Alliance for Coastal Technologies Indexing No. ACT-05-04

Workshop Proceedings

GROUNDWATER-SURFACE WATER INTERACTIONS SENSOR TECHNOLOGY

Savannah, Georgia

March 7-9, 2005

Funded by NOAA's Coastal Services Center through the Alliance for Coastal Technologies (ACT)

Ref. No. [UMCES]CBL 05-084

An ACT 2005 Workshop Report

A Workshop of Developers, Deliverers, and Users of Technologies for Monitoring Coastal Environments:

Groundwater-Surface Water Interactions Sensor Technology

Savannah, Georgia

March 7-9, 2005

ALLIANCE FOR COASTAL TECHNOLOGIES

Sponsored by the Alliance for Coastal Technologies (ACT) and NOAA's Center for Coastal Ocean Research in the National Ocean Service.

Hosted by ACT Partner organization the Skidaway Institute of Technology (SkIO).

ACT is committed to develop an active partnership of technology developers, deliverers, and users within regional, state, and federal environmental management communities to establish a testbed for demonstrating, evaluating, and verifying innovative technologies in monitoring sensors, platforms, and software for use in coastal habitats.

TABLE OF CONTENTS

ACT WORKSHOP: GROUNDWATER-SURFACE WATER INTERACTIONS SENSOR TECHNOLOGY

EXECUTIVE SUMMARY

The Alliance for Coastal Technologies (ACT) held a Workshop on Sensor Technology for Assessing Groundwater-Surface Water Interactions in the Coastal Zone on March 7 to 9, 2005 in Savannah, GA. The main goal of the workshop was to summarize the general parameters, which have been found to be useful in assessing groundwater-surface water (GW-SW) interactions in the coastal zone. The workshop participants (Appendix I) were specifically charged with identifying the types of sensor systems, if any, that have been used to obtain time-series data and to make known which parameters may be the most amenable to the development/application of sensor technology. The group consisted of researchers, industry representatives, and environmental managers.

Four general recommendations were made:

1. Educate coastal managers and agencies on the importance of GW-SW interactions, keeping in mind that regulatory agencies are driven by a different set of rules than researchers: the focus is on understanding the significance of the problem and providing solutions. ACT could facilitate this process in two ways. First, given that the research literature on this subject is fairly diffuse, ACT could provide links from its web site to fact sheets or other literature. Second, ACT could organize a focused meeting for managers and/or agency groups.

2. Encourage development of primary tools for quantifying flow. The most promising technology in this respect is flow meters designed for flux chambers, mainly because they should be simple to use and can be made relatively inexpensively. However, it should be kept in mind that they provide only point measurements and several would need to be deployed as a network in order to obtain reliable flow estimates. For evaluating system wide GW-SW interactions, tools that integrate the signal over large areas would be required. Suggestions include a user-friendly hydrogeologic models, keeping in mind that freshwater flow is not the entire story, or continuous radon monitors. Though the latter would be slightly more difficult to use in terms of background knowledge, such an instrument would be low power and easy to operate and maintain. ACT could facilitate this recommendation by identifying funding opportunities on its web site and/or performing evaluations of existing technologies that could be summarized on the web site.

3. Gather more detailed and comprehensive information on the market for the aforementioned sensor technologies, and on what instruments are needed and how they

will be used. ACT could facilitate this in part through one of their standard needs and use assessments.

4. Encourage wider use of technology by lobbying for a GW-SW interaction component into existing regional monitoring programs. This could be performed in part through ACT outreach activities as described in recommendation #1. This recommendation is timely given the forthcoming U.S. Integrated Ocean Observing System, which includes a Coastal Ocean Observatory component.

