contain brackish water unsuitable for drinking and domestic purposes.

As indicated above, the coastal aquifers in Sri Lanka are diversified in character and show variable hydrgeological and hydrochemical properties. These variable characters should be taken in to consideration in their development, rehabilitation, conservation or management.

Tsunami Impacts on Shallow Groundwater and Associated Water Supply on the East Coast of Sri Lanka

Karen G. Villholth,
Senior Researcher, Groundwater Specialist
IWMI, International Water Management Institute, Colombo, Sri Lanka

Abstract

The major Tsunami of Dec. 26, 2004 that hit many South Asian countries bordering the Bay of Bengal severely devastated the coastal regions of Sri Lanka. A key concern is the nature and extent of the Tsunami impact on the water supply and, in more general, the water resources of these areas. In the coastal areas of Eastern Sri Lanka, the majority of the population, which is rural or semi-urban, is relying on groundwater for their domestic and agricultural activities, most predominantly through traditional private shallow open dug wells in the sandy aquifers. As the Tsunami destroyed practically all wells within the reach of the flood waves, access to freshwater for these people was suddenly cut off and interim alternatives had to be sought urgently in the form of freshwater trucked in from unaffected areas. With the aim to assess and document the extent of the damages and the long term impacts of the Tsunami on groundwater and associated water supply, a field monitoring program was initiated in March 2005 (2.5 month after the Tsunami) in three areas of the east coast. A total of approximately 150 wells were selected within 1.5 km distance from the coastline covering both affected and non-affected wells. Salinity, groundwater level, turbidity, and occurrence of mosquito larvae were monitored on a regular basis, with from 20 to 40 days interval. In addition, salinity levels in sea and lagoon water were measured. Results indicate that 38 % of the wells had been flooded by the Tsunami, with the flooding being more severe in the two most northern sites (48 % in Kallady and 47 % in Kaluthavalai), as compared to the last site (21 % in Oluvil). This pattern could be explained by the way the waves had come in and had been received by the land complex. Salinity levels in wells decreased significantly from the estimated levels at the time of the Tsunami till the start of the monitoring. At this latter point, only 55 % of the flooded wells had salinity levels above an acceptable level for drinking (here defined as 2000 µS/cm), as opposed to 100 % initially. This can be explained by the rainfall that occurred shortly after the Tsunami and the rapid dissipation and mixing of intruding seawater with pre-Tsunami fresh groundwater. As time passed, average salinity levels in flooded wells decreased more slowly, until middle of July, when 43 % of flooded wells were not suitable for drinking. The slower decrease can be attributed to the unset of the dry season and the slower mixing and dissipation mechanisms as concentration gradients decreased. Non-flooded wells showed an opposite trend with salinity levels slightly increasing during the dry season, a generally encountered phenomenon. One half year after the Tsunami, flooded wells had higher mean salinity levels than background, non-flooded wells, indicating that the groundwater still had not recovered fully from the Tsunami.

"Current statge of water quality monitoring and laboratory facilities in SL"

A.M. Mubarak, Director-ITI

Water quality monitoring and modeling studies are important for analysing pollution conditions and predicting trends in major water bodies. Legal responsibilities for these activities vest in several different agencies operating in local or regional areas- such as the Mahaweli Authority in its jurisdiction, Board of Investment in its. Nationally, the Central Environmental Authority (CEA) has overall authority, along with its regulatory responsibilities. The Coastal Conservation Department (CCD) and Marine Pollution Prevention Authority (MPPA) have authority to monitor water quality in the coastal zone and regulate discharge within it. National Aquatic Resources Research and Development Agency (NARA) has the broadest national responsibilities for research on aquatic resources. Its authority includes the collection and dissemination of aquatic resource data, and the conduct of R & D, management and conservation of aquatic resources. It also has the authority to prepare an Aquatic Resources Management Development and Research Plan.

