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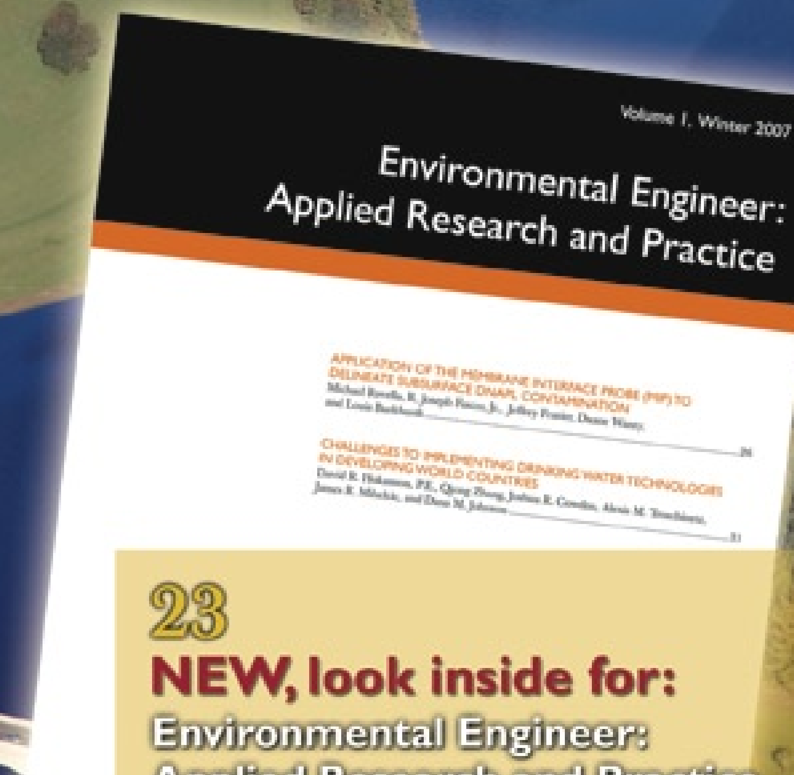

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ENVIRONMENTAL ENGINEER

BY STEPHEN R. KELLOGG, P.E., BCEE

MOVING FORWARD

Your Board of Trustees and Academy Committees are working hard on a five-year Strategic Plan for the AAEE

YOUR ACADEMY IS HEALTHY AND WELL. However, its health will be short-lived without substantive change in 2007 and beyond. The Academy has a rich and storied history. As the founders endeavored to take environmental engineering to a new level in 1955, today's AAEE must strive through change to achieve its own new level of visibility and activity. Resources – volunteer, staff, and financial - will be required to overhaul and upgrade the existing information systems and communication processes. This upgrade began in earnest in 2006, but much more needs to be done and it will require time, expertise and financial support. Outstanding work is being accomplished in the Excellence in Environmental Engineering Competition, ABET accreditation of environmental engineering programs, Kappe Lecture Series, Publications, and the new AAEE CareerCenter, but for these fine activities to grow, and touch more and more of our colleagues in the field, the Academy needs a plan.

Your Board of Trustees and Academy Committees are working hard on a five-year Strategic Plan for the AAEE. It is nearly complete and will be presented for approval at the May Board of Trustees meeting. The e-survey you received in January was part of the plan formulation process as it sought to measure member's reactions and preferences to many of the key initiatives in the plan. I thank each of you who took the time to contribute to our direction. If we don't know exactly where we want to go, we'll certainly never get there. The Strategic Plan features include an aggressive program to double membership, upgrade AAEE tools and systems, reach out to student members, and invite the many highly qualified but non-registered Environmental Engineers to become AAEE members.

I will be launching a campaign in 2007 designed to provide the financial resources to implement the Strategic Plan's key objectives. As a start to this effort your Academy's Board of Trustee members have committed to pledge $1,000 each to the Academy payable over three years. While this may seem like a modest amount for funding such a huge initiative, I believe that opening this opportunity up to the full membership will achieve the desired objective of funding our growth and highest strategic priorities over the next five years.

I am deeply committed to doing all that I can to work with the AAEE leaders past and present, members and staff to provide AAEE with a vision and a plan to achieve our goals in 2007 and the ensuing years. All successful and vibrant organizations rely on committing the resources necessary to ensure growth. Our profession is at a crossroads, and now is clearly the time for the American Academy of Environmental Engineers to take the leadership role for guiding and growing the Environmental Engineering profession. A

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AAEE LAUNCHES NEW ONLINE JOB SERVICE

The Academy launched its interactive job board in September 2006, the AAEE Career Center. With its focus on companies and professionals in the field of environmental engineering, the AAEE Career Center offers its members–and the industry at large–an easy-to-use and highly targeted resource for online employment connections.

"We're very excited about the AAEE Career Center, because we know how critical it is for employers in environmental engineering to attract first-rate talent with a minimum expenditure of time and resources," said Alan H. Vicory, AAEE President. "And it's important for us to help enable smooth career transitions for those seeking industry jobs."

Both members and non-members can use the AAEE Career Center to reach qualified candidates. Employers can post jobs online, search for qualified candidates based on specific job criteria, and create an online resume agent to e-mail qualified candidates daily. They also benefit from online reporting that provides job activity statistics.

For employers, the AAEE Career Center helps streamline your hiring process with:

- Unmatched exposure for job listings – the AAEE represents a highly qualified audience of environmental engineering professionals.
- Easy online job management – You can enter job descriptions, check the status of postings, renew or discontinue postings, and even make payments online.
- Resume searching access – With a paid job listing, you can search the resume database and use an automatic notification system to receive e-mail notifications when new resumes match your criteria.
- Company awareness – Along with each job posting, you can include information about your individual company and a link to your web site.

For job seekers, the AAEE Career Center is a member service that provides access to employers and jobs in the field of environmental engineering. In addition to posting their resumes, job seekers can browse and view available jobs based on their criteria and save those jobs for later review if they choose. Job seekers can also create a search agent to provide email notifications of jobs that match their criteria.

For job seekers, the new AAEE Career Center will provide:

- FREE and confidential resume posting – Make your resume available to employers in the industry, confidentially if you choose.
- Job search control – Quickly and easily find relevant industry job listings and sign up for automatic e-mail notification of new jobs that match your criteria.
- Easy job application – Apply online and create a password-protected account for managing your job search.

The Career Center can be accessed through the AAEE website www.aaee.net or directly at www.aaee.net/website/careercenter.htm

FIVE AAEE E3 COMPETITION AWARD WINNERS WIN IWA PROJECT INNOVATION AWARDS

Leading international water engineering firms and organizations were rewarded for their innovative approaches to the challenges of the water industry at a September ceremony in Beijing, China organized by the International Water Association (IWA). IWA's Project innovation awards honored excellence and innovation in water engineering projects around the world. Focusing exclusively on engineering and water, the awards recognized originality in project conception and results. Awards were presented in the categories of applied research projects, design projects, operations/management, and small projects.

Five 2006 winners of the AAEE Excellence in Environmental Engineering (E3) Competition were among the sixteen IWA award winners. The E3's Grand Prize in Research winner, Poseidon Resources Corporation for the Carlsbad, CA Seawater Desalination Demonstration Facility, was IWA's Global Grand Prize winner in the Applied Research Project category. Academy member Nikolay S. Voutchkov, P.E., BCEE was the engineer in charge of the project.

❖ *Continued on 11* ❖

BY LAWRENCE A. PENCAK

FIRST EDITION...ONE OF MANY FIRSTS FOR 2007

Our intent is to keep you well informed in 2007, on these pages, through regular electronic updates, as well as immediate electronic reports to you...

I FELT SOMEWHAT AWKWARD after only a few weeks as the new executive director cobbling together an executive director's message for the last issue of the *Environmental Engineer*. Not so with this edition. I see Volume 43: Number 1 - Winter/2007 as my first edition of the magazine, and for the *Environmental Engineer* magazine this is a first as well - the first edition of its newly expanded format. My first months with the Academy have seen the introduction of electronic member communications, the AAEE Career Center, and an entirely new electronic submission and judging process for the AAEE's E3 Competition. The immediate next months will see additional new initiatives. And, as you will note in some of the commentary on these pages the driving theme for 2007 and beyond is to aggressively develop a demand for BCEEs and BCMs, double the size of the Academy, and increase the profile of the Academy and BCEE in the professional community. But, this executive director's message is in the *Environmental Engineer* magazine, itself the significant first of the moment.

This and subsequent issues of the Environmental Engineer will consist of **Part 1 – News, Currents, and Careers**; and **Part 2 – Applied Research and Practice** featuring 2-4 peer-reviewed papers emphasizing case studies and useful practical research. Part 1 closely resembles in content previous issues of the magazine. Robert Baillod, Ph.D., P.E., BCEE, the AAEE Publications Chair and Editor of the **Applied Research and Practice**, section has assembled a notable Editorial Board (pg. 23) for this new section composed of seven practitioners and four educators; two are members of the National Academy of Engineering and five are current or former Academy Trustees. Each Editorial Board member has accepted the responsibility to review papers submitted, and to either write or actively recruit paper submissions from colleagues. If you are asking if this section is intended to be the embryonic precursor to a future Academy journal of environmental engineering practice, to definitively answer yes would be premature, but clearly there is an intent toward that direction. Dr. Baillod's section introduction (pg. 24) outlines the new effort's focus and objective.

The Academy is also diligently studying the future format – print vs. electronic - of the magazine. An unexpected large number of members responded to the format preference survey that was enclosed with their 2007 renewal package. Through the end of December, 725 responses were received with members voting 51% to 49% to maintain the print format. Some of the comments received along with the votes were: "I'll definitely read an electronic format, and tend not to read the print copy I receive," to "I greatly prefer the print version as I take it with me when I travel and read each page," and "I delete most of the electronic publications I receive; they're too difficult to read." And, "As environmental engineers we should practice what we preach, go electronic and stop depleting the environment," to "I support any decision that will save the AAEE money." Comments not surprisingly reflective of the almost 50-50 nature of the vote.

An electronic format would save considerable financial resources, but there is no majority mandate for that direction. In fact the vote is so close, 13 votes separating print over electronic, that an overwhelming mandate for print also does not exist. Providing a choice of either print or electronic would not significantly save financial resources, and could possibly increase them. Indeed a clear challenge, but one that will be resolved in the coming year with member's preferences a primary consideration in the final outcome.

Our intent is to keep you well informed in 2007, on these pages, through regular electronic updates, as well as immediate electronic reports to you of surveys and questionnaires that you participate in. I know you will find with this first expanded magazine edition that 2007 will be a year of several Academy firsts. A

ANDREW W. EDWARDS, P.E., BCEE, became Principal in the Houston location of ENVIRON. Mr. Edwards is Active and has been certified in Water Supply and Wastewater since 2002.

BRIEN N. GIDLOW, P.E., BCEE, has joined the Denver location of HDR as a Senior Project Manager. Mr. Gidlow is Active and has been certified in Water Supply and Wastewater since 1996.

HERBERT I. HOLLANDER, P.E., BCEE, has be presented with the ASME and IT3 2006 Pioneer Award. Mr. Holland, a consultant of Hollander Associates, is Active and has been certified in Solid Waste Management since 1974.

GEORGE E. KURZ, P.E., BCEE, has joined Barge Waggoner Sumner & Cannon as Senior Technical Leader. Mr. Kurz, the current president of Kentucky-Tennessee Water Environment Association, is Active and has been certified in Water Supply and Wastewater since 1995.

PHILIP C. SINGER, PH.D., P.E., BCEE, was presented with the Harrison Prescott Eddy Medal from the Water Environment Federation (WEF) as one of the authors of "Insights to False Positive Total Cyanide Measurements in Wastewater Plant Effluents" featured in *Water Environment Research*. Dr. Singer, a professor at University of North Carolina, is active and has been certified in Water Supply and Wastewater since 1989.

THOMAS D. PARKER, P.E., BCEE, has been appointed president of the Solid Waste Association of North America (SWANA). Mr. Parker, a principal engineer at CDM, is Active and has been certified in Solid Waste Management since 2004.