ALLIANCE FOR COASTAL TECHNOLOGIES

There is widespread agreement that an Integrated Ocean Observing System (IOOS) is required to meet a wide range of the Nation's marine product and information service needs. There also is consensus that the successful implementation of the IOOS will require parallel efforts in instrument development and validation and improvements to technology so that promising new technology will be available to make the transition from research/development to operational status when needed. Thus, the Alliance for Coastal Technologies (ACT) was established as a NOAA-funded partnership of research institutions, state and regional resource managers, and private sector companies interested in developing and applying sensor and sensor platform technologies for monitoring and studying coastal systems. ACT has been designed to serve as:

- An unbiased, third-party testbed for evaluating new and developing coastal sensor and sensor platform technologies,
- A comprehensive data and information clearinghouse on coastal technologies, and
- A forum for capacity building through a series of annual workshops and seminars on specific technologies or topics.

ACT Headquarters is located at the UMCES Chesapeake Biological Laboratory and is staffed by a Director, Chief Scientist, and several support personnel. There are currently seven ACT Partner Institutions around the country with sensor technology expertise, and that represent a broad range of environmental conditions for testing. The ACT Stakeholder Council is comprised of resource managers and industry representatives who ensure that ACT focuses on service-oriented activities. Finally, a larger body of Alliance Members has been created to provide advice to ACT and will be kept abreast of ACT activities.

The ACT workshops are designed to aid resource managers, coastal scientists, and private sector companies by identifying and discussing the current status, standardization, potential advancements, and obstacles in the development and use of new sensors and sensor platforms for monitoring, studying, and predicting the state of coastal waters. The workshop goals are to both help build consensus on the steps needed to develop and adopt useful tools while also facilitating the critical communications between the various groups of technology developers, manufacturers, and users.

ACT Workshop Reports are summaries of the discussions that take place between participants during the workshops. The reports also emphasize advantages and limitations of current technologies while making recommendations for both ACT and the broader community on the steps needed for technology advancement in the particular topic area. Workshop organizers draft the individual reports with input from workshop participants.

ACT is committed to exploring the application of new technologies for monitoring coastal ecosystem and studying environmental stressors that are increasingly prevalent worldwide. For more information, please visit http://www.act-us.info/.

GOALS FOR THE WORKSHOP

The ACT Workshop on Groundwater-Surface Water Interactions was held from March 7-9, 2005 in Savannah, GA to summarize the general parameters which have been found to be useful in assessing groundwater-surface water interactions in the coastal zone. The workshop was specifically charged with identifying the types of sensor systems, if any, that have been used to obtain time-series data and to make known which parameters may be the most amenable to the development/application of sensor technology. The final goal was to make strategic recommendations for how the development of the technology might move forward and how its application in coastal environmental monitoring and management might be encouraged.

Workshop attendees were given the following charge questions to address:

(1) What parameters are of most interest in relation to environmental issues involving groundwater-surface water interactions? Why are they of interest?

(2) Are there existing sensors that have been used to monitor these parameters to gain a better insight into groundwater-surface water interactions? What are the lessons learned regarding their application?

(3) What would be the ideal characteristics of sensors for application to monitoring and management of coastal groundwater-surface water interactions? And what are technology, infrastructure and other limitations that impede the development of such sensors?

ORGANIZATION OF THE WORKSHOP

The workshop was sponsored by ACT and hosted by the Skidaway Institute of Oceanography (SkIO), an ACT partner institution. The workshop was organized by Drs. Herb Windom (SkIO), Eric Stein (Southern California Coastal Water Research Project) and Matt Charette (Woods Hole Oceanographic Institution), who also served as Workshop facilitator. On the evening of March 7, workshop participants convened for a reception and dinner during which Dr. Windom gave a presentation on the mission of the ACT program and a brief outline of the workshop goals. The workshop commenced the following day with a Plenary Introduction to the charge questions and workshop procedures followed by two breakout sessions. In Breakout Session I (morning), groups were formed according to professional background: researchers, managers, and industry representatives. Each group appointed a chair who led the discussion of charge questions 1 and 2. In Breakout Session II (afternoon), three "mixed" groups were organized to discuss charge question 3. The mixed grouping allowed for discussion of cross cutting issues that arose during the morning session. The next (and final) day was designed to formulate consensus conclusions and to develop overall recommendations.

