

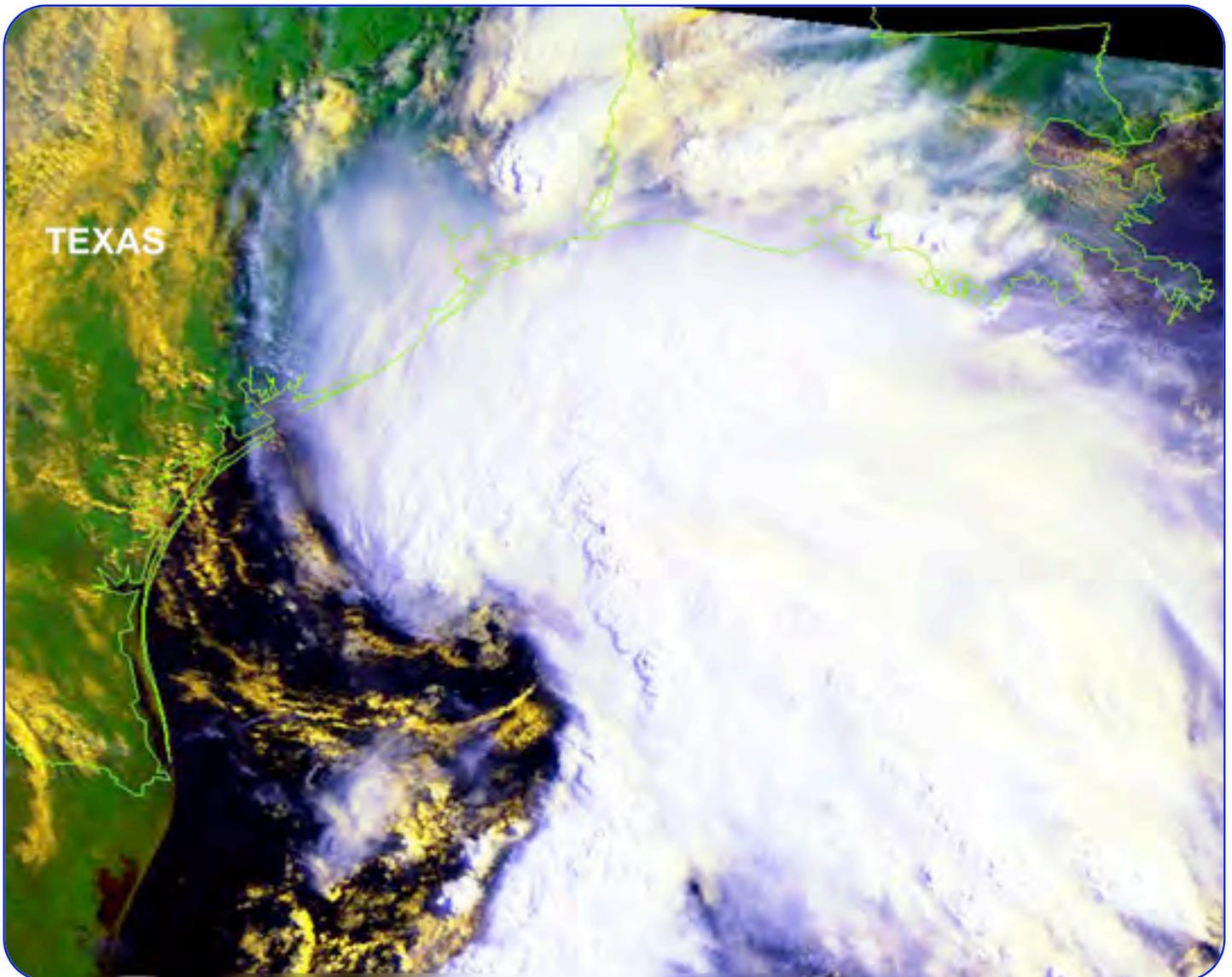
Pollution Prevention

Natural Resource Conservation

Environmental Policy Issues

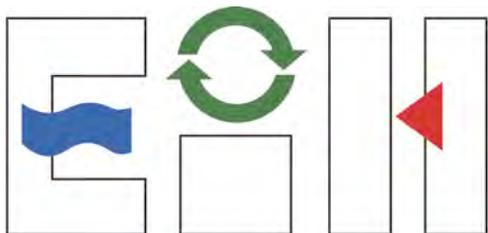
Public Participation

Environmental Education



2001 Annual Report  
The Environmental Institute of Houston

University of Houston-Clear Lake  
and the  
University of Houston  
Houston, Texas