Comprehensive water quality data on surface water, groundwater, estuaries and coastal waters are not available in part because of diffused resources management responsibilities. The Irrigation Department, Water Resources Board (WRB), national Water Supply & Drainage Board (NWSDB), NARA, Mahaweli Authority, and coast conservation Department (CCD) all manage water resources and collect data. Many independent water quality studies have also been carried out by Industrial Technology Institute (ITI) – successor to CISIR), National Building Research Organization (NBRO), Institute of fundamental Studies (IFS) and Universities. But with data scattered, unpublished, or available in unprocessed form, analysis of water quality trends becomes difficult. Although NARA did initiate some long term monitoring studies on major river systems and surface water bodies they were not sustained.

Water quality measurements of samples from various drains and canals in Colombo confirms the fact that the entire canal system within the city has degenerated into a virtual open sewer. Other effects, not generally apparent to public are groundwater degradation due to dumping in uncontrolled landfills, and subsequent burial without leachate controls.

Comparison of quality of water bodies with different types of catchments- Beira lake, Parliament lake, Kandy lake, Bolgoda lake and Labugama reservoir clearly demonstrates that urbanisation without any planning to control pollution will inevitably lead to degradation of water quality.

Since 1994, a comprehensive programe has been initiated by NARA to monitor water quality of Kelani and Kalu Ganga. Catchment waters were of extremely good quality with very low dissolved salts with electrical conductivity of 20-60 uS/cm, lowest turbidity and high DO and low BOD levels. But, significant levels of nutrients, nitrite, nitrate and phosphate were found indicating agro-chemical leaching from tea plantations. The waters close to and within the estuaries showed increased pollution levels with very high BOD and organic matter and high dissolved salts/conductivity due to salinity intrusion. Depletion of DO indicated the increased organic loading of the receiving bodies. Microbiological results showed the presence of coliform bacteria throughout both river systems from the catchment to the coast indicating improper disposal of anthropogenic waste. However these levels are within freshwater norms for bathing and recreational use but not for potable water.

Low levels of industrialisation have kept industrial pollution of the Mahaweli below that of the Kelani, but expansion of the agricultural and agro-based industrial sector, and hospitality industry in this region will pose a serious threat to the after quality if not properly controlled.

A detailed study undertaken in 1995 by NARA indicated that the quality of water in feeder streams and drains entering the Lake Gregory in Nuwara Eliya contained nitrates, nitrites, phosphates and ammoniacal nitrogen well in excess when compared with groundwater samples in the vicinity. Human activity in close proximity to these streams and drains were attributed for such elevated levels.

Sr Lanka's 1585 km coastline is broken by extensive lagoons, bays, brackish water lakes, and wetlands. Pollution monitoring data is available only for a few water bodies. No major lagoons except at Jaffna, are linked to urban centres, and no coastal towns heavily industrialised except around the Kelani estuary. Consequently with the assimilative capacity of the sea, pollution loads have so far been absorbed. Pollution of other small lagoons and bay estuaries is much more serious, however. Lunawa logoon and the Bolgoda riverine estuary show how uncontrolled urban and industrial waste disposal affects the aquatic environment. Lunawa lagoon, located south of Colombo in an area developed as an industrial and residential suburb, which supported a significant fisheries industry a decade ago, has a highly depleted aquatic life today due to discharge of untreated industrial effluents. Although Bolgoda lake has not been polluted to the same extent as Lunawa lagoon there is rising concern that the long term impact of the continued discharge of industrial and urban pollution into the catchment area will compromise its economic and ecological value.

Groundwater is increasingly used for potable water, especially in small towns and rural areas. Estimated groundwater potential for the country is 780 000 hectares/meters per annum. For this water to remain safe, water extraction must not exceed the aquifer's replenishment capacity. Otherwise the well will run dry or, in coastal areas, invite brackish water intrusion. This problem of saltwater intrusion has occurred in northern coastal areas and northwest agricultural belt where groundwater irrigates rice and cash crops.