GROUNDWATER-SURFACE WATER INTERACTIONS: STATEMENT OF THE PROBLEM

Seventy-five percent of the world's population is expected to live within 35 miles of a coastline by 2020. As a result, understanding and managing human impacts on coastal surface waters is becoming an important area of focus for coastal environmental scientists and resource managers. Impacts can arise through direct interaction between humans and the coastal ocean or indirectly through changes in terrestrial surface and groundwater quantity and quality. Surface water and groundwater both discharge to and interact with the coastal ocean in important ways. Such interactions often lead to negative societal and ecological impacts on the costal zone. Examples include eutrophication from groundwater-derived nutrient inputs to coastal waters and overuse of freshwater resources in coastal aquifers.

Fresh groundwater flowing from upland areas of a coastal watershed may either discharge from a seepage face at the shore or flow directly into the sea (Fig. 1). Because salt water is denser than fresh water, seawater will enter coastal areas of an aquifer. As fresh groundwater interacts with the saline water, salt will disperse into the seaward flowing freshwater. Because salt is discharged into the coastal ocean through this process, additional seawater will flow into the sediments to accommodate this salt transport and a dispersion-driven saltwater circulation cell develops. If multiple aquifers and confining layers exist, then each aquifer will have a saltwater interface, and deeper aquifers may discharge farther off shore. For example, freshwater has been found in aquifers as far as 100 km off the Atlantic Coast. Much research on coastal hydrology over the last one hundred years has focused on groundwater-surface water interactions and, in particular, the subsurface saltwater-freshwater interface. In illustrations such as in Figure 1 the interface is sharp, but it may often be very disperse.

A key biogeochemical problem associated with coastal groundwater flow is the introduction of "new" nitrogen, either through dissolution of nitrogen as precipitation flows into the subsurface and becomes aquifer recharge (where the "new" nitrogen enters the system via atmospheric deposition and fertilizer use) or introduced to groundwater by septic tank leach fields located along the coastline. It is not unusual to observe dissolved inorganic nitrogen (DIN) concentrations ranging from 100-1,000 times greater than in surface waters. In such areas, nitrogen-laden groundwater discharge has led to eutrophication of many coastal embayments in the U.S. and around the world. In addition to nutrients, groundwater is sometimes a non-point source of heavy metals and organics (fuels, solvents) to surface waters.

Population growth along coastlines where groundwater is the primary source of municipal freshwater has sometimes led to overpumping of aquifers. Where such aquifers are hydraulically connected to the coastal ocean, saltwater intrusion has threatened the viability of the water resource for the local community. For example, the water table elevation near Savannah, GA decreased from 12 m above sea level in 1880 to 30 m below sea level in 1984. This problem is even more compounded in arid regions.

The quantity and quality of coastal groundwater resources are important to understand and quantify because of their importance as a freshwater resource and because of their potential influence on coastal biogeochemical cycles. From a water quantity perspective, the primary issues are to understand the rate of freshwater discharge to coastal waters, the rate of saline inflow to coastal aquifers, and the geologic and physical processes that control those rates over multiple time scales. From a water quality perspective, it is imperative that chemical loads to and from coastal aquifers be understood, which requires delineating inputs and important biogeochemical transformations along fluid flow paths. The freshwater-salt water interface is a particularly interesting area because it is the location where two water reservoirs with very different chemical properties meet, establishing the potential for important transformations.