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Debbie V. Bush, Editor and Web Site  
Manager

Environmental Institute of Houston  
University of Houston-Clear Lake  
Box 540  
2700 Bay Area Blvd.  
Houston, Texas 77058-1098

University of Houston  
Environmental Institute of Houston  
504 Science & Research 1, Rm 510G  
Houston, TX 77204-5006

<http://www.eih.uhcl.edu/>

April 2002

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Photo courtesy of Jon Schultz

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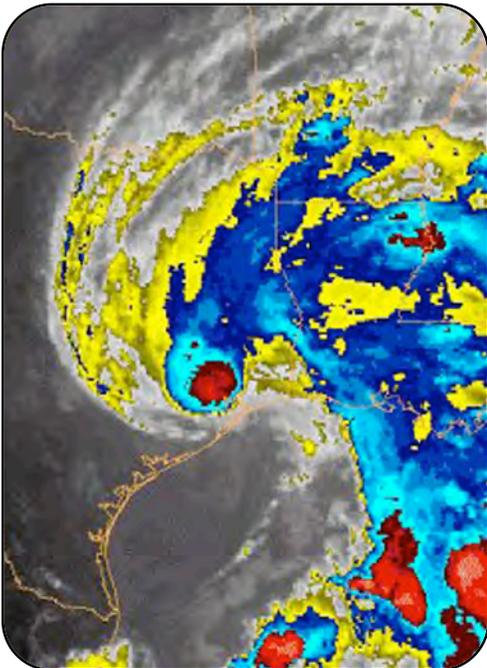


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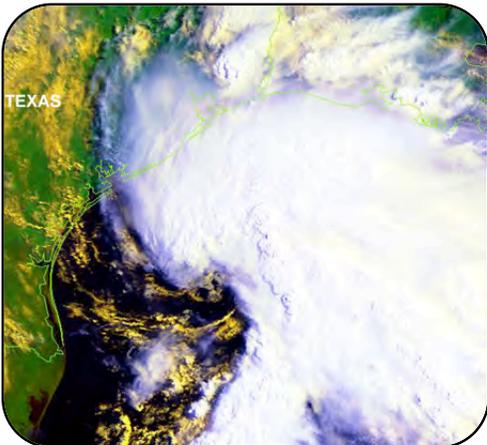


Photo courtesy of NOAA

**Top left: The University of Houston's O'Quinn Law Library was heavily damaged by flood waters. Pumping began on June 10th and took several days to complete. The atrium stairway is shown after two hours of pumping out water. Over 200,000 books, shelving systems, furniture, and equipment were lost.**

**Middle left: Enhanced infrared image of Tropical Storm Allison's landfall on June 5, 2001.**

**Cover and bottom left: This multi-spectral false color image of Tropical Storm Allison was taken on June 5, 2001. Tropical Storm Allison, the first named storm of the 2001 Atlantic Hurricane Season, devastated portions of Southeast Texas, including the Houston Metro area and surrounding communities, with severe flooding. Damage estimates in Harris County alone have surpassed \$4.88 billion.**

# Director's Message

Jim Lester

University of Houston–Clear Lake

**A**FTER THE TERRORIST ATTACKS on the World Trade Center and the Pentagon, priorities and approaches that seemed natural before seem stilted now. In this Director's Report, I will try to be simple and brief. The cloud of terrorism and war casts its shadow even over the pride I feel in the achievements of EIH.

First, I commend the good work of the principal investigators and EIH staff described in these reports for your perusal. This report summarizes a lot of good work by very talented people.