The most serious threat to groundwater comes from leaching of agrochemicals and sewage from pit latrines leading to pollution from nitrate and pesticides and, fecal contamination. In agricultural and non-agricultural areas in the Jaffna peninsula, nitrate concentrations over 200 mg/1 of NO_3 have been recorded. The presence of crevices and channels in the karstified limestone has helped the ready percolation of pollutants within the limestone aquifer. The Kalpitiyia peninsula is a low lying sand peninsula on the North-West coast of Sri Lanka with extensive coconut plantations. In recent years, however there has been a significant expansion of intensive horticulture-onion, chillie, gherkin and potato are the most important crops. A comprehensive study has revealed that irrigation wells within the extensively cultivated area had nitrate concentrations in excess of the WHO guideline of 10 mgN l^{-1}; chloride concentrations in these wells were typically in the range of 50-200 mg l^{-1}. This study has also demonstrated that insecticides are leached to the water table rapidly. Unlike in Jaffna were cavernous limestone aquifer enhances lateral migration of pollutants, the sandy aquifer in Kalpitiya does not promote such dispersion thus limiting the spread of pollution to non-cultivated areas.

Several state organisations such as the ITI (CISIR), NBRO, Rubber Research Institute (RRI), NERD and the Universities have the facility to monitor basic water quality parameters-physical, chemical and microbiological. In addition a few private sector companies also have set up laboratories to serve the growing demand in the country for water quality testing. However only a handful of them are accredited for water testing. ITI has a fully-fledged environmental laboratory accredited by the Swedish Accreditation Body SWEDAC. They undertake a wide range of analytical studies in water, soil and environment. ITI was expanded and strengthened under the ADB S&T Manpower Development Programme recently by setting up a modern analytical laboratory-GCs, HPLCs, GC-MS, P&T, AAS with Graphite & Flame and a mobile laboratory for field-work. They are the only accredited laboratory in the country to analyse toxic residues such as pesticides, heavy metals and PCBs.

Coastal Groundwater, Water Supply and Sanitation : A Vicious Cycle?

Nalin Wikramanayake
Dept. of Civil Engineering
Open University of Sri Lanka
tomwiks@yahoo.com

Most of the western and eastern coasts of Sri Lanka consist of features such as barrier spits and dunes created by the strong longshore sediment transport. These processes result in relatively high ground along the shoreline with low-lying areas further inland. These low lying areas are wetlands – marshes, lagoons or estuaries which are subject to regular flooding during the monsoons.

The human response to this coastal morphology has been to concentrate settlements and infrastructure on the narrow strip of mostly sandy ground along the coast. The reasons for this pattern include access to the sea and protection from flooding but also because of the availability of fresh water from the perched coastal aquifer. The surface water in the wetlands is generally not suitable due to salinity or turbidity.

The settlement along the coastal strip means that the release of human waste is also concentrated in this area, with,a possibility of polluting the aquifer. However the actual mechanism by which human wastes reach the aquifer are highly dependent upon the sanitation practices and the level of service of water supply. When people change from defecating on the beach to internal flush toilets both the water demand and the wastewater discharge increase, leading to a double threat to the aquifer.

This sequence of improved water supply and sanitation leading to degradation of the aquifer will be accelerated by the post-tsunami reconstruction. It is the stated goal of the reconstruction effort that people will have "improved" houses, water supply and sanitation. The conventional response to this issue would be to obtain the water from a distant source or to dispose of wastewater in a distant location or both of these actions. However, these actions are not practical in many tsunami-affected areas due to cost, unavailability of alternate water supply and unavailability of alternate discharge locations.

Therefore the contamination of the coastal aquifer by domestic wastewater has to be considered in conjunction with the possibility of excess withdrawal of water. A comprehensive public health risk assessment of the various options available for sanitation and wastewater treatment – ranging from the zero-discharge solution of ecological sanitation to the conventional western solution of centralized sewerage and treatment - that takes into account the dependence of the population on the coastal aquifer and the social aspects of sanitation should be carried out.