YVES E. POLLART, P.E., BCEE, has been named president of the Pennsylvania Water Environment Association (PWEA). Mr. Pollart, Director of Environmental Engineering at RETTEW Associates, Inc., is Active and has been certified in Water Supply and Wastewater since 1997.

C. HERB WARD, PH.D., P.E., BCEE, is the 2006 AAEE-AEESP Frederick G. Pohland Medal recipient. The Pohland Medal recognizes recipient's lifelong commitment to bridge environmental engineering research, education, and practice. Dr. Ward, the Foyt Family Chair of Engineering in the George R. Brown School of Engineering at Rice University, has been certified since 2004 in Hazardous Waste Management.

MEMBERSHIP STATUS CHANGE

HAROLD J. CURTIS, II, P.E., BCEE, and SHERYL LYNN MAYS, P.E., BCEE, have both been transferred to Active status.

IN MEMORIAM

BRADFORD S. CUSHING, P.E., BCEE, passed away on October 24, 2006. He was Vice President and Principal of Applied Environmental Management, Inc., Malvern, PA, and had been certified since 1992 in Hazardous Waste Management.

WILLIAM A. GARLOW, P.E., BCEE, passed away in 2006. He had been certified since 1973 in Sanitary Engineering.

NASH O. GERALD, P.E., BCEE, passed away on March 18, 2006. He was Environmental Engineer with USEPA-OAQPS, Durham, NC, and had been certified since 1997 in Air Pollution Control.

MORTON I. GOLDMAN, SC.D., P.E., BCEE, passed away. He was a Consultant and had been certified since 1960 in Radiation Protection.

JOSEPH J. HARRINGTON, PH.D., P.E., BCEE, passed away on October 9, 2006. He was a Professor at Harvard University and had been certified since 1995 in General Environmental Engineering.

LOUIS HERSCHLER, P.E., passed away in September 2006. He was a Life member and had been certified since 1956 in Sanitary Engineering.

FRED C. HOBSON, P.E., BCEE, has passed away. He was a Life member and had been certified since 1979 in Water Supply and Wastewater.

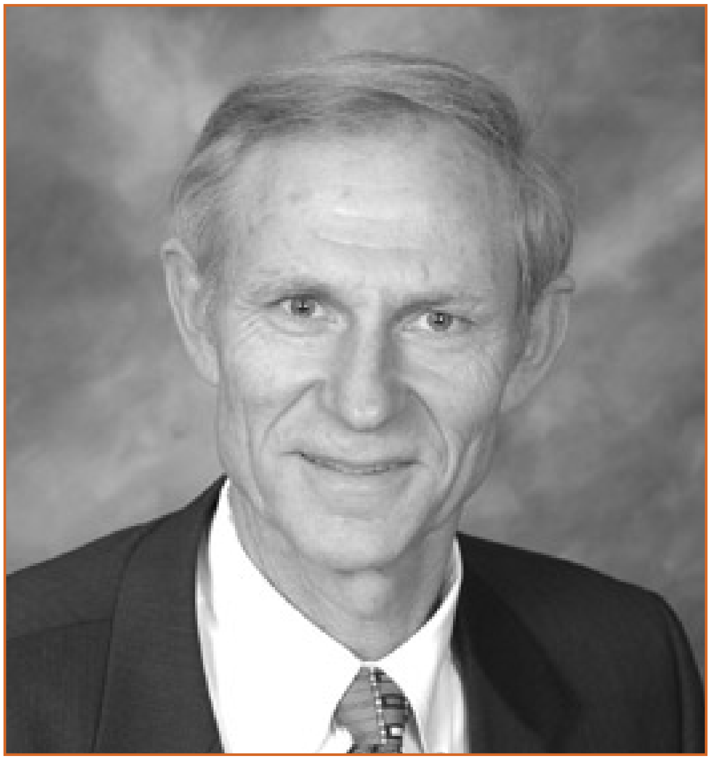
CHARLES A. STRYKER, P.E., BCEE, passed away on June 13, 2006. He was President and Owner of CAS Construction, Inc., and had been certified since 2002 in Water Supply and Wastewater. A

Looking for a qualified employee? Seeking a position?

The Academy can help!

AAEE launched it's AAEE Career Center in September. There is no charge for members to use this service, and recruiters can post available positions for a fee of $250/position for a 30-day listing. Check our website at http://www.aaee.net for more details.

The 2007
KAPPE LECTURER



RUDY J. TEKIPPE, PH.D., P.E., BCEE
Senior Vice President, MWH

EDUCATION

Iowa State University	1965	BS
Iowa State University	1966	MS
University of Wisconsin	1970	PhD
Harvard University	1992	AMP

PROFESSIONAL CREDENTIALS
Registered Professional Engineer in two states
Diplomate, American Academy of Environmental Engineers
Professional Honors
Distinguished Service Award, University of Wisconsin

DR. TEKIPPE HAS SERVED IN THE ENVIRONMENTAL ENGINEERING field for over 40 years. He grew up on a farm in Iowa and attended Iowa State to get his BS in Civil Engineering and his MS in Sanitary Engineering. His MS research and thesis were focused on settling tanks used in wastewater treatment. At the University of Wisconsin, he completed his Ph.D. in the field of coagulation and flocculation in water treatment.

In 1969, he began work for James M. Montgomery, Consulting Engineers (JMM) in Pasadena, CA. This firm's name later evolved to Montgomery Watson and then MWH. Early on, he conducted research on water and wastewater treatability, corrosion, algae in ponds and other related issues. In 1972, he served for two years as JMM's project manager for a 303 Basin Plan project for the State of California. In 1974, he became manager of the firm's Wastewater Engineering Department and served as project manager on a number of large wastewater treatment plant studies and designs nationwide. In the years that followed, he became a company officer and member of the board of directors. In 1982 he became manager of the firm's Pasadena Office.

Given an opportunity to return to academic life, he took a teaching and research position as an associate professor at Iowa State University in academic year 1983/84. He returned to JMM as the Assistant Chief Engineer and subsequently became the Director of Technology as well as the Product Line Leader of Wastewater Engineering.

In 1990, Dr. Tekippe was awarded the role of Program Manager for his firm's program management project for the Water Board in Sydney, Australia. He led a team of over 100 people in the client's office and was chartered with comprehensive planning and early project implementation for wastewater management facilities serving 3.6 million people in the greater Sydney area. Upon returning to the USA, he resumed his role as Director of Technology, became the first president of MWH Soft, and was active in training.

Dr. Tekippe has written over 30 papers, chapters in several books and many reports on the subject of wastewater treatment. His specialties are suspended growth biological treatment and clarifier design. He has served as the lead chapter author of the past two issues of the WEF text "Design of Municipal Wastewater Treatment Plants" and WEF's manual "Clarifier Design".

His professional memberships include: AWWA, WEF, IWA, ASCE, NSPE, and AAEE, for which he was an elected member at large to the Board of Trustees for three years.

ABSTRACTS OF LECTURES OFFERED

Wastewater Treatment Clarifier Design and Research

Clarification has served as a cost-effective process in the treatment of water and wastewater for centuries, yet the practice of designing these units has continued to evolve with few experts believing that a true optimum design has been found. In the field of municipal wastewater treatment, this basic process is commonly used in primary and secondary treatment, with some minor application in tertiary treatment. Rectangular and circular units have largely replaced all other shapes, however, within this pair lies a wide array of details that have a profound influence on the effectiveness of the process. Indeed, performance of some tanks with the same basic geometry can vary by a factor of two or more, depending on the design of details.

The construction costs of wastewater treatment clarifiers in the USA each year is in the hundreds of millions of dollars. The units often occupy a large portion of the footprint of most plant sites. Because of the extremely low velocities and performance sensitivity to temperature and density variables, research and process improvements are most commonly conducted on full-scale facilities. In recent years, digital computer models have been developed to simulate these units and have found to be successful in many applications to assist in design improvement. The development of membrane technology and its use to separate solids from wastewater in treatment will compete for some of the separation market, but clarifiers will perform this function for most plants for years to come; especially in the larger facilities. Thus, improvements in clarifier design represent a way to save large amounts of money and resources.

This lecture will illustrate a few of the fundamentals of clarifier engineering and focus on the array of details that are available to achieve success in treatment. It will explain some of the types of designs that have been used in the past to serve as a basis for comparison to the state-of-the-art practices of today. Figures, photos and performance data are presented to show how each of the key variables in design can affect results. The comprehensive evaluation of all of the variables is needed to define the best design for each treatment plant application. Features that are found to be favorable to most design engineers to achieve balance between cost and performance are presented and discussed.

In the late 1980's, Dr. Tekippe completed a project for the USEPA that defined research needs for secondary clarifiers in wastewater treatment. The priorities established at that time will be examined and compared to what has since been completed. His recommendations on further research needs and methodology to further improve this process and its application by design engineers will be included.

Consulting Environmental Engineering on a Global Basis and its Relationship to Wastewater Treatment Technology

For most of the past century, wastewater treatment engineering was performed by private and public professionals who operated in rather limited circles of collaboration. Many different technologies were applied to meet a range of objectives and product water quality. Numerous innovations have been created to improve the cost effectiveness of treatment. Through the use of publications and presentations among professionals, these technologies have been shared around the world, but many differences still remain.

In the past two decades, the community of large consulting engineering firms has changed in the way in which technology and professionals are applied to projects. Several of these firms have expanded to form truly global organizations that have native employees performing designs with the support of instantly available experts and state-of-the-art tools that revolutionize the profession. This is complimented by the fact that product development and research in several countries is continually bringing to the forefront new process concepts, details and equipment. Furthermore, the means of project delivery acceptable to public institutions has expanded to a wider range of alternatives. The common USA practice of completing a design, putting it out to bid and awarding the construction to the low bidder has given way, to a large degree, to alternatives such as design-build, construction management at risk, and other such alternative delivery methods. Some of these options give more opportunity to the engineering-construction professionals to incorporate innovative technologies as they take on the added risks in competition to secure the work.

This lecture will describe these global changes and how they affect the future of engineering applications and research in the environmental engineering market. It will include a case study of one large firm that is highly globalized and uses leading edge methods of knowledge management to facilitate the latest information in project planning and execution. The advantages and disadvantages of bringing in process innovations from various countries around the world are compared. A specific example of how technical improvements found effective in a foreign country, but have constraints in USA applications is given. A broader set of examples including numerous processes, such as belt presses, special screens, unique tertiary filters and others, is shown to illustrate how and why some such technical transfers succeed and others fail.

Conclusions and recommendations relative to teaching and research at universities in the USA are offered. Also, the merits of new engineering graduates considering working for global engineering consulting firms will be discussed and recommendations given to help them prepare for practicing their new profession in an increasingly global world. A

REFLECTIONS ON THE 2006 KAPPE LECTURE SERIES

By Jerome B. Gilbert, PE, BCEE

As I completed the 2006 series I felt rewarded beyond the honor of being invited. My understanding of academia and environmental engineering research has been updated. The current programs, particularly graduate research agendas, are truly impressive. Nonetheless, most schools still have a recognizable gap in the very subject area of my lecture: *Water Management: Optimizing Systems In An Era Of Limits.* Using case studies in including Southwestern Pennsylvania water quality, New York City filtration and watershed protection, and Colorado River water planning, I illustrated how our regulations and institutions try to deal with fundamental environmental engineering problems.

The watershed or basin was presented as the fundamental organizing unit for all water management activities. While there are many examples of partial success in recognizing this principle, our legislation and institutions are based on individual accountability through enforcing standards and not on a comprehensive approach to better and more efficient health and environmental protection. To achieve this we need professionals committed to evolutionary optimization within a regional context. In the 1960s the National Water Resources Council made efforts to include economic efficiency in water management; unfortunately this concept has been lost and now needs to be restored. Although in some ways our current approach is tied to watershed-based optimization (e.g. TMDL and Sec 208 of the CWA), we now have a basically case-by-case regulatory system.