Second, two issues exemplify the current environmental "climate" of the Houston region: air quality and land use. Air quality efforts are benefiting from the output of last summer's Texas Air Quality Study (TEXAQS). One conclusion is that emissions of reactive hydrocarbons from industry play a large role in the high ozone events typical of the Houston region. The UH Air Quality Modeling team is working closely with other researchers and the regulatory agencies to quickly improve the science on which air pollution policy is based.

Tropical Storm Allison flooded the UH campus and many neighborhoods and roads around the region. The damage to research at UH and the Texas Medical Center was great and the hardship on many families was terrible. However, we must realize that this is not a flooding problem, it is a development problem.



Photo courtesy of Billy Underwood

The weather is not to blame for the damage, the location and design of structures is. Houston is not designed or operated to be compatible with the weather of the wet subtropics and the flat topography of the coastal plain. This problem could be minimized through land use planning and appropriate building codes.

Third, EIH has organized a public participation and outreach program that recognizes our obligation to facilitate discussions of environmental issues and empower people to participate in them. Quite a few faculty already share their knowledge and time with the community. EIH has dedicated some resources to help community groups develop their environmental and organizational expertise. We are always open to suggestions and partnership opportunities.

**Tropical Storm Allison turned University parking lots into temporary lakes (above). Many buildings on the UH campus were damaged by floodwater.**

Finally, I return to the topic of the year, our response to terrorism. The United States faces a challenge to its security and its role in the world, which has captured and focused the attention of experts in political science, military operations, law enforcement, foreign affairs, etc. But I can not shed my environmental perspective and focus on these as only political or military issues. When I summarize the big events of the year, it boils down to a repetitive list.

- Destruction of the World Trade Center, four jetliners, and part of the Pentagon...loss of life and environmental degradation
- Bioterrorism assaults with anthrax...loss of life and environmental degradation
- Bombing of Afghanistan...loss of life and environmental degradation
- Houston industrial pollution...loss of life and environmental degradation
- Flooding from Allison...loss of life and environmental degradation

So I ask myself whether a safe, clean, sustainable world is a pipe dream or a worthy goal. I believe in the latter, but how long will it take?

Many of the world's people see American military, commercial and cultural power as one. That combination of powers has sometimes been used in ways that are not benign for other cultures or the environment. What we need is a plan to use our power to spread democracy and education, not sitcoms and consumption. If we do not reduce ignorance and authoritarianism, people and the environment will continue to suffer.

One key to sustaining environmental quality is a democratic process. A cornerstone of strong democracy is an educated citizenry. An educated citizenry is also a path to sustainability. If we export the processes of democracy and education to more places,

the world will be less threatened by violence and environmental degradation. That seems to be America's plan. I hope the implementation comes soon enough for the environment and us.



Photo courtesy of Cynthia Dickey

**A United States flag flies over the World Trade Center ruins.**

# Cyanide Remediation Using Microbial Enzymes

Michael Benedik and Dakshina Jandhyala  
University of Houston

THE GOALS of this study were to complete the cloning of the genes for a variety of cyanide hydrolytic enzymes, establishing high level expression systems for them, and to carry out the biochemical characterization of the enzymes. Each candidate would then be screened for ease of production (*i.e.*, low projected cost), resistance to inhibition by common metal-cyanide complexes often found in mixed industrial wastes, and stability. Lastly, the research team hoped to demonstrate that cyanide degrading enzymes have evolved from a related enzyme, bacterial nitrilases, with whom they share significant sequence homology and which carries out a similar nitrogen chemistry reaction. The team planned to clone and express bacterial nitrilase genes from related organisms, and employing laboratory selections, to establish methods to evolve one of these nitrilases into a cyanide degrading enzyme.

*Gene Cloning.* Previously, the genes from the fungus *Gloeocercospora sorghi* and from the bacterium *Pseudomonas stutzeri* were cloned using PCR methods and designing amplification primers from the published sequences. Also cloned was the previously uncharacterized gene from *Bacillus pumilus* strain C-1 which had been a major goal of the team. The approach taken to cloning was quite complex, based on using primers designed from the *P. stutzeri* sequence and inverse PCR approaches to get increasingly larger fragments. Finally, the entire gene was cloned and its DNA sequence determined. At the DNA level, the *Bacillus* sequence is quite different from the *P. stutzeri* sequence (less than 70 percent identity), but at the amino acid level they are quite homologous (greater than 88 percent identical).