On the water supply side it is necessary to investigate augmentation of supply by rainwater harvesting and the possibility of using simple on-site water treatment to minimize the threat posed by the contaminated aquifer.

Groundwater Conditions in the Coastal Region of Sri Lanka

Abstract

A.P.G.R.L. Perera, Hydrogeologist,
Water Resources Board, 2 A, Gregory's Avenue, Colombo -07

Seven main types of groundwater aquifers have been identified and characterized in this country. Of these seven, five aquifers are associated with the coastal region of Sri Lanka. These are as follows.

1. Shallow Karstic Aquifer of Jaffna Peninsula
2. Deep Confined Aquifer
3. Coastal Sand Aquifer
4. Alluvial Aquifer
5. South Western Lateritic Aquifer

The shallow karstic aquifers are mainly confined to Jaffna peninsula, which is underlain by shallow highly karstified limestone aquifer, which occurs in the channels and cavities of this Miocene Limestone. This shallow groundwater forms mounds or lenses floating over the saline water and is used most intensively for agriculture and domestic purposes.

Deep confined aquifers are found in the coastal regions of North and North-west which extending from Puttalam to Jaffna and then towards Mulativu. Eight distinct deep aquifer basins have been identified in these coastal regions. The average depth of wells reaching the artesian aquifer in these basins is from 60 to 80 m and the yield of these wells is around 300 – 1500 lpm. Groundwater in Vanathavilluwa basin is used more intensively for irrigated agriculture of high value crops. Palavi and Madurankuliya basins are intensively used for Prawn Culture farming. Electrical Conductivity values of groundwater in this region are moderate to high.

Within the coastal sand aquifers 3 types have been recognized and characterized in the coastal belt of Sri Lanka. (a). Shallow aquifers on coastal spits and bars in the region of North-west are found in Kalpitiya peninsula and Mannar island. (b).Shallow aquifers on

raised beaches and low sand dunes in the regions of South and East are predominantly found in Nilaveli, Pulmudei, Kalkuda and Koggala. Generally they are distributed all round the island. (c). Moderately deep shallow aquifers on prior beach plains in the region of west are found in Katunayake and Chilaw.

Groundwater in these aquifers gets collected in the forms of a fresh water 'lens' floating above the denser saline water. Coastal sand aquifer regions of Sri Lanka are densely populated and intensively cultivated. Abstraction of groundwater is largely uncontrolled in these regions and excessive in some places causing brackish water intrusions. Previous studies show that significant contamination of the aquifer takes place with nitrates due to extensive use of agrochemical and fertilizers in Jaffna and Kalpitiya peninsula. Electrical conductivity of groundwater in these regions is good to moderate.

One of the largest carriers of groundwater among the sedimentary formation is river alluvium. The flood plains of Rivers such as Kelani Ganga and Deduru-oya have broad and deep alluvial beds in their lower reaches in the coastal region of West.

The laterite aquifers are found in the coastal region of south-west Sri Lanka and it is found in the coastal region extending Kalutara to Matara. Wherever laterite outcrops, a large number of wells are developed on it. Owing to the variable thickness wells are generally deep often going down to between 15 and 30 meters below surface level.

The remaining hard rock regions of Sri Lanka covers about 80% of the Island. Groundwater is found in the fractured and weathered zone of this hard rock area. Weathered rock zone is identified as a regolith aquifer. Only few extents of this hard rock region are exposed in the coastal boundary.

More than 90% of the total requirement of water in Town supplies such as Puttalam, Mannar Jaffna and Baticallo in the coastal region is used groundwater. Biological contamination of groundwater is a common problem in all the coastal regions.