The Safe Drinking Water Act of 1974 has evolved from the 1980s litigation compromise on the TTHM regulation, which gave priority to regulatory standards, with regulated systems free to choose compliance technology. Considering the plethora of pending and potential standards for drinking water, a new technology-based regulatory approach is needed. Similar to the CWA, the SDA should establish source water categories that provide the basis for requiring utilities to use the latest proven technologies. Currently the San Diego County Water Authority's Twin Oaks Valley Water Treatment Plant would be a good model for its type of raw water, a Northern California and Colorado River blend.

Students and researchers at the universities I visited are interested in these topics and faculty, recognizing the need, are seeking ways to broaden the curriculum to provide this context. Perhaps AAEE members who have day-to-day experience with water planning and regulation could volunteer lectures on a regular schedule at a nearby university. At the other end of the spectrum, universities are engaged in wide-ranging research activities. Nano-technologies, endocrine disruptors, membrane performance, and biofilms are but a few of the advanced research topics. Unfortunately, federal and other sources of funding for projects and student support are increasingly limited. In the long-run, this kind of governmental support is probably much more important than short-run assistance with water and wastewater system improvements. Expanded support is also needed to provide more international opportunities for individual students. There is growing interest in individual exchanges through such organizations as "Engineers Without Borders." Perhaps degree programs could be modified to incorporate an international or work experience, that could be foundation or federally sponsored.

The umbrella term, "Environmental Engineering" now covers professionals from increasingly diverse backgrounds, including a larger number of professionals with non-engineering college education. They are engaged in multi-media and advanced technology research that will provide tools for future water management. Therefore I believe that the Academy's new category of "Board Certified Member" should be advanced in order to promote a broader professional concept of the Academy.

Since 1998 Poseidon Resources has been working with the City of Carlsbad to construct a 50 Million Gallon per Day saltwater desalination plant, which would supply a cost-certain, locally controlled, drought-proof supply of water. A pilot desalination facility began operations in 2003 on the project site adjacent to the Encina Power Station to demonstrate the desalination process and showcase the balance of environmental protections inherent in the project.

Poseidon developed and tested a new approach to location siting the desalination facility along side of the power plant enabling the desalination plant intake and discharge system to directly connect to the discharge of the power generation plant that used seawater for cooling. This configuration allowed the warm power plant discharge to be used as both a source water for the desalination plant and as a blending water to reduce the salinity of the concentrate before it was discharge to the ocean. This approach also reduced both capital costs and energy requirements.

Research at the plant also proved that marine organisms lost their ability to reproduce at salinity levels below those set in the EPA's Whole Effluent Toxicity test. A new methodology was developed that found the maximum salinity level at which marine organisms survive, grow, and reproduce normally.

The Environmental Impact Report prepared independently by another firm for the City of Carlsbad concluded that the proposed plant could be constructed and operated with no significant impact related to thirteen different areas studied including noise, traffic, growth-inducement, air & water quality, land use, public utilities, and natural resources. The full- scale plant is scheduled to be completed and producing potable water by 2008.

E3 Competition Grand Prize in Operation & Management winner, Sanitation Districts of LA County Antelope Valley Green Energy Program: The Power of Innovation, was the IWA's Global Grand Prize winner in Operations/Management. AAEE member James F. Stahl, P.E., BCEE was the engineer in charge of the project.

As part of the Antelope Valley Green Energy program of the Palmdale and Lancaster Districts, a 250 kilowatt fuel cell was installed at the Palmdale wastewater treatment works and a 230 kilowatt microturbine was installed at the Lancaster works, both of which provide secondary treatment. Both units used waste heat recovery for digester heating. Each of these is a first for its type to use digester gas as fuel. The projects include innovative systems to clean trace contaminants from the digester gas stream, produce zero or ultra-low air emissions, and the facilities can be operated from a remote control center.

By adopting advanced technologies, the Districts blazed a trail for the wastewater treatment industry as a whole, and opened the way for large scale, industry-wide reductions in fossil fuel use, air emissions, and energy-related costs.

CH2M Hill's Alexandria Sanitation Authority Advanced Wastewater Treatment Facility Upgrade, the E3 Grand Prize in Design winner, was an IWA Regional winner in Design Projects and the recipient of the IWA's Superior Achievement Award.

The upgrade developed a unique wastewater treatment plant that incorporates a small footprint, environment and energy-efficient systems, as well as an advanced biosolids pasteurizer – the first of its kind in North America and the largest in the world – that ensured the biosolids were suitable for beneficial reuse. The project implemented construction in phases to avoid problems with the restrictive site, high water table and contaminated soils. The design also set large air-collection ductwork underground to reduce to reduce its visual impact.

The E3 Honor Award in Research winner, Malcolm Pirnie, Inc. for Watervliet Arsenal Chemical Oxidation Remediation Project, was an IWA Applied Research Projects Regional Winner.

The remediation project confronted groundwater contaminated by volatile organic compounds from operations at the Watervliet Arsenal in New York State. Groundwater contaminated by volatile organic compounds from operations at the Arsenal had infiltrated the sites fractured bedrock and diffused throughout the bedrock pore matrix and associated pore water, turning the rock itself into a source of continuing contamination spread. Malcolm Pirnie employed a first-of-its-kind in-situ oxidation remedial strategy utilizing an integrated suite of site characterization tools, field pilot study data, laboratory studies, carbon isotope analyses, and numerical modeling. Pilot studies and treatability tests proved the effective delivery and reaction of the oxidant permanganate with volatile organic compounds in the rock matrix.

Malcolm Pirnie, Inc. was also an IWA Regional Design Projects winner for the Lee Hall Water Treatment Plant, Newport News, VA. The project was the 2006 E3 Honor Award in Design winner.

The project design called for a new plant at the site of the old Lee Hall Plant using innovative technologies of Dissolved Air Filtration technology and ozone disinfection with biologically active granular media filtration.

The complete list of IWA 2006 Awardees include:

Category: Applied Research Projects

Global Grand Prize Winner:

- Poseidon Resources Corporation for the Carlsbad Desalination Demonstration Project

Regional Winners:

- Poseidon Resources Corporation for the Carlsbad Desalination Demonstration Project
- Malcolm Pirnie, Inc. for Watervliet Arsenal Chemical Oxidation Remediation Project
- University of New South Wales for EGOWS for Improved Oil-Water Separation
- Kiwa Water Research for Critical Analysis of Valve Location and Reliability

Category: Planning

Regional Winner and Global Grand Prize Winner:

- Gold Coast Water for the Pimpama Coomera Master Plan

Category: Design Projects

Global Grand Prize Winner:

- Black & Veatch for the Tai Po Water Treatment Works & Aqueducts, Hong Kong, China

Regional Winners:

- Malcolm Pirnie, Inc. for Lee Hall Water Treatment Plant
- CH2M Hill the Alexandria Sanitation Authority Advanced Wastewater

Treatment Facility Upgrade
- Earth Tech for Eastern Irrigation Scheme
- Black & Veatch for the Tai Po Water Treatment Works & Aqueducts, Hong Kong, China

Category: Operations/Management

Global Grand Prize Winner:
- Sanitation Districts of Los Angeles County for the Antelope Valley Green Energy Program: The Power of Innovation

Regional Winners:
- Sanitation Districts of Los Angeles County for the Antelope Valley Green Energy Program: The Power of Innovation
- Sinclair Knight Merz for the Sydney Water Sewage Network: Dry Weather Overflow (Sewer Choke) Management Strategy
- Kiwa Water Research for the Prevention of Mechanical Well Clogging; Increasing the Sustainability of Groundwater Abstraction

Category: Small Projects

Regional and Global Grand Prize Winner:
- The City of Salisbury and Kellogg Brown & Root Pty Ltd. For the Parafield Urban Stormwater Harvesting Facility

Superior Achievement Award:
- CH2M Hill the Alexandria Sanitation Authority Advanced Wastewater Treatment Facility Upgrade

Professional Development Award:
- Brown & Caldwell

REP. CALLEGARI, P.E. SPEAKS ON TEXAS' WATER ISSUES AT AAEE/WEF/AIDIS BREAKFAST

Texas State Representative Bill Callegari, P.E. addressed over 130 attendees about Texas' water issues at the AAEE/WEF/AIDIS Breakfast held at the October WEFTEC 2006 in Dallas.

AAEE President Alan H. Vicory serving as Master of Ceremonies introduced Representative Callegari who described Texas' water outlook in his opening comment as, "Texas' water trends may be summed up as follows, years of growing demand for water that is occasionally plagued by drought."

In his remarks, Representative Callegari outlined the growing demands for Texas' water resources. Using data from the Texas Water Development Board, Representative Callegari noted that as Texas' population doubles between now and the year 2050, the demand for water will increase by 18 percent during that time. By 2050, nearly 900 Texas cities will need to either reduce their water demands or develop additional sources of water beyond those currently available to meet their needs during times of drought.

"Our water planning objective in Texas is simple," said Representative Callegari. "We need to provide for water supplies that will serve our growing population and endure in the time of drought. We also have a secondary objective, that of maximizing use of our surface water resources while minimizing the use of our less permanent groundwater supplies."

Representative Callegari identified four strategies that the Texas Legislature may consider in 2007 to improve Texas' water resources. Those strategies include wastewater re-use, water conservation, seawater desalination, and the authorization of water transfers between river basins.

"Texas law needs to be changed to give cities and utilities the ability to re-use their water resources," said Representative Callegari. "I am currently working on legislation addressing this issue in addition to legislation addressing the transfer of water between river basins. There are too many legal barriers in place to allow for the more effective use of our water resources. I am interested in reducing those barriers in order to provide for better flexibility with our resources."

On the issue of water conservation, Representative Callegari noted that while such measures may help save water and prevent waste, they might also be too overreaching and restrictive. "While I favor water conservation in principle, I'm fundamentally opposed to legislative efforts that over-regulate, and would apply stringent conservation standards across the state," said Representative Callegari.

Last year Representative Callegari was recognized by the Water Environment Association of Texas for his contributions to Texas' water policy. With over 30 years' experience in water resource development, Representative Callegari was appointed as Vice Chairman to the House Committee on Natural Resources in 2003. Since then, Representative Callegari has authored significant pieces of legislation affecting water utilities and municipal utility districts. A

Officer Nominees 2 • 0 • 0 • 8

Full profiles and voting ballots will be available in the Spring issue of *Environmental Engineer*.

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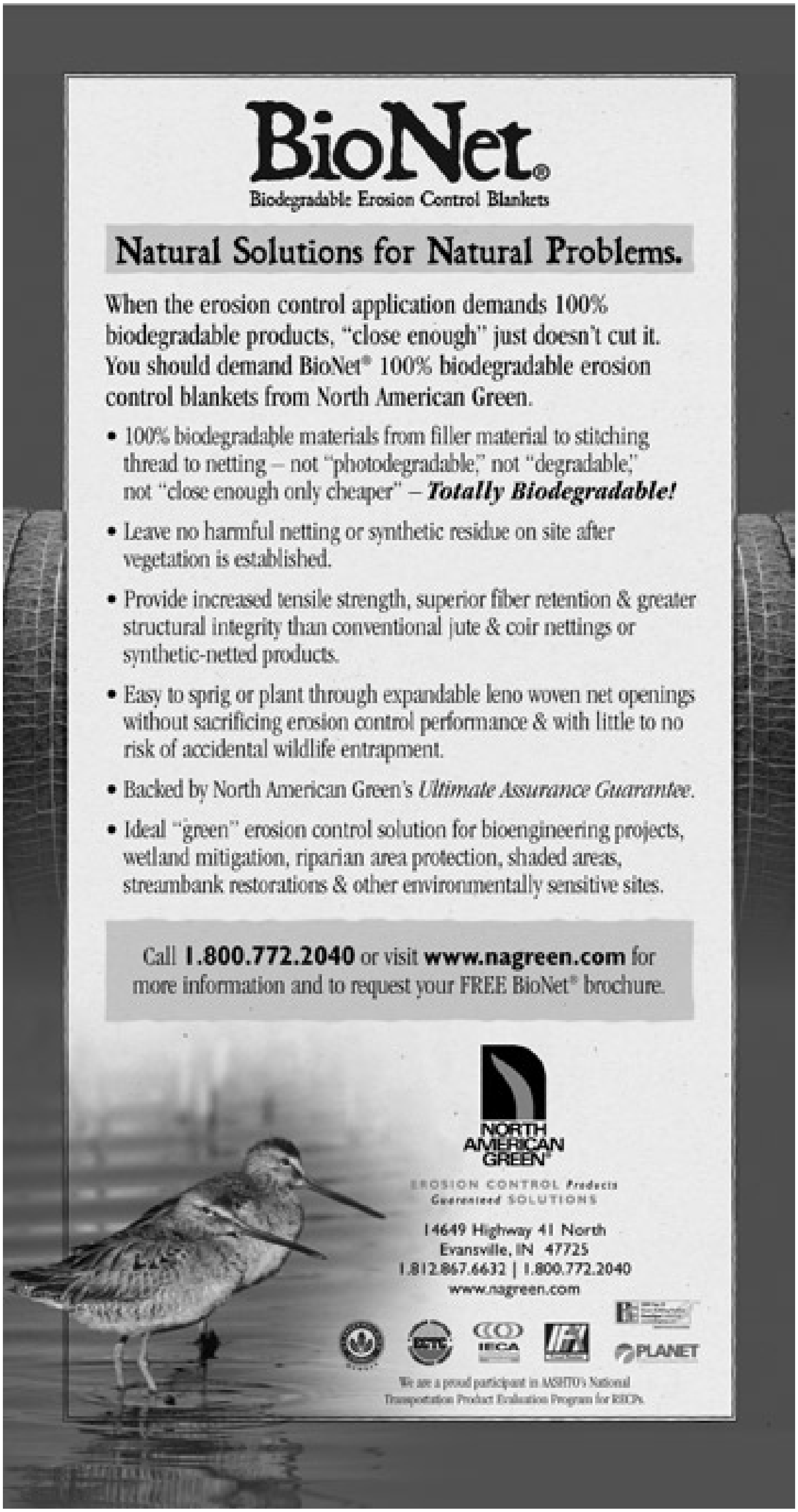