The genes for two related nitrilases, which do not act on cyanide but perform similar carbon nitrogen chemistry on related compounds, have also been cloned. These will be used as sources of domains in evolution experiments. The genes from *Synechocystis* nitrilase and also a *Bacillus* OxB-1 nitrilase have been cloned, one by PCR and the other by gene synthesis approaches.

*Expression.* All three of the cyanidase genes have been cloned into a pET26b expression vector and high level expression of active and soluble protein has been achieved. Cloning has been done for each to generate native enzyme or enzyme carrying a 6-His purification tag.

*Protein Purification and biochemical characterization.* The tagged as well as the native enzyme have all been purified to homogeneity and have similar kinetic properties. No effect of the His tag on activity can be detected. As demonstrated, the enzyme is stable for up to 24 hours. Over that time period, enzymes at the concentration of 0.5mg/ml can degrade 14mM of cyanide, a molar ratio of more than 800,000. Using rough cost estimates for production of recombinant enzymes, this suggests that less than five cents worth of enzyme can remediate a liter of wastewater contaminated at 1000 ppm of cyanide.

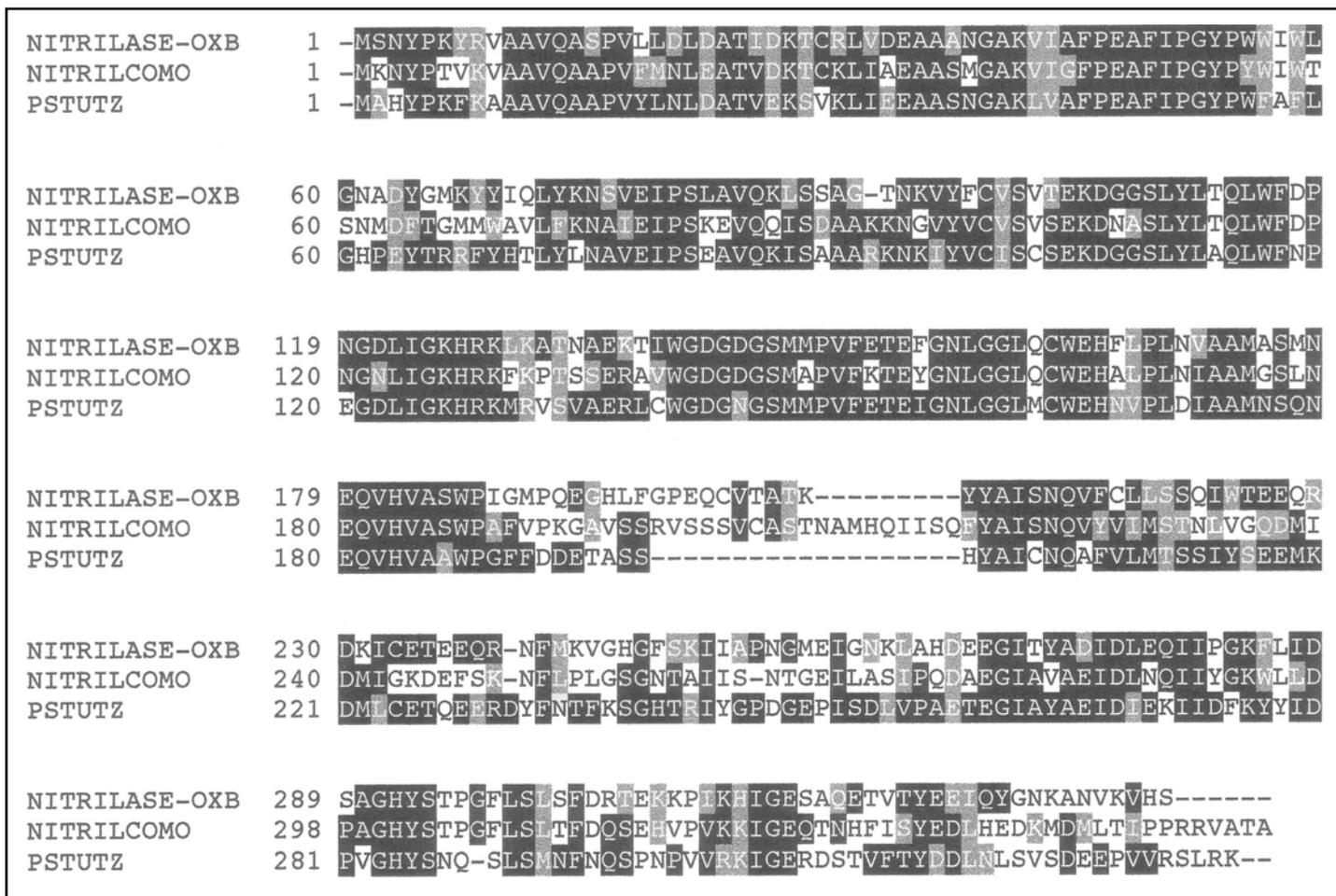
*Evolution of a cyanidase.* Growth conditions for the selection of cyanide tolerance was investigated first. Using growth medium requiring respiratory growth (cyanide inhibits respiration enzymes but not fermentation enzymes) identified conditions where expression of cyanidase were beneficial to bacterial growth. A long term selection experiment using a nitrilase to ascertain whether selected mutations of the nitrilase would convert it to a cyanidase was initiated. So far, the team has increased the ability of that strain to grow in the presence of cyanide by 10-fold. The strain at the molecular level has not been characterized.