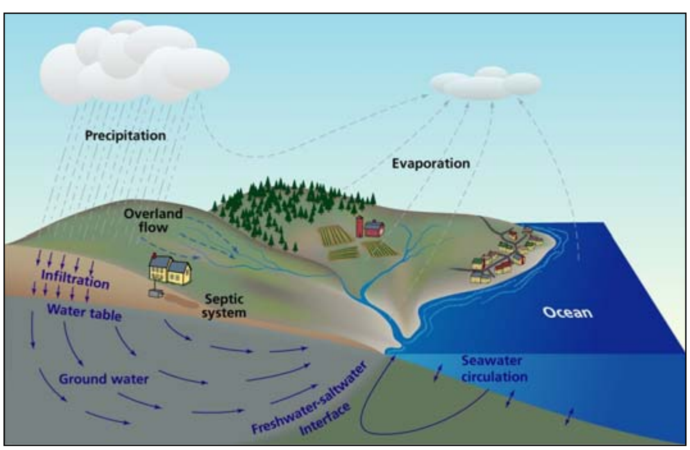

Figure 1. Schematic of groundwater-surface water interactions in the coastal zone (J. Cook, WHOI Graphic Services).

THE NEED FOR SENSOR TECHNOLOGY FOR ASSESSING GROUNDWATER-SURFACE WATER INTERACTIONS

The extent of groundwater discharge in the coastal zone is difficult to constrain using traditional techniques, mainly because it is often diffuse and is difficult to sample and quantify. In addition, the forces that drive the fresh and saline groundwater discharge occur on a wide range of time scales from minutes to years. Examples of these include tidal pumping and wave driven exchange, as well as groundwater recharge driven by seasonal patterns in rainfall. Thus, assessments and monitoring programs of groundwater-surface water interactions must consider these variables in order to be accurate.

The major high-frequency process that modulates groundwater-surface water interactions in coastal areas is the tide. An illustration of this process in shown in Figure 2, which depicts a time series of fluid flux across the sediment water interface measured with an automated seepage meter. During low tide, there is net flow into surface waters (positive flow), with the highest flows occurring during the lowest tides. Conversely, there is net recharge from surface waters into the aquifer (negative flow) during high tide periods, indicating that, at this location, sea level rises above the water level in the aquifer. To generate this time-series manually would have been a major undertaking. Also, typical monitoring programs do not collect samples frequently enough to capture such variability.

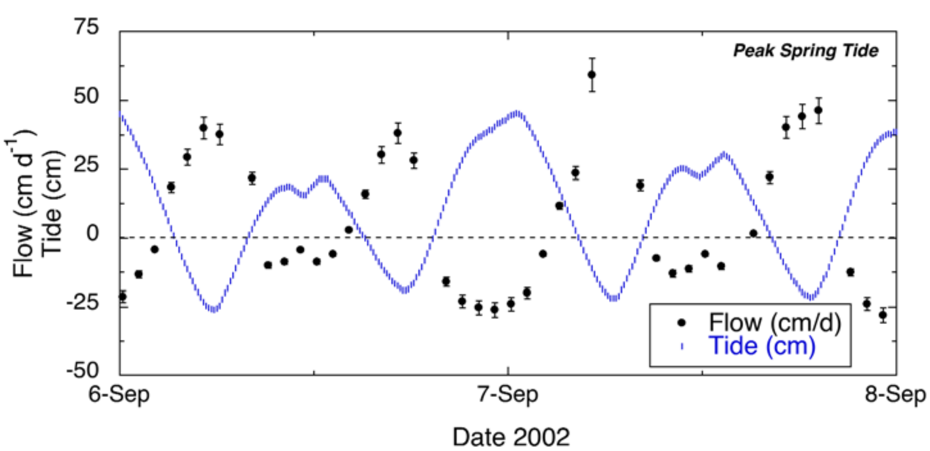

Figure 2. Groundwater flow (solid circles) and tide height (hatched line) at Waquoit Bay, MA. The WHOI dye-dilution seepage meter recorded the flow measurements at hourly intervals.