2007 Application Cycle Ends March 31, 2007

Don't let your colleagues miss their chance to be part of the Academy's next class of to become **Board Certified**.

Encourage them to apply for Specialty Certification, showing the rest of the world that they are among the **Best of the Best**.

Completed applications must be submitted to the Academy offices no later than March 31, 2007. Call Academy Headquarters at 410-266-3311 for an application package.

The Class of 2006

THESE INDIVIDUALS were Board Certified in November 2006.

From the first applicants in 1956 to the 91 Board Certified Environmental Engineers and Board Certified Members listed on the following pages, the Academy has undergone growth and changes, but has never wavered from it's core objective to "identify and credential persons with special capabilities in environmental engineering."

Today, there are over 2,400 Board Certified Environmental Engineers and Board Certified Members in the Academy and interest continues to grow on an annual basis.

A brief description of the specialty certification process follows: To be included in an annual class, the application for specialty certification must be submitted to the Academy by March 31. Any application received after that date is held over to the next class. The applications received by March 31 are then reviewed by the Admissions Committee for adequacy of education and qualifying experience in April and May. Examinations are administered to the qualified applicants during July and August at convenient locations throughout the country. The examination results are reviewed by the Admissions Committee in September and recommendations for each candidate are presented to the Board of Trustees. Each person's history is reviewed by the Board members at the Academy's Annual Meeting and decisions made to certify or not.

THE ACADEMY announces the issuance of specialty certificates and Board Certified Environmental Engineers and Board Certified Members status to those individuals portrayed in this special section of the *Environmental Engineer*®. These persons have demonstrated to their peers that they possess the requisite formal education and environmental engineering practical experience and have successfully completed the Academy's examinations to be board-certified environmental engineering specialists. The special capability of each person is shown after their name using the following codes:

AP	Air Pollution Control,
GE	General Environmental Engineering,
HW	Hazardous Waste Management,
IH	Industrial Hygiene,
RP	Radiation Protection,
SW	Solid Waste Management,
WW	Water Supply and Wastewater Engineering.

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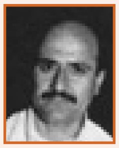

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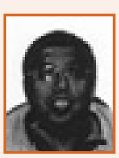

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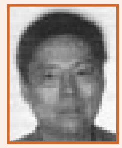

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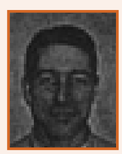

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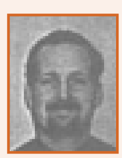

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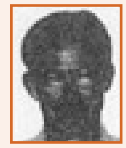

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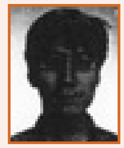

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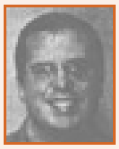

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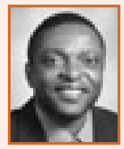

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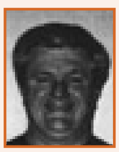

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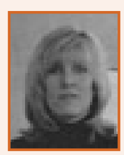

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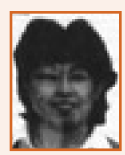

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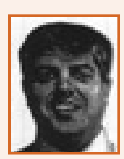

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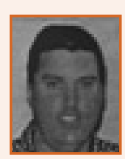

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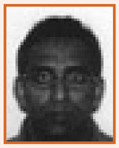

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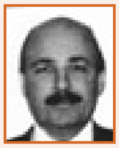

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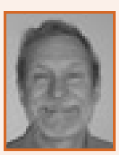

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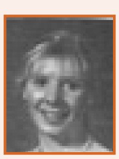

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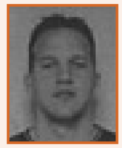

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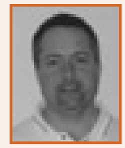

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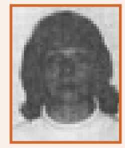

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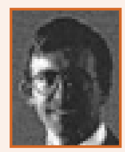

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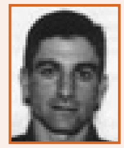

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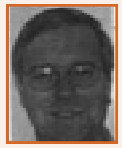

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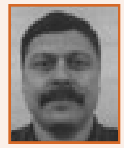

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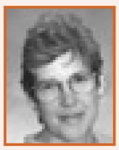

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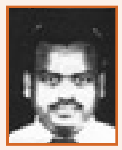

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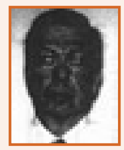

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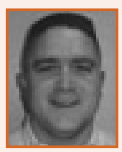

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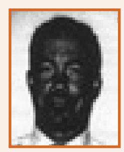

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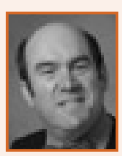

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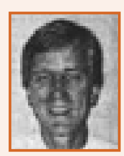

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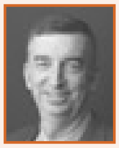

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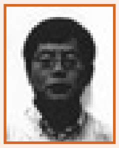

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Volume 1, Winter 2007

Environmental Engineer: Applied Research and Practice

APPLIED RESEARCH AND PRACTICE SECTION

Useful Peer Reviewed Papers Emphasizing Technical Real-World Detail

The Academy is pleased to launch a new section of *Environmental Engineer,* focused on applied research and practice in environmental engineering. The Academy Publications Committee recognized the need for a peer reviewed publication focused on practical research and useful case studies related to environmental engineering. The Academy Board concurred, an editorial board was formed and papers were solicited. Our first two original papers are included in this issue.

Many archival engineering journals emphasize fundamental research and view reports on successful engineering projects as inappropriate for peer reviewed publication. On the contrary, the Applied Research and Practice Section of *Environmental Engineer* encourages publication of useful reports and applied research with an emphasis on technical, real-world detail. Quality is ensured by peer review and by an Editorial Board of experienced practitioners and educators.

It should be pointed out that the Academy is not alone in recognition of the need for a more practice-oriented publication related to environmental engineering. The International Water Association recently launched a new online journal titled *Water Practice & Technology*, and the Water Environment Federation plans to start a new journal titled *Water Practice*. We intend that *Environmental Engineer: Applied Research and Practice* focus will transcend water to include multi-media and professional issues as well.

The Editorial Board encourages submission of papers focused on practical research and useful case studies related to environmental engineering. Practical "know-how" reports, interesting designs, and evaluations of engineering processes and systems are examples of appropriate topics. Manuscripts should follow the general requirements of the ASCE authors guide (http://www.pubs.asce.org/authors/index.html#1) and should be submitted electronically in WORD format to: C. Robert Baillod, Editor, *Environmental Engineer: Applied Research and Practice*, baillod@mtu.edu. The Editorial Board strives for prompt review and publication.

Instructions to Contributors

PURPOSE AND SCOPE

Environmental Engineer: Applied Research and Practice, is a peer-reviewed journal focused on practical research and useful case studies related to the multi-disciplinary field of environmental engineering. The journal strives to publish useful papers emphasizing technical, real-world detail. Practical reports, interesting designs and evaluations of engineering processes and systems are examples of appropriate topics. Papers relating to all environmental engineering specialties will be considered.

MANUSCRIPT REQUIREMENTS:

Manuscripts should follow the general requirements of the ASCE authors' guide (http://www.pubs.asce.org/authors/index.html#1) and should be submitted electronically in WORD format to the Editor and Assistant Editor.

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REVIEW PROCESS

All papers submitted to the journal are subject to critical peer review by three referees, who have special expertise in a particular subject. The Editor will have final authority over a paper's suitability for publication.

CATEGORIES

Papers may be submitted in the following areas:

Applied Research

Original work presented with careful attention to objectives, experimental design, objective data analysis, and reference to the literature. Practical implications should be discussed.

Review

Broad coverage of an environmental engineering application or a related practice with critical summary of other investigators' or practitioners' work.

Practical Notes

Novel methods that the author(s) have found to be sufficiently successful and worth recommending.

Case Studies

Recently completed projects or studies in progress that emphasize novel approaches or significant results.

Design/Operation

Conceptual or physical design or operation of engineering systems based on new models or techniques.

Management

Papers describing novel approaches to problems in environmental management, or to the global, sustainability or business asects of environmental engineering.

ABSTRACT

An abstract of up to 200 words should be provided, including a statement of the problem, method of study, results, and conclusions. References, tables, and figures should not be cited in the abstract. Up to six key words or terms should be included for use by referencing sources.

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APPLICATION OF THE MEMBRANE INTERFACE PROBE (MIP) TO DELINEATE SUBSURFACE DNAPL CONTAMINATION

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ABSTRACT

Definition of source and plume architecture at heterogeneous and homogeneous dense non-aqueous phase liquid (DNAPL) sites is highly complex and requires a detailed characterization approach. The membrane interface probe (MIP) can be used at many sites to perform cost-effective, detailed investigations. The MIP is a commercially available tool that has been described by the manufacturer as a semi-quantitative tool, by others as a quantitative tool, and yet others as a qualitative tool. A variety of methods have been used in an attempt to establish correlations between MIP data and environmental media concentration data. Application of a spatial correlation approach at two sites resulted in the development of semi-quantitative relationships between MIP data and environmental media concentration data, which were used to define volumes of impacted media that exceed applicable regulatory thresholds.

INTRODUCTION

Recent research has demonstrated that the distribution of chlorinated solvents present as dense non-aqueous phase liquid (DNAPL), diffused or sorbed contaminant mass, and resultant dissolved-phase contaminant plumes in both homogenous and heterogeneous geologic media are highly complex, and require detailed characterization for adequate definition (e.g., Guilbeault et al., 2005; Chapman and Parker, 2005). Such research was conducted using highly detailed sampling and analysis schemes, which are not commonly employed by environmental practitioners. However, relatively innovative commercial technologies, such as the membrane interface probe (MIP, U.S. Patent Number 5,639,956), make it possible to conduct similarly detailed investigations at less cost.