Kandy Workshop ( ) Colombo Workshop ( ) Conference ( )

Proposal Form

Impacts of tsunami on groundwater, soils and vegetation in coastal regions of Sri Lanka

Sponsored by United States National Science Foundation, Sri Lanka National Science Foundation and Soils Science Society of Sri Lanka

Name (s): ____________________

Agency: ____________________

Email or address: ____________________

Area of relevance: **Surface Water ( ) Groundwater ( ) Soils ( ) Vegetation ( )**

Nature of proposal (identify one or more) : **Research ( ) Policy ( ) Fieldwork ( )**

Monitoring ( ) Modeling ( ) Short Term ( ) Long Term ( ) Capacity Building ( )

Exchange ( ) Database ( )

Briefly describe your proposal and expected outcome (use a second sheet if necessary)

Please return the completed forms to Director , NSF, Vidya Mawatha, Colombo 7. Sri Lanka.

Kandy Workshop (   ) Colombo Workshop (   ) Conference (   )

Please return the completed forms to Director , NSF, Vidya Mawatha, Colombo 7. Sri Lanka.

Plan of activities

17th Arrival of Delegates

18th 7.30 a.m.- 9.00 a.m. NSF chairperson's Breakfast
9.15 a.m. Leave for Kandy from Hotel Galadhari
11.15 a.m. Arrival at Pinnavala Elephant Orphanage
12.30 p.m. Lunch at Pinnawala
1.30 p.m. Leave Pinnawala
2.30 p.m. Visit to Peradeniya Royal Botanical Gardens (may need to be cancelled if there is no sufficient time for this activity)
4.00 p.m. Leave RBG to Kandy to visit temple of tooth
5.30 p.m. Leave Kandy
6.00 p.m. Arrival at La Kandyan Hotel
7.30 p.m. Dinner with Vice Chancellor and other invitees from Kandy

19th 8.00 a.m. Leave Hotel La Kandyan for Workshop
(on the way sight seen of University of Peradeniya)
8.30 a.m. Arrival at the workshop
8.30 a.m. Meeting of the Presenters
9.30 a.m. to 6.30 p.m. Workshop
7.30 p.m. Dinner

20th 6:30 a.m. to 7.30 a.m. Breakfast
7.30 a.m. Leave Hotel La Kandyan towards Ampara via Bibile
1.00 p.m. Arrive Ampara and Lunch at Irrigation Dept.
2.00 p.m. Leave Ampara
3.00 p.m. Visit Marathamunai site
4.30 p.m. Visit Oluville site
6.00 p.m. Arrive in Arugambay and stay at Tri Star hotel
7.30 p.m. Dinner

21st 6.30 a.m. to 7.30 a.m. Breakfast
7.30 a.m. Leave Hotel Tri Star towards Hambantota via Wellawaya
1.00 p.m. Arrive Matara – University of Ruhuna- Lunch
2.30 p.m. Leave Matara
3.00 p.m. Site seeing at Weligama
3.30 p.m. Leave Weligama
5.00 p.m. Arrive Peraliya and site seeing
6.00 p.m. Leave Peraliya
9.00 p.m. Arrive Colombo – Hotel Galadari
9.30 p.m. Dinner

22nd 7.30 a.m. to 8.30 a.m. Breakfast
8.45 a.m. Leave Hotel for Workshop
9.30 a.m. Workshop at ITI

5.30 p.m. Leave ITI
6.30 p.m. to 9.00 p.m. Meeting of the USA Team at Hotel Galadari
9.30 p.m. Dinner

23rd 7.30 a.m. to 8.30 a.m. Breakfast
8.45 a.m. Leave Hotel Galadari
9.00 a.m. Arrival at Conference at Palm Lounge Hotel Galle Face
9.30 a.m. -1.00 p.m. Conference
1.00 p.m. Lunch
2.00 p.m. Leave Hotel Galle Face
2.30 p.m. Arrival at Hotel Galadari

Note : It is expected that US team will have a meeting with the Hon Minister of Science and Technology before the conference