In regions where the public relies on groundwater for their source of freshwater, there is considerable attention paid to the balance between aquifer recharge and withdrawal rate. In coastal areas, the major consequence of overpumping is saltwater intrusion. An example of this is shown in Figure 3. In Truro, MA, a narrow (~2 mile) peninsula on outer Cape Cod, MA, the water table "floats" on top of saline surface water derived from Cape Cod Bay (to the west) and the Atlantic Ocean (to the east). The groundwater beneath public water supply well is closely monitored for saline intrusion by conductivity sensors. During late 2001, the public water supply well was turned off in favor of another well. A striking result was the relatively rapid decrease in well TSW-260 (solid triangles) conductivity, a direct result of aquifer recharge forcing the saltwater interface seaward.

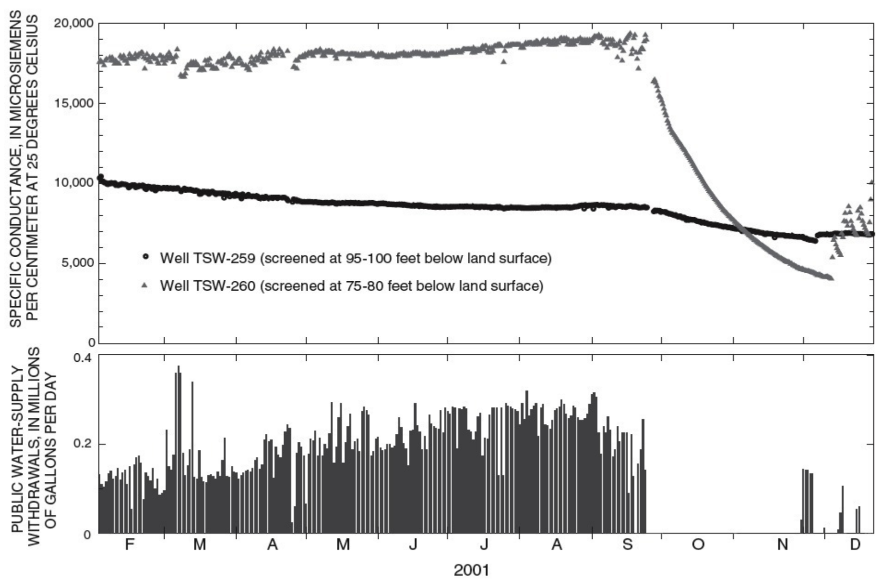

Figure 3. (Top panel) Conductivity measurements in two monitoring wells from Truro, MA. Wells are screened 25 and 50 ft. below the public water supply well. (Bottom panel) Public water supply withdrawals in millions of gallons per day. From USGS Circular 1262.

EXISTING SENSOR TECHNOLOGY FOR ASSESSING GROUNDWATER-SURFACE WATER INTERACTIONS

Scientists have generally used four kinds of approaches to investigate groundwater discharge rates into the coastal ocean: (1) seepage meters, (2) naturally-occurring radionuclide or chemical tracers, (3) piezometers and potentiomanometers, and (4) numerical hydrogeologic-based models. The past decade has seen rapid advances in sensor technology that can either directly perform or greatly assist with these three approaches. The first discussion in the workshop was to identify the parameters of interest, why they are of use, and lessons learned in their use, all in the context of environmental issues involving groundwater-surface water interactions.

Salinity/Temperature
Why it is of interest
-for embayments not heavily impacted by rivers, salinity (via conductivity sensors) is often a simple solution for determining groundwater input
-conductivity sensors are also used for detecting saltwater intrusion in aquifers
-there are often sharp contrasts between groundwater and surface water temperature, making it an ideal indicator of groundwater input
Lessons learned regarding use
-sensors that automatically convert salinity from conductivity may not be using the correct algorithms
-many coastal systems have multiple sources of fresh and saline water
-corrosion of sensors/sensor housings in saline environments
-temperature not appropriate during certain times of year and in all locations