The MIP is a direct-push, real-time, direct-sensing tool that provides near-continuous data on the distribution of volatile organic compounds (VOCs) in the subsurface (Christy, 1996). It was introduced in 1986 and is sold and distributed solely by Geoprobe® Systems of Salina, Kansas. The MIP consists of a semi-permeable polytetrafluoroethene membrane impregnated into a stainless steel screen, which is set into a steel block that is heated electrically to approximately 100 to 120 degrees Celsius (°C) (Geoprobe®, 2005). The heated block accelerates diffusion of VOCs present in the soil and/or groundwater through the membrane under a concentration gradient. Compounds the size of naphthalene and larger do not readily pass through the membrane and cannot be detected. Once a compound has passed through the membrane it is picked up by a carrier gas (e.g., nitrogen) that flows at a constant rate of about 35 to 45 milliliters per minute (mL/min). The gas carries the VOCs up a trunk line to the surface (travel time varies from 40 to 60 seconds in a 100 foot trunk line) where it passes through one or more serial detectors.

A variety of detectors can be employed, including a photoionization detector (PID) to measure aromatic compounds (e.g., benzene, toluene, ethylbenzene, xylenes), an electron capture detector (ECD) to measure chlorinated compounds (e.g., tetrachloroethene (PCE), trichloroethene (TCE) 1,1,1-trichloroethane (TCA)), and a flame ionization detector (FID) to measure straight chain hydrocarbons (e.g., methane) and elevated concentrations of some chlorinated compounds. Results are reported as detector response in microvolts (uV) and represent relative total VOC concentrations (Figure 1). A variety of factors can affect the detector responses. These factors include the type of chlorinated VOC (e.g., TCE v. TCA), geologic conditions, (e.g., grain size and degree of saturation), and tool-related issues (e.g., the amount of wear on the membrane).

In general, PCE and TCE must be present at concentrations greater than or equal to approximately 200 micrograms per liter (ug/L) in groundwater to be detected by the MIP ECD. The PID and FID detect chlorinated VOCs present at higher concentrations than the ECD. The MIP PID has a 10.0 electron volt (eV) lamp, which will not detect most chlorinated ethanes (e.g. TCA) and methanes (e.g. carbon tetrachloride), which have higher ionization potentials. Therefore, it is necessary to use an FID to characterize sites impacted by chlorinated ethanes and methanes at concentrations beyond the range of the ECD. Because the concentration range for detecting chlorinated VOCs using the ECD overlaps with those for the PID and FID, it is possible to evaluate both source areas and plumes at most chlorinated solvent sites using the MIP and multiple detectors. However, it is not possible to detect most compounds at concentrations corresponding to their Federal Drinking Water Standards.

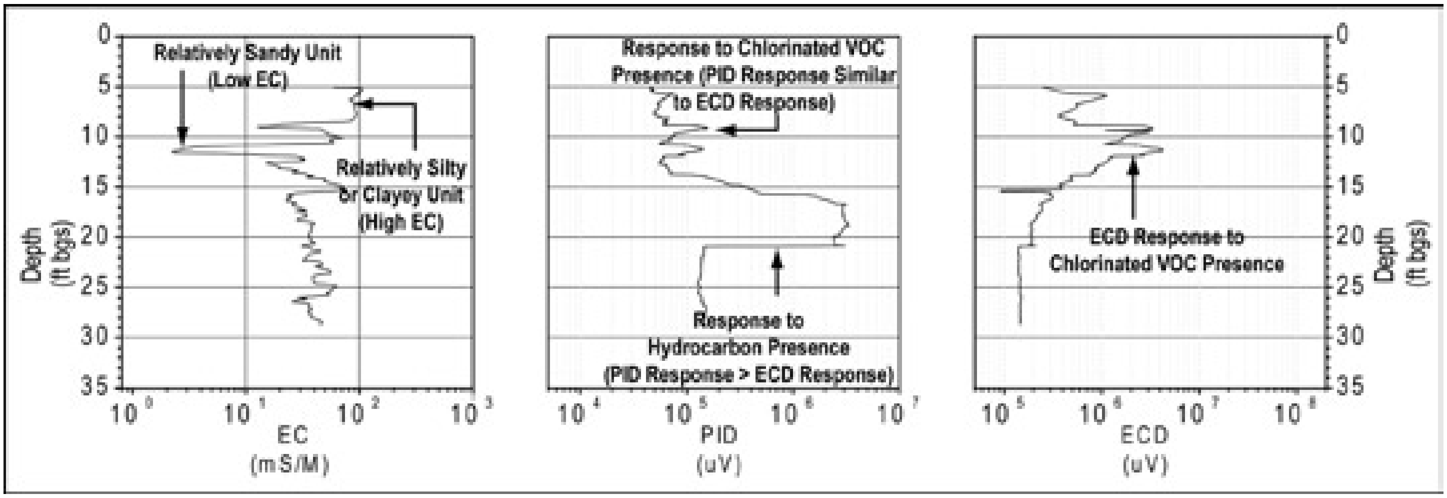

FIGURE 1 MIP log showing how: (1) EC data are used to interpret geologic heterogeneities; (2) PID and ECD data are used to differentiate between aromatic and chlorinated hydrocarbon contamination (Site 2).

In addition to the membrane and heater, typical MIP systems also include an electrical conductivity (EC) dipole array at the tip of the probe. The EC dipole array measures the electrical conductance of the soil and any fluids in the soil in units of milliSiemens per meter (mS/m). Figure 1 shows MIP EC, PID, and ECD profiles from a site underlain by inter-bedded sand and silt, and illustrates how these profiles can be interpreted to gain information on geological characteristics and contaminant distribution (both hydrocarbon and chlorinated VOCs). By understanding the variability in electrical properties of various geologic media, the electrical conductivity log can provide a good indication of stratigraphic changes in many environments (Schulmeister et al., 2003). However, interferences may render EC data interpretation challenging (e.g., groundwater exhibiting high electrical conductivity). At some sites, the electrical properties of geologic units may be too similar to decipher one unit from another using EC data.

Generally the MIP is advanced using a direct-push drill rig at a rate of one foot per minute (ft/min). When necessary, borehole advancement is halted every foot to allow the heater plate to achieve the optimal temperature range (i.e., 100 to 120 °C). Detector response and electrical conductivity data are recorded continuously and are viewable in real-time. The MIP is effective in evaluating both vadose and saturated zones in unconsolidated porous media, and can collect up to 300 vertical feet of data in a day (i.e., depending on geologic conditions, borehole depths and work schedules). In essence, this represents collection of VOC data for up to 300 discrete-interval environmental media samples in a single day. Collection of 300 discrete-interval soil samples for laboratory analysis of VOCs using traditional drilling methods would be extremely cost prohibitive (approximately 17 times more expensive than one day of MIP). Thus, the MIP is an excellent tool for rapidly locating and defining source areas and dissolved-phase chlorinated VOC plumes down to the lower detection limit for ECD in the carrier gas samples.

Data generated by the MIP can be used to develop a three-dimensional image of subsurface conditions. Figure 2 shows a three-dimensional distribution of DNAPL contamination and silt lenses developed from MIP EC, ECD and PID data. These spatial representations are particularly valuable when designing in situ remediation programs, where remedial additives (e.g., permanganate, zero valent iron (ZVI) or carbon substrates) are injected into and/or around zones of contaminant mass to effect treatment.

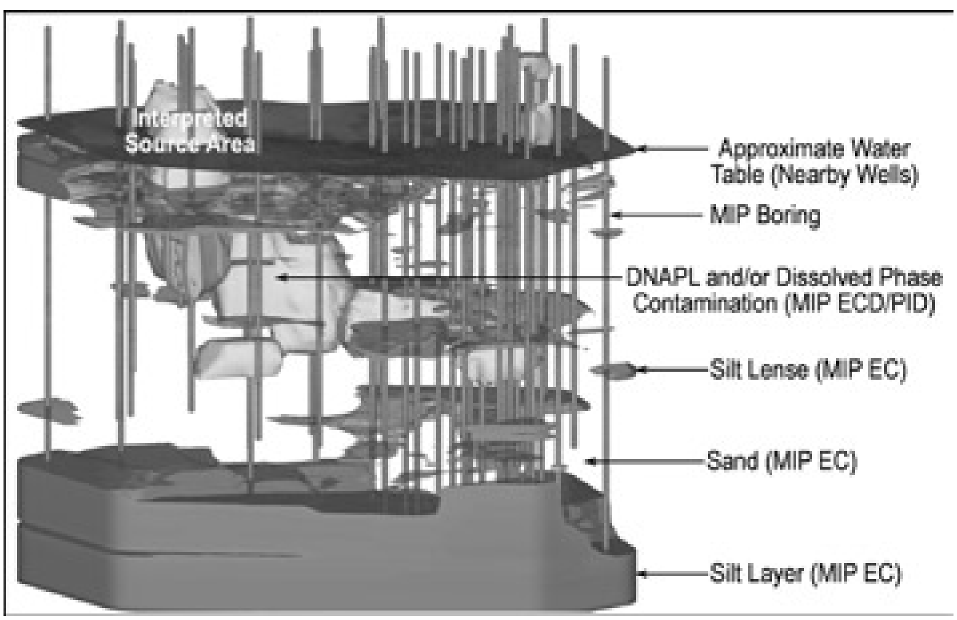

Figure 2. Three-dimensional image showing TCE distribution identified using MIP ECD/PID data relative to the location of silt lenses identified using MIP EC data within a heterogeneous sand and silt source (Site 2).

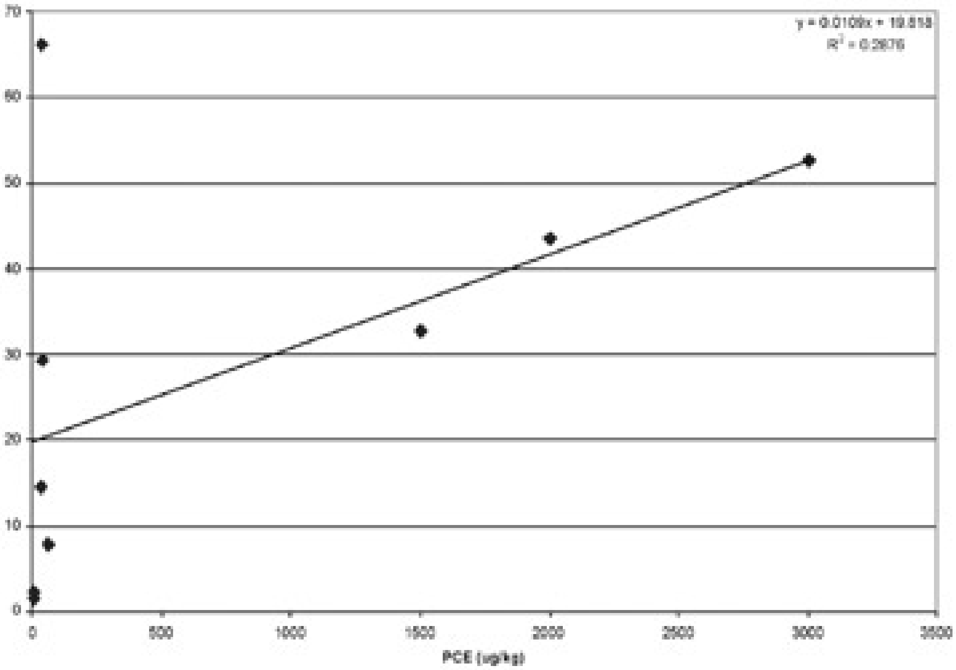

FIGURE 3. Site 1: linear regression of PCE concentrations in vadose zone soil vs. MIP ECD.

FIGURE 4. Site 1: plan view figure showing MIP ECD contours and soil boring PCE results (regulatory criteria = 1,000 ug/kg).

BACKGROUND

Geoprobe® (2005) markets the MIP as a "screening tool with semi-quantitative capabilities acting as an interface between contaminates in the subsurface and gas phase detectors at the surface." However, given the detailed nature of the data, it is tempting to try to quantify the MIP detector results. This has been attempted in two ways: (1) linear regression and (2) visual correlation of MIP detector data with environmental media concentration data.