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**Figure 1. Sequence alignment of the *P. stutzeri* cyanidase with two closely related nitrilases.**

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"Engineering of a Cyanide Dihydratase for the Detoxification of Cyanide Containing Waste Water," Gordon Conference on Applied and Environmental Microbiology; University of Houston Research Day.

"Alanine Racemase: A Target for Structure-Based Drug Design," Gordon Conference on Tuberculosis Drug Development.

#### **Funding**

"Genetic Engineering of Enzymatic Cyanide Clearance." Co-PI: R. Willson; Gulf Coast Hazardous Substance Research Center, Aug. 2000-May 2003, \$47,500/yr.

# Identification of Novel Genes Essential for Bacterial Survival During Environmental Biofouling

Steven R. Blanke and Rong Yang  
University of Houston

**B**IOFOULING results from the build-up of biotic communities on surfaces exposed to fresh and marine water. Biofouling costs marine industries over \$6.5 billion per year by damage and/or degradation to wells, pipes, ships, and other structures.

Biofouling is caused in part by the growth of bacteria on surfaces and the subsequent formation of communities of microorganisms called biofilms. Biofilms are formed to protect bacteria from environmental conditions that are detrimental to their growth and survival. As the various microbial biofilms form, they interact and consortial (community) biofilms form in which strains cooperate within a common biofilm. The biofilm continues to grow with many of the nutrients along with any other recalcitrant chemicals (*e.g.*, iron, manganese) that accumulate and are retained within the biofilms. Water quality can be ruined by a dramatic increase in chemical and particulate loading, leading to a significant capacity loss in wells and pipes. The extensive development of clog formations maturing towards dense amorphous or crystalline forms together with the “locking” of water within the porous media leads to a critical loss in the capacity to the point that it is no longer economical or desirable to keep the vessel on line. When total clogging occurs, the capacity often suddenly falls to the point of where the vessel is no longer usable.

Inhibiting bacteria from forming biofilms may be a powerful approach for preventing biofouling, however, the molecular mechanisms of bacterial biofilms are not well understood. This research focuses on a novel approach for identifying bacterial components that are essential for survival under conditions that promote biofilm formation. Not only will this research contribute to understanding the fundamental mechanisms of biofilm formation, but importantly, may reveal bacterial products that could be targets for reagents preventing biofilm formation.