Tracers
Why it is of interest
-most useful tracers are highly enriched (or depleted) in groundwater relative to surface water (including rivers) such that a surface water excess of the tracer can be used to quantify flow
-Radon/Radium: both now are widely applied examples of chemical tracers for groundwater-surface water interactions
-at least two field deployable radon sensors; no in situ radium sensor is presently available

Lessons learned regarding use
-power-hungry pumps required for radon determination
-not capable of high frequency (~seconds) measurements (compared with a conductivity sensor)

Pressure
Why it is of interest
-pressure sensors, when installed in monitoring wells along a shore perpendicular transect, can be used to calculate the hydraulic gradient, which can be used to calculate groundwater flow rates

Lessons learned regarding use
-lack of sensors specifically designed to withstand use in saltwater (also, potential for contamination of monitoring well for other measurements such as trace metals)
-many require atmospheric pressure correction
-need to be able to deploy pressure sensors in small diameter (1 cm) piezometers

Flow Rate
Why it is of interest
-a direct measure of fluid flow across the sediment-water interface when coupled with a seepage meter
-a number of in situ flow sensors now available: e.g. thermal, ultrasonic, dye-dilution, EM

Lessons learned regarding use
-the presence of the seepage meter can affect flow by (a) initial disturbance of the sediment/water interface, (b) effects on macrofauna, and (c) creating flow in high energy environments ("Bernoulli effect")
-not useful in hard-rock environments; best suited for permeable sea beds
-seepage meters provide net discharge estimates, need to correct for freshwater component in coastal settings

Once we identified the key parameters of interest and associated sensor technology, the second discussion of the workshop focused on the ideal characteristics of new sensors for monitoring and management of coastal groundwater-surface water interactions. We also explored the factors limiting the development of such sensors:

-the number one characteristic of a sensor for groundwater-surface water interactions was that it be capable of broad application (i.e. easy to use, calibrate, and interpret the data)

-it should be resistant to biofouling

-it should have sufficient data storage capability

-easy to incorporate into existing monitoring programs

-it should be low power

-it should be relatively low cost

RECOMMENDATIONS

Four general recommendations were made by the workshop participants:

1. Educate coastal managers and agencies on the importance of GW-SW interactions, keeping in mind that regulatory agencies are driven by a different set of rules than researchers: the focus is on understanding the significance of the problem and providing solutions. ACT could facilitate this process in two ways. First, given that the research literature on this subject is fairly diffuse, ACT could provide links from its web site to fact sheets or other literature. Second, ACT could organize a focused meeting for managers and/or agency groups.

2. Encourage development of primary tools for quantifying flow. The most promising technology in this respect is flow meters designed for flux chambers, mainly because they should be simple to use and can be made relatively inexpensively. However, it should be kept in mind that they provide only point measurements and several would need to be deployed as a network in order to obtain reliable flow estimates. For evaluating system

wide GW-SW interactions, tools that integrate the signal over large areas would be required. Suggestions include a user-friendly hydrogeologic models, keeping in mind that freshwater flow is not the entire story, or continuous radon monitors. Though the latter would be slightly more difficult to use in terms of background knowledge, such an instrument would be low power and easy to operate and maintain. ACT could facilitate this recommendation by identifying funding opportunities on its web site and/or performing evaluations of existing technologies that could be summarized on the web site.

3. Gather more detailed and comprehensive information on the market for the aforementioned sensor technologies, and on what instruments are needed and how they will be used. ACT could facilitate this in part through one of their standard needs and use assessments.

4. Encourage wider use of technology by lobbying for a GW-SW interaction component into existing regional monitoring programs. This could be performed in part through ACT outreach activities as described in recommendation #1. This recommendation is timely given the forthcoming U.S. Integrated Ocean Observing System, which includes a Coastal Ocean Observatory component.