Costanza and Davis (2000) coupled the MIP with a cone penetrometer (CPT) and ion-trap spectrometer (ITS) to develop the Site Characterization and Analysis Penetrometer System (SCAPS) in an attempt to quantify MIP detector data. The results of this study indicated that soil type and degree of saturation affect the ability to quantify the MIP detector results. Myers et al. (2002) conducted further tests with the SCAPS system, which indicated that strong correlations could be developed between MIP detector and saturated soil VOC concentration data (R^2 of 0.95). However, similarly strong correlations could not be developed with vadose zone soil VOC concentrations (R^2 of 0.60). They also found that stronger correlations could be made in sand matrix material than in other soil types. Costanza et al. (2002) indicated that, in addition to soil type and degree of saturation, groundwater temperature and exterior gas pressure are important physical factors that affect MIP response. Costanza (2002) and Heinze and DiGuiseppi (2002) concur that the MIP should be used as a qualitative tool.

Griffen and Watson (2002) used the MIP to define the presence or absence of DNAPL by calibrating the MIP with pure 1,1,2 trichloro-1,2,2 trifluoroethane (Freon 113) and using the recorded response as an indicator of the presence of DNAPL. Confirmatory soil samples collected during their study indicated that the MIP can identify DNAPL in the subsurface using this approach. Effectively, definition of DNAPL is semi-quantitative in nature, given that it does not produce a quantifiable contaminant concentration.

CASE STUDIES AT TWO SITES

An alternative approach involves spatial correlation of MIP detector data with environmental media concentration data, an approach referred to as a collaborative data set. Typically, this approach uses the MIP to generate a detailed three-dimensional data set followed by collection of a limited number of strategically located discrete-interval soil and/or groundwater samples for laboratory analysis of VOCs. These datasets are then compared using graphical overlays (i.e., plan view and/or cross-sectional iso-concentration maps) and visual correlation of the results. This approach

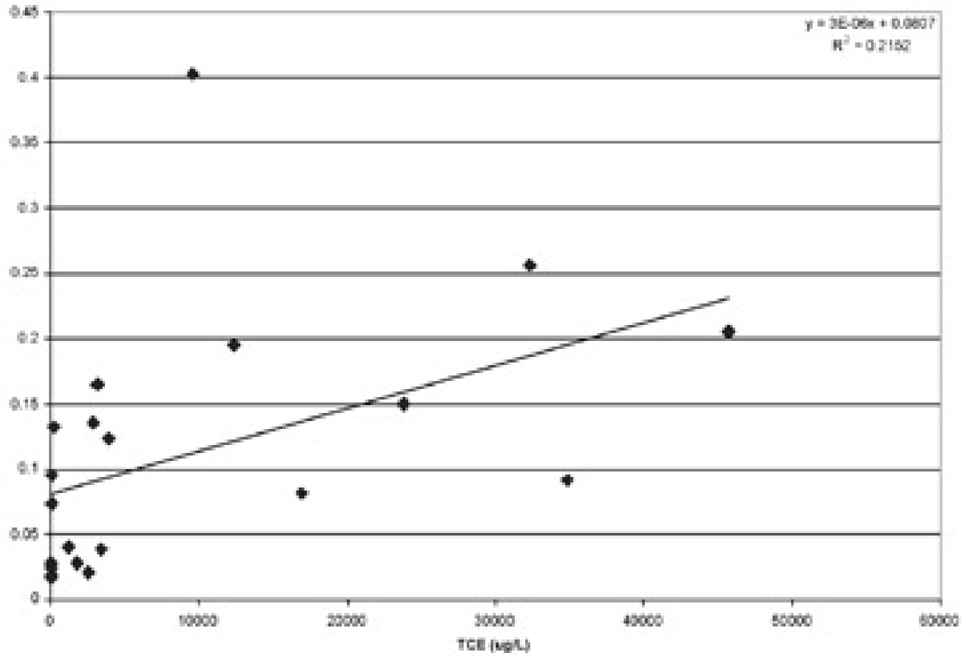

FIGURE 5. Site 2: linear regression of TCE concentrations in groundwater vs. MIP PID.

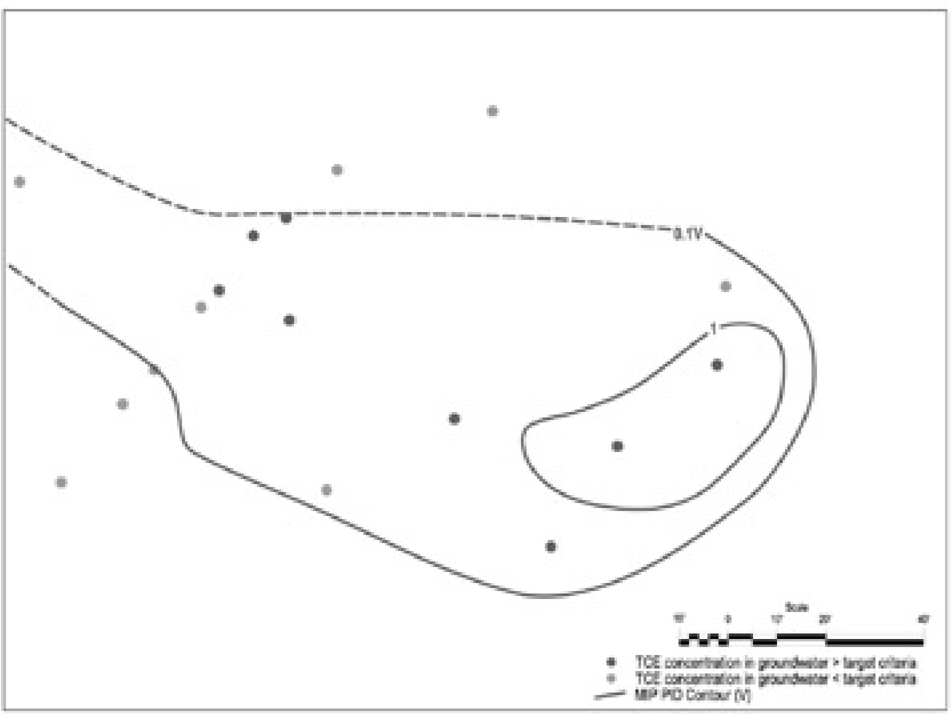

FIGURE 6. Site 2: plan view figure showing MIP PID contours and groundwater TCE results (target criteria = 1,000 ug/L).

can be used to convert MIP detector data to approximate soil or groundwater concentrations. This approach was used at two sites to develop a semi-quantitative relationship between MIP and environmental media data.

SITE 1

Site 1 is impacted by PCE in glacial till. Because the compact nature of the till prevented advancement of the MIP beyond 18 feet in depth, this investigation focused on identification and definition of PCE source areas within the vadose and shallow saturated zones. A total of 46 MIP borings were advanced across the site. Following the MIP investigation, 14 discrete-interval soil samples were collected from locations and depth intervals based on the results of the MIP investigation, and submitted for laboratory analysis of VOCs by EPA Method 8260B/5035, including PCE. Soil samples were collected using direct-push drilling methods, and were field screened using a PID and the jar-headspace method (Massachusetts Department of Environmental Protection, 1991). The field screening data were used to identify zones of elevated VOC concentrations and the soil samples were selected for analysis based on the field screening results. The depths of the soil samples were consistent with or similar to the depths at which selected MIP readings were taken. The field screening helped to minimize the potential for collecting confirmation soil samples from improper depth intervals, given the potential for soil compaction during borehole advancement and/or soil loss during sample retrieval.

Figure 3 presents a linear regression of PCE concentrations in vadose zone soil vs. MIP ECD response. This figure depicts a poor correlation between PCE concentrations in vadose zone soil and MIP ECD data, particularly at the low end of the soil concentration scale. In addition, the high-resolution MIP data were plotted in plan view and cross section, and compared with VOC concentration data for vadose zone soil. Figure 4 presents the results of the visual correlation of plan view MIP and vadose zone soil concentration data for a portion of the site. It is apparent that all seven points with PCE concentrations above the regulatory limit fell within the envelope enclosed by the 10 v ECD contour, and four of the seven points with PCE levels below the regulatory standard fell outside the 10 v ECD contour.

SITE 2

Site 2 is impacted by TCE in saturated, inter-bedded, sands and silts. A total of 43 MIP borings were advanced at the site. Following the MIP investigation, discrete-interval groundwater samples were collected using a modified Waterloo Profiler (Pitkin et al., 1999 and Cho et al., 2004) from

17 locations at depth intervals based on the results of the MIP investigation, and submitted for laboratory analysis of VOCs using a field gas chromatograph and mass spectrometer (GC/MS).

Figure 5 presents a linear regression of TCE concentrations in groundwater vs. MIP PID response. This figure depicts a poor correlation between TCE concentrations in groundwater and MIP PID data. In addition, the high-resolution MIP data were plotted in plan view and cross section, and compared with VOC concentration data for discrete-interval groundwater samples. Figure 6 presents the results of the visual correlation of plan view MIP and groundwater concentration data for the site. Of the 12 locations falling within the 0.1 v contour, eight had TCE concentrations above the target limit of 1000 ug/l and all of the locations falling outside of the 0.1 v contour had concentrations below the regulatory limit.

DISCUSSION

The inexact correlation between MIP data and actual soil and/or groundwater data is likely caused by one or more of the following issues:

- highly heterogeneous distribution of chlorinated solvents in soil and groundwater;
- differences in soil type;
- variable subsurface temperatures and down hole pressures;
- the MIP measures separate-phase, sorbed-phase, dissolved-phase, and gaseous-phase VOCs, whereas soil and groundwater sampling techniques can only effectively measure a sub-set of these contaminant phases;
- burn off from the MIP after it passed through a high VOC concentration interval;
- variability in MIP response due to membrane wear; and/or
- various issues associated with collection of discrete-interval soil samples (e.g. friction loss of VOCs, sample compaction, sample loss, sample handling and collection methods).

Even though the correlation was inexact, the MIP data generated at the two sites described above were useful for delineating areas of soil and groundwater contamination. At Site 1, all soil samples that exceeded regulatory criteria (i.e., 1,000 ug/kg) fell within the 10 volt (V) MIP ECD contour. At Site 2, all groundwater samples that exceeded a target concentration (i.e., 1,000 ug/L) fell within the 0.1 V MIP PID contour. Some confirmatory samples within the respective contours contained the target compound at concentrations below the target criteria, but no confirmatory samples outside the respective contours exceeded the target criteria. In these cases, the 10V (ECD) and 0.1V (PID) contours were used to conservatively delineate impacts to soil and groundwater relative to target criteria, and to estimate remediation volumes at Sites 1 and 2, respectively.

CONCLUSION

High resolution MIP data can be used with a limited number of laboratory soil or groundwater sample analytical data to delineate volumes of soil and groundwater impacted by DNAPL and other VOC contamination. This approach is considerably more cost-effective than relying solely on traditional investigation methods and high resolution laboratory analytical data.

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CHALLENGES TO IMPLEMENTING DRINKING WATER TECHNOLOGIES IN DEVELOPING WORLD COUNTRIES

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ABSTRACT

Access to a sufficient quantity of high quality water is important for improving health and economic livelihood of people residing in developing countries. The purpose of this paper is to identify some of the technical, economic, and social barriers to implementing drinking water technologies in these countries. The intent is to provide guidance to practitioners regarding the barriers and to assist development of strategies for successful implementation. Four representative regions and six water purification technologies were selected for this study. Information on engineering attributes and cost for these technologies were collected and evaluated. A survey of U.S. Peace Corps Volunteers was conducted to understand current practice in developing world countries. Successful implementation of technology in developing world countries requires it be culturally and economically appropriate. Also, it is very important to provide water and sanitation education to local communities before implementing the technologies so families understand the interaction between clean water, sanitation, and improved health.

INTRODUCTION

By one measure, nearly two billion people currently suffer from severe water scarcity-a number that will climb to three billion by 2025 and in the next two decades, 20% of water scarcity issues will be directly associated with the effects of climate change (Vorosmarty et al. 2000). Other "global change" issues that impact water availability and quality are urbanization and population growth. Urbanization is one of the critical global trends shaping the future. Currently, 150,000 people are added to urban populations in developing countries every day and by 2025, it is estimated that two-thirds of the world's people will live in cities. In contrast, only one third of the world's population was urban 35 years ago.