The overall objective of this study was to identify bacterial gene products essential for bacterial survival under conditions

promoting biofilm formation. In particular, the team is adapting an approach called signature-tagged mutagenesis for important environmental problems.

The research team is using *Pseudomonas aeruginosa* as a model system for investigating biofilms. This ubiquitous bacterium is from a genus of bacteria that is widely found in the environment and is considered a major source of biofouling. *P. aeruginosa* is easily grown in the laboratory and has provided a readily tractable system for study. During the past year, a tagged mini-Tn5 transposon system with a kanamycin resistance gene has been genetically constructed. The mini-Tn5 transposon is readily introduced into *P. aeruginosa* to generate a library of randomly mutagenized strains. In addition, an experimental system for generating biofilms has been established within the laboratory. Pools of random mutants (Input Pool), each of which has been “tagged” with a unique “signature sequence” to allow for PCR amplification attached to the transposon, are exposed to conditions known to promote biofilm formation using our established experimental system. Those mutants that did not survive biofilm formation are identified by their absence in the recovery pool. Culturing these bacteria from the original input pool and sequencing the DNA sequences flanking the inserted transposon identify the mutagenized genes that are essential for survival of bacteria during biofilm formation.

This research represents a significant departure from current approaches for studying biofouling. Signature-tagged mutagenesis has been used successfully in bacterial pathogenesis to identify genes that are essential for bacterial survival within an alternative environment (within the host). These investigations represent the first attempts at using signature-tagged mutagenesis for identifying potentially complex arrays of gene responses in environmental conditions that promote biofilm formation.

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- Blanke, S. R. "How to Build a Host Cell Modulator: Intracellular Mechanisms of the *Helicobacter pylori* Vacuolating Cytotoxin," State University of New York at Buffalo, Department of Microbiology, Buffalo, NY, Oct. 20, 2000.

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## Funding

- "Adaptive Cardiac Connective Tissue Remodeling through Directed Delivery Into Cardiac Myofibroblast Cells." Consultant. PI: Daniel Martinez; American Heart Association, Jan. 1, 1999-Dec. 31, 2003, \$260,000.
- "Combinatorial Approaches to Probe Molecular Discrimination in Enzyme Catalysis." Welch Foundation, June 1, 1999-May 31, 2002, \$135,000.
- "Molecular Mechanisms of the *Helicobacter pylori* Vacuolating Toxin." National Institutes of Health, April 1, 2000-March 31, 2005, \$953,525.

# Photoionization of *N*-Alkylphenothiazines in Mesoporous Me-*A*/MCM-41 Materials Containing Transition Metal Ions Me = Ni(II), Fe(III) and Cu(II)

Larry Kevan and Sunsanee Sinlapadech  
University of Houston

PHOTOIONIZATION with net electron transfer has been a subject of much research. One interesting application involves light energy storage and conversion with minimal environmental pollution. In a photoredox system, the stored chemical energy of photoproducts serves as an energy source to drive chemical reactions. Back electron transfer must be minimized to achieve a net production of photoproducts. Several photoredox systems have been designed to improve the net energy conversion efficiency.

Generally, a photoredox system consists of a photosensitive electron donor and an electron acceptor to generate a pair of radical ions. It is desirable to extend the lifetime of the photoinduced radical ions to be able to utilize the stored energy before back electron transfer occurs. Net photoionization efficiency is enhanced in porous materials such as silica gels and zeolites by trapping the electron inside the porous materials.

Mobil scientists first synthesized MCM-41 mesoporous silica molecular sieves. MCM-41 materials have uniform pore sizes from 15 to 100 Å, which can be controlled during synthesis. Aluminum can substitute for some silicon in MCM-41 to form *A*/MCM-41, which has a negatively charged framework and net ion-exchange capacity. The structures of MCM-41 and *A*/MCM-41 are hexagonal as characterized by x-ray powder diffraction (XRD) and nitrogen adsorption techniques. One advantage of *A*/MCM-41 materials over siliceous MCM-41 is that they exhibit greater ion-exchange capacity and acidity.