CONCLUSIONS

In the last decade, marine scientists have come to appreciate the influence of GW-SW interaction on a wide range of coastal biological and geochemical processes. Because of the dynamic nature of this process, sensor technology for studying this process has seen some significant advances recently. As the importance of the process becomes better understood by those outside the research arena and the technology becomes more refined and easier to use, it will become available to a wider audience, and perhaps become a core component of many coastal monitoring and management programs. ACT can play a major role in this respect by hosting or attending workshops, evaluating existing technology, and encouraging the development of new or existing sensors by industry.

WORKSHOP PARTICIPANTS

Brian M. Anderson
AMS
7353 Cedar Crest Drive
Sauk City, WI 53583
Phone: 608/643-4913 (and fax)
E-mail: briana@chorus.net

Tony Arnerich
In-Situ Inc.
221 East Lincoln Avenue
Fort Collins, CO 80524
Phone: 800/46-7488
Phone: 970/498-1500
or 970/498-1536
Fax: 970/498-1598
E-mail: TArnerich@IN-SITU.COM

Jeff Baker
Regional Manager
Hdrolab/Hach
442 Huntington Creek Rd.
Weddington, NC 28104
Phone: 707/957-1664
E-mail: jbaker@hach.com

John "Chip" A. Breier
Graduate Student
University of Texas
750 Channel View Drive
Port Aransas, TX 78373
Phone: 361/749-0994 (home)
E-mail: jbreier@utmsi.utexas.edu

Bill Burnett
Professor
Department of Oceanography
Florida State University
Tallahassee, FL 32306-4320
Phone: 850/644-6703
Fax: 850/644-2581
E-mail: wburnett@mailer.fsu.edu

Matt Charette
Department of Marine Chemistry and Geochemistry
Woods Hole Oceanographic Institution (MS #25)
Woods Hole, MA 02543
Phone: 508/289-3205 (Clark 461)
Fax: 508/457-2193
E-mail: mcharette@whoi.edu

D. Reide Corbett
Assistant Professor
East Carolina University
Department of Geology
Coastal Resources Management
Greenville, NC 27858
Phone: 252/328-1367 (voice)
Fax: 252/328-4391
E-mail: Corbettd@mail.ecu.edu

Ali Chowdhury
Groundwater Resources Division
Texas Water Development Board
Room 434B, Stephen F. Austin Building
1700 North Congress Av
Austin, Texas 78711
Phone: 512-936-0834
Fax: 512-936-0889
Email: ali.chowdhury@twdb.state.tx.us

Richard Fagioli
HydroTechnics, Inc.
PO Box 92828
Albuquerque, NM 87111
Phone: (505)797-2421
Fax: (505)797-0838
Email: richf@hydrotechnics.com

WORKSHOP PARTICIPANTS (CONTINUED)

Paul Gannett
Onset computer
470 MacArthur Blvd.
Bourne, MA 02532
Phone: 800/564-4377
E-mail: Paul_Gannett@onsetcomp.com

Tom Greenhalgh
Florida Geological Survey
903 West Tennessee Street, MS#720
Tallahassee, FL 32304-7700
Phone: 850/488-4191
E-mail: tom.greenhalgh@dep.state.fl.us

Randall T. Hanson
Research Hydrologist
U.S. Geological Sruvey
5735 Kearny Villa Road, Ste. O
San Diego, CA 92123
Phone: 858/637-6839
E-mail: rthanson@usgs.gov

Richard Hicks
FDEP Ground Water Protection Section
Bureau of Watershed Managmeent
260-0 Blair Stone Road, MS 3575
Tallahassee, FL 32399-2400
Phone: 850/245-8229
E-mail: Richard.W.Hicks@dep.state.fl.us

Janet Jensen
Joint Service Agent Water Monitor
Edgewood Chemical Biological Center
5183 Blackhawk Road
Building 5554
Aberdeen, Maryland 21010
E-mail: janet.jensen@us.army.mil

Richard Kaiser
Onset Computer Corporation
Phone: (800) 564-4377, (508) 759-9500
Richard_kaiser@onsetcomp.com