The World Health Organization (WHO) reports that 1.1 billion people lack access to improved water sources. Target 10 of Goal 7 of the Millennium Development Goals aims to halve "by 2015, the proportions of people without sustainable access to safe drinking water." For people living in poverty, illness and disability translate directly into devastating economic hardship. Approximately half of the environmental risk for people living in the developing world is from unsafe water, sanitation, and hygiene (Mihelcic et al. 2006). The effects of ill health have significant ramifications at the macroeconomic scale as well. For instance, a significant portion of Africa's economic shortfall may be attributed to climate and disease burden (WHO, 2001).

This paper is based on a project undertaken to evaluate the technological, social, economic and business aspects of supplying water purification technologies to rural and peri-urban areas of less developed countries. The study was broken down into two aspects: (1) technological, economic, and social evaluation of drinking water technologies for developing countries and (2) evaluation of the business attractiveness of supplying drinking water technologies for developing countries.

The paper focuses on the technological, economic, and social barriers. Issues considered include engineering attributes, power and knowledge requirements, and the need for community "buy-in" to the technology. Recommendations are made for what is necessary for the successful implementation of "appropriate technology" in developing world countries.

METHODOLOGY

Preliminary Evaluation of Technologies

Waterborne diseases cause severe health problems, for example, approximately 2.2 million people, mostly children under the age of five, die each year because of diarrhea. Bacteria and viruses causing the waterborne diseases are typically the primary contaminants to be removed in the regions addressed by this study. Therefore, for preliminary evaluation of technologies, two criteria are established in this study: 1) the technology should have disinfection capability to remove or inactivate microbiological contaminants; 2) the technology should be applicable to domestic use in rural, small communities. Water purification technologies available were listed and pre-selected based on the above criteria.

Screening of Technologies

Twenty purification technologies (not shown here) were first screened for their disinfection capability and application for domestic use. Engineering attributes considered were:

- Source water requirements
- Pretreatment requirements
- Life of technologies
- Treatment efficiencies
- Operation/maintenance requirements (power, labor, materials, knowledge)

Each of these attributes is relevant to feasibility of implementing a given technology in rural and peri-urban areas of developing countries. For example, a technology may not be technically feasible if it is effective for low turbidity water and the available source water is highly turbid. For rural areas where neither fuel nor electricity is readily available (or reliable), technology with large power requirements is not appropriate. Technologies such as distillation and demineralization, electrolysis and vapor compression were screened out because they are primarily applied in industrial use and have high power requirements. For example, electrolysis is used during manufacture of hydrogen. For domestic uses this technology is applied for extracting chlorine from sodium chloride brine instead of directly purifying water. Currently, vapor compression technology is primarily used by the pharmaceutical industry, bottled water industry, and for water desalination. Ozonation and lime softening were not considered for future investigation because both technologies are not very effective pathogen inactivators with ozonation used primarily for pre-disinfection and lime softening used primarily for water softening.

Survey of US Peace Corps Volunteers

Michigan Technological University's (Michigan Tech's) Master's International program in Civil and Environmental Engineering provided an opportunity to gather case-specific information on water purification technology in the developing world. Through this program, Michigan Tech graduate students have the opportunity to combine graduate studies with 2+ years of engineering service in the U.S. Peace Corps, and use their Peace Corps training and service as part of their course and research requirements. A survey was distributed via email to Peace Corps volunteers (PCVs) affiliated with the Michigan Tech Master's International Program in Civil and Environmental Engineering. Surveys were distributed to a total of thirty-one current and returned PCVs. Sixteen surveys were returned representing eight countries. Key survey questions requested a description of the technology in use in a given country; power requirements; costs of the technology (capital, O&M); sources of funding to purchase the technology (local, World Bank, NGOs); information on operators (who, how many); cost for purified water use (per household, per liter, etc.); an assessment whether the technology is "appropriate"; designation of the locale as urban, peri-urban, or rural; information on the source water (groundwater, surface water, or both); and a description of common waterborne diseases encountered before implementation of water purification technology (or currently if no technology is in place).

Selection of Technologies

Based on the selection criteria described above, on the results of the Peace Corps Volunteer Survey, and on the attributes of the technologies, the following six technologies were selected for further investigation:

- Media Filtration (sand filtration)
- Reverse Osmosis (RO)
- Membrane Filtration
- Chemical Disinfection by Chlorine Bleach or Hypochlorite
- Ultraviolet Radiation (UV)
- Flocculation/Coagulation plus Sedimentation (or filtration)

Table 1 summarizes the engineering attributes and typical cost ranges for each selected technology. The selected technologies have the capability to remove or inactivate pathogens and are primarily applied for water treatment prior to domestic use. Sand filtration, chlorine disinfection and flocculation/coagulation plus sedimentation represent current practice in developing countries based on results from the survey of Peace Corp Volunteers and information obtained from several non-governmental organizations (NGOs). Reverse osmosis, membrane filtration and ultraviolet radiation are technologies less frequently implemented in developing countries.

Representative Community Size

For the selected technologies, a community with a population of 1,000 people was selected as a reasonable size because the common population of the communities and neighborhoods in the selected countries or regions is 500 to 800 people. For the given community size of 1,000, the system capacity, capital cost, and operation and maintenance cost for the water purification system applying each of the selected technologies were estimated (see Table 1).

RESULTS

Business Aspects

Selection of regions/countries for the business attractiveness portion of the study was broken down based on twelve characteristics and four representative regions/countries (Mozambique, Honduras, Madhya Pradesh province in India; Sichuan province in China), as shown in Table 2. The four selected regions/countries represent a wide range of annual domestic water consumption rates, with Mozambique (4 m^3/capita or 1,060 gal/capita) and Madhya Pradesh, India (51 m^3/capita or 13,500 gal/capita) the extremes. The GDP per capita varies with Mozambique ($US 233) and Honduras ($US 1,026) the extremes. Electricity use also varies with Mozambique (270 kWh) and Sichuan, China (760 kWh) the extremes. There is also geographic variation involving a country in Central America, a country in Africa, and regions in India and China. In addition, there are business risks to the implementation of water purification technology in developing world countries including government corruption, political instability, fluctuating monetary units, and low literacy levels. Clearly, these characteristics influence the business aspects of providing water treatment technology. For further details of the business case studies for each of these regions, see Johnson et al. (2007).

Evaluation of Technologies

Table 1 provides some insights on implementation of technologies in developing countries. The survey of Peace Corps Volunteers resulted in useful information regarding the technologies. Each survey response discussed one to three types of drinking water treatment technology occurring at the volunteer's site, with the following mentioned: chlorine disinfection (13 survey responses), slow sand filtration (6), municipal plant incorporating coagulation, flocculation, sedimentation, sand filtration, and chlorination (or some combination thereof) (5), ceramic or activated carbon filter (3), and

TABLE 1. Comparison of Engineering Attributes and Cost of Selected Water Purification Technologies

Technology	Source Water Requirements	Pretreatment Requirements	Life of echnology	Treatment Efficiency	Operating Requirements				Capital Costa ($US)	O&M Costa ($US/yr)
					Power	*Labor*	*Material*	*Knowledge*		
Chemical Disinfection by Chlorine Bleach or Hypochlorite	relatively effective with <20 NTU	prefiltration may be needed for highly turbid water	20 years (assumed)	99% bacteria, virus, and protozoa removal	none to minimal power required	minimal	chlorine, delivery mechanism	skilled and/or trained labor	~ 15,000	~2,400 - 2,500
Flocculation/ Coagulation plus Sedimentation (or filtration)	primarily used for raw surface water sources	grit removal and pH adjustment may be needed	20 years (assumed)	Bacteria 30-90%; Virus 30-70%; Protozoa 30-90%	none to minimal power required	minimal	coagulant, concrete	skilled and/or trained labor	~ 60,000 - 70,000	~8,000
Membrane Filtration	can be used for most sources except salt water	taste/odor control	5-10 years	Bacteria 99.9-99.9%; Virus < 90%; Protozoa 99.9-99.9%	large power requirements	minimal labor requirements for operation	chemical, membrane, and support structures	skilled and/or trained labor	~40,000 - 110,000	~4,000 - 7,000
Reverse Osmosis	used primarily for brackish or salt water	scale control, prefiltration, and disinfection	20 years (assumed)	100% bacteria, virus, and protozoa removal	large power requirements (3-30 kWh/1000 gal)	minimal (1 - 3 people for up to 4000 m^3/day plant)	chemical, membrane, and support structures	skilled and/or trained labor	~50,000 - 130,000	~5,000 - 15,000
Media Filtration (sand filtration)	primarily used for raw surface and water sources	pretreatment for high turbidity	20 years (assumed)	Bacteria 50-99.9%; Virus 20-99.9%; Protozoa 50-99%	minimal power requirements	minimal (1-2 days/2-6 months for cleaning)	PVC pipe, gravel, sand, concrete, copper sulfate	does not require skilled labor	~20,000 - 30,000	~2,000 - 4,000
Ultraviolet Radiation (UV) (Low Pressure/ Intensity)	Used for low turbidity water, UV transmittance should be >75%	filtration or disinfection for low transmittance	15 years (assumed)	99% bacteria, virus, and protozoa removal	medium power requirements (.05-.15 kWh/1000 gal)	medium labor requirements	lamps, ballasts, sleeves, support structure	skilled and/or trained labor	~12,000 - 14,000	~900 - 1,100

[a]Capital and O&M costs are based on 1,000 people and are rough estimates for manufacturing/constructing and operating the technology in the U.S. and are useful for relative cost comparisons of the technologies. A substantial cost savings may be realized by manufacturing/constructing and operating the appropriate technologies in rural areas of the developing world due to use of local materials and local labor. Design flow rates range from 15 m^3/d (4,000 gpd) to 85 m^3/d (20,000 gpd). All costs are 2004$US. Sources of Data in Table 1: Baker et. al. (1991); Central Contra Costa Sanitary District (2005); Chlorine Chemistry Council (2003); Crittenden et al. (2005); Duranceau (2001); Hendricks (1991); IETC (1997); IETC (1998a); IETC (1998b); Kawamura (2000); Lueck (1999); Mackey et al. (2001); NEWTTAC (2002); NFESC (2005); Pickering and Wiesner (1993); Reid and Coffey (1978); Remco Engineering (2005); Rottier and Ince (2003); U.S. EPA (1979); U.S. EPA (1986); U.S. EPA (1992); U.S. EPA (1999); WHO (2004)

ultraviolet disinfection (2). These technologies were not observed more in one political region versus another. Furthermore, these technologies were identified in urban and rural areas. Aside from the plants operated by municipalities, most of these technologies are operated at the household level or within a community. The survey responses showed relatively equal use of groundwater and surface water. Often times, it is not a matter of preference of which water source is more suitable for a technology, but supply and accessibility that drive usage of a particular source of water.

As mentioned before, chlorine bleach, coagulation/sedimentation, and slow sand filtration are three most widely used technologies in developing countries. These three technologies have some common features: minimal pretreatment, minimal power requirements, potential application of local materials in construction, and minimal skills required for operation and maintenance.

Barriers to Implementation of Selected Technologies

For reverse osmosis technology, which is rarely practiced in rural areas of developing countries, a high level of pretreatment and a large amount of power, manufactured equipment, and professional labor are required. Clearly, these four factors are critical for implementation of technologies and address the technical, economic, and social aspects for implementing water purification technologies in these countries. For example, the power requirement is directly related to operation/maintenance (O&M) cost, and the skill requirement is related to technology complexity and has impact on community assuming ownership of a project.

The investment cost (capital cost) and O&M costs of the selected technologies were estimated using cost information from several governmental, industrial, and professional organization sources in conjunction with the system capacity (design flow) data. The design flow was determined based on a water consumption rate that ensures improved health through, not only access to safe water, but also sanitation, and the community size. The per capita water consumption rates (15 L/d-capita - 85 L/d-capita) used in this study are in line with what is recommended by the World Health Organization for a successful public health improvement. For a community with a population of 1,000, the design flow varied from 15 to 85 m^3/d (4,000 to 22,500 gpd) for different regions/countries. The capital and operation/maintenance costs of each selected technology were estimated based on manufacturing and construction in the United States (see Table 1). Sand filtration, chlorine bleach, and ultraviolet radiation (UV) have relatively low capital cost and O&M cost; whereas, reverse osmosis has the highest capital cost and O&M cost.