Jim Nelson
Skidaway Institute of Oceanography
10 Ocean Science Circle
Savannah, GA 31406
Phone: 912-598-2473
E-mail: nelson@skio.peachnet.edu

Bill Poruhsky
Graduate Student
Department of Marine Sciences
The University of Georgia
Athens, GA 30602-3636
Phone: 706/247-5626

Derek Lane-Smith
Durridge Company
7 Railraod Avenue, D
Bedford, MA 01730
Phone: 781/687-9556
Fax: 781/687-0955
E-mail: DLS@durridge.com

Kevin McClurg
General Manager and Systems/Marine Sales Manager
Endeco/YSI an SonTek
13 Atlantic Drive
Marion, MA 02738
Phone: 508/748-0366, ext. 225
Fax: 508/748-2543
E-mail: kmcclurg@usi.com

WORKSHOP PARTICIPANTS (CONTINUED)

Scott McLean
Vice President Research and Development
Chief Technology Officer
Satlantic Incorporated
3481 North Marginal Road
Halifax, Nova Scotia
CANADA B3K 5X8
Phone: 902/492-4780
E-mail: scott@satlantic.com

Willard S. Moore
Department of Geological Science
University of South Carolina
Columbia, SC 29208
Phone: 803/777-2262
E-mail: moore@geol.sc.edu

Geoff Morrison
Technical Director
The international SeaKeepers Society
Phone: 954/766-7100, ext. 115
Fax: 305/675-0256
Cell: 786/325-3733
E-mail: Morrison@SeaKeepers.org

Ann E. Mulligan
Marine Policy Center, MS 41
Woods Hole Oceanographic Institution
Woods Hole, MA 02543
Phone: 508/289-2609
Fax: 508/457-2184
E-mail: amulligan@whoi.edu

Alyssa Olson-Callahan
Perot Systems Government Services
NOAA Coastal Services Center
2234 South Hobson Avenue
Charleston, Sc 29405-2413
Phone: 843/740-1219
E-mail: Alyssa.Olson-Callahan@noaa.gov

William Reay
Director/CBNERRVA
Department of Physical Sciences
College of William and Mary
Virginia Institute of Marine Science
Greate Road
Gloucester Point, VA 23062
Phone: 804/684-7119
Fax: 804/684-7120
E-mail: wreay@vims.edu

Timothy Shaw
University of South Carolina
Department of Chemistry and Biochemistry
Marine Sciences Program
Columbia, SC 29208
Phone: 803/777-0352
E-mail: shaw@mail.chem.sc.edu

Justine Stadler
Program Coordinator
Cooperative Institute for Coastal and Estuarine
Environmental Technology
(CICEET)
144 Gregg Hall
Durham, NH 03824
Phone: 603/862-2817
Fax: 603/862-2940
E-mail: Justine.stadler@unh.edu

Eric Stein
Principal Scientist - Watershed Department
S. Ca. Coastal Water Research Project
7171 Fenwick Lane
Westminster, CA 92683-5218
Phone: 714/372-9233
Fax: 714/894-9699
E-mail: erics@sccwrp.org

WORKSHOP PARTICIPANTS (CONTINUED)

Herbert Windom
Skidaway Institute of Oceanography
10 Ocean Science Circle
Savannah, GA 31406
Phone: 912-598-2490
E-mail: herb@skio.peachnet.edu

Xavier Swamikannu
Storm Water Program
CalEPA - Regional Eater Board, LA Region
320 W. 4th Street, Suite 200
Los Angeles, CA 90013
Phone: 213/620-2094
Fax: 213/576-6625
E-mail: xswami@rb4.swrcb.ca.gov

Ref. No. [UMCES] CBL 05-084

Copies may be obtained from:
ACT Headquarters
c/o University of Maryland Center of Environmental Science
Chesapeake Biological Laboratory
Post Office Box 38
Solomons, Maryland 20688-0038
Email: info@act-us.info