The "appropriate" technologies are those with low capital and O&M costs. However, for technologies with low total cost, technical and social factors have to be considered. For example, UV technology has low total cost, but it is not widely practiced in rural areas of developing countries because it has relatively strict requirements on source water and also requires more power than other technologies. In addition, it is often difficult for the local community to visually see the difference between raw water and treated water, which in turn makes it difficult for the community to buy in to this technology. For example, PCVs in Mali noted that community members often prefer the taste of untreated water from wells to the treated water, demonstrating the need for community education to teach the benefits of safe water for drinking and sanitation.

Project failure has become an increasing concern to aid agencies and host governments involved in water resource development in less developed countries. Past top-down approaches in which outside "experts" dictated project plans and implementation on developing communities littered the globe with well meant but defunct water projects. Reasons for these failures are technological, economical,

TABLE 2. Key Variable Data for the Four Countries/Regions Evaluated in this Study.

Characteristics	Units	Honduras	Mozambique	Madhya Pradesh, India	Sichuan, China
GDP per capita	$US	1026 (2004)	233 (2004)	603 (2004)*	697 (2002)
Gross Domestic Product-Annual Growth Rate	%	4.79	1.6	4.33	10.15
Political Stability[a]	percentile ranking	38.4	63.8	22.2*	51.4*
Government Effectiveness[a]	percentile ranking	27.3	42.8	54.1*	63.4*
Total Population	thousands	7257	19495	60385	86730
Percentage Rural	%	53.6	62	73.33	82
Literacy Rate	% population over age 15	76.2	53.5	64.11	86.45
Average Household Size	# persons	5.4	4.1	5*	4*
Water Use per capita	M^3/yr	133	36	635*	80.55**
% of urban population with access to improved water	%	99	76	>85	92*
% of rural population with access to improved water	%	82	24	100	68*
Electric Generation Capacity	MW	865	2388	3816	10900
Electricity use per capita	kWh	508.3	266.06	318	761.6

* National data, not province/state specific at this time.
** Rural water use (domestic); urban water use is 153.38.
[a]Note: For political stability and government effectiveness, the higher the percentile the more stable or effective, respectively. The United States is typically in the 90th+ percentile in both categories.
Sources of Data in Table 2: Ping 2005, IMF 2005, Office of the Registrar General-India 2001, DDWS 2005, Government of Madhya Pradesh 2003a-b, NBSC 2003, UNESCO 2005, UNEP 2005, UNESA 2004, UNESA 2005, The World Bank Groupa-d, U.S. CIA 2005, BBS 2003, Dev 2004

and institutional and create distortions in all steps of project life, from identification through operation and maintenance (Howe and Dixon 1993). A PCV in the Philippines commented that water treatment by household activated carbon filters (70USD capital cost, 10USD O&M) can be unaffordable and treatment by the municipal chlorination and softening process is unreliable due to governmental corruption of the water sector. For both treatment methods, the need for external financing makes these efforts unsustainable.

As project failures continue to appear in public view, the appropriateness of the technology for a given community and need has garnered more attention from governments and non-governmental organizations (NGO). Barriers to appropriate technologies, though more prevalent and identifiable 10 to 20 years ago, still continue to hinder water project success. One problem exists in the lending/grant process itself, where excess funds are exceeding host countries' abilities to identify and implement good projects. Host countries may have the attitude of "use it before you lose it", thereby constructing large, technical projects with little planning for operation and maintenance (O&M). In addition, aid agencies often don't attach O&M and follow-up stipulations to project financing for fear of losing donor investment, as host countries may go with another lender with less requirements (Howe and Dixon 1993). Four out of five PCV survey respondents noted initial funding needs being fulfilled by local governmental loans or non-governmental agency aid programs.

Additional problems occur in project design and construction when host countries desire the prestige associated with higher technology and donor countries are willing to oblige and in some cases demand such technology exports (Howe and Dixon 1993). This limiting of technology choices weakens sustainability initiatives and ultimately project success (Breslin 2003). Developed country engineers and planners sometimes operate under the assumption that more technical, capital-intensive projects require less maintenance in the future. While this assumption is valid in the developed world, the same does not necessarily hold in developing countries, where failure of complex water projects only exacerbates the O&M problem (Howe and Dixon 1993; Breslin 2003). Lack of local input also has been and will continue to be a barrier to successful water project planning and construction. The capability of local supply and production systems is often underestimated by donor countries or central governments, and local labor and expertise are sometimes wrongly seen as limiting.

Factors Supporting Successful Implementation

There are indications that implementation is meeting some level of success. The effectiveness of specific interventions to improve water, sanitation, and hygiene in developing countries was assessed from 39 studies, and most interventions were found to significantly reduce the levels of diarrhea illness (Fewtrell and Colford, 2005). The World Bank's Water Supply and Sanitation (WSS) sector has a significant role in implementing drinking water treatment technology in developing communities, as evidenced by the $13.3 billion committed to 304 projects between 1990 and 2001. A recent assessment by the World Bank's Operations Evaluation Department (OED) utilized its own ranking system, as well as the WSS performance indicators, to gage the WSS sector's effectiveness at achieving its objective of "efficient, sustainable service for all." OED ratings for project outcome of "satisfactory" rose from 58 percent for projects in the 1980s to 64 percent for projects in the 1990s. Perhaps even more demonstrative of project success are the WSS performance indicators, which include water supply connection coverage, sewerage connection coverage, share of connected households receiving continuous service, share of connected households receiving biologically safe water, unaccounted water, employees per thousand water households connected, financial working ratio, and share of wastewater treated. For each of the eight performance indicators, improvements were evidenced following a World Bank WSS-funded project (World Bank 2003).

For sand filtration and chlorine bleach, a substantial cost savings may be realized in rural communities located in the developing world, compared to constructing the same technology in the United States. Readily available local materials and cheap labor result in much lower costs than in the U.S. For example, the construction cost for a typical springbox, coupled with slow sand filtration technology, in Cameroon (West Africa) is approximately $1,600 (Fry et al. 2006). In addition, the PCV survey showed the initial investment of chlorine bleach system in Honduras is only $30-$35, and the O&M cost is as low as $15-$20 per year. Cost savings resulting from the use of local materials and local labor is an important factor for successful implementation.

Failure of O&M mechanisms, partly due to previously mentioned reasons, and follow-up are perhaps the main cause of project failure. As mentioned before, many aid agencies haven't required these plans in order to prevent loss of "business". Fortunately this trend is changing, with many donor countries and aid agencies budgeting for future O&M expenses, as well as local communities taking initiatives in planning and structuring their own O&M schemes. A demand-responsive approach, where the local community takes more responsibility for the decisions and actions regarding project planning and O&M, is now becoming more common and showing more promise where it is needed, such as in rural areas of Mozambique where protected wells and rope/bucket systems are more successful than more complicated pumping technologies (Breslin 2003).

Other aid agencies are also seeing success in water projects planned and implemented with community participation (Haws 2006). Community buy in is key, as shown by experiences in Zambia, India, Kenya, and Uganda with PREPP (participation-ranking-experience-perception-partnership), a consumer consultation process used by engineers and community development workers that illustrates ways to alleviate some of the social barriers to introducing a new technology for drinking water treatment into a developing community (Coates et al. 2005). Two respondents to the PCV survey noted the success of water treatment projects when implemented at the household level, especially with technology that was inexpensive, easy to use, effective at removing pathogens and that required local materials.

DISCUSSION

This study demonstrated the many technological, economic, and social challenges to implementing drinking water technologies in developing countries. Simpler, appropriate technologies have been successfully implemented in the developing world countries. As part of its Millennium Development Goals, the United Nations has set aggressive targets for the water purification industry.

- By 2015, reduce by half the proportion of people without access to safe drinking water.
- Target for 2015: Halve the proportion of people living on less than a dollar a day and those who suffer from hunger.

The first target relates directly to the water industry, and the second goal would make safe drinking water more affordable. These targets have been adopted by the world community. It is for reasons such as these that a plausible business strategy for private funding of water purification projects may be to approach water purification as a corporate social responsibility in the short term, which will allow one's organization to be positioned well once the economic ability of individuals, governments, and donor agencies are better aligned. As one individual from a non-governmental organization informed the project team, taking the time now to learn about people and culture and develop appropriate business models without the pressure of making a profit will provide a competitive advantage when the market for water purification technology evolves over the next decade. Some emerging economies are also possibilities for introduction of more advanced water treatment technologies. For example, according to the US Commercial Service, China's market for imported water treatment equipment is currently about $US 2 billion a year (U.S. DOC, 2005).

There is a clear link between health and hygiene and providing safe drinking water and cooking water is only one aspect of improving public health. Personal water use rates as low as 4-8 L/capita/day account only for cooking and drinking and are not close to what any health agency would promote for a successful improvement in public health. For example, WHO/UNICEF (2000) defines the term *reasonable access* as the "availability of at least 20 liters per person per day (l/c-d) from a source within one kilometer of the user's dwelling." Water use includes four items: 1) consumption (drinking and cooking); 2) hygiene (including basic needs for personal and domestic cleanliness); 3) productive use (brewing, animal watering, construction, and small-scale gardening); and, 4) amenity use (car washing, lawn watering). The first two categories of water use, 'consumption' and 'hygiene', have direct consequences for health both in relation to physiological needs and in the control of diverse infectious and non-infectious water-related disease. Productive water may be critical among the urban poor in sustaining livelihoods and avoiding poverty and therefore has considerable indirect influence on human health. The importance of including hygiene in water use evaluations cannot be overstated (Howard and Bartram, 2003).

Population density is typically low in rural areas of developing countries and could be one of the larger impediments to growth in new or expanded markets for technology. Urban and peri-urban regions of the developing world may represent a larger potential market based on population trends and density. Urbanization is one of the critical global trends shaping the future. By 2025, it is estimated that two-thirds of the world's people will live in cities.

Some technologies may be favorable for either disaster relief, regions where fresh water is scarce, regions where water suppliers rely on desalination of brackish groundwater and sea water, and water reuse projects. In the case of disaster relief, extreme hydro-meteorological events now account for over 70% of international disaster deaths (IRC, 2002) and waterborne diseases are a well recognized outcome of these events. In addition, waterborne disease is not only becoming endemic in some parts of the world, but combating it through technology, capacity building, and education is limited because of access limitations due to civil strife. This societal instability presents a great challenge to implementing any form of water purification technology in some parts of the world. Regions of the world where fresh water is scarce include coastal urban areas for municipal use, vacation resorts located in coastal areas that depend on an uninterrupted supply of high quality water for tourist-based economic development, and the bottled water industry in coastal areas. Many countries currently identified as water scarce and ones that may become water scarce in the future have coastal boundaries and may be able to utilize desalination of high-salinity water as a means of meeting their water demand needs.

CONCLUSIONS

Based on the results of this investigation it is concluded that:

1. The most applicable water treatment technologies to rural and peri-urban areas of developing world countries are those with minimal pretreatment, minimal power requirements, potential application of local materials in construction, and minimal skills required for operation and maintenance. This includes chlorine bleach and slow sand filtration.
2. There are a number of business risks beyond a cost analysis that should be taken into consideration with regard to implementation of water treatment technologies in developing world countries. The business risks include government corruption, political instability, fluctuating monetary units, and low literacy levels. Other business risks are specific to a given region, such as inflation and past failures for implementing water purification technology. In the latter, the implementation failures have primarily been due to lack of training and maintenance of the water purification system.
3. Numerous barriers to implementing water treatment technology were identified. Most important among

these are high capital and O&M costs, a high level of complexity associated with the technology, lack of community education, lack of planning and funding for operation and maintenance, and an often-seen desire of donor countries to provide higher technology rather than appropriate technology.

4. Several factors supporting successful implementation were identified. Most important among these are the use of local materials and local labor to reduce capital and O&M costs (e.g. with chlorine bleach and slow sand filtration), increased focus on operation and maintenance including community education and involvement from the project planning to the O&M phase, and employment of strategies to engender community buy-in and reduce social barriers to implementation of new drinking water technologies in developing world countries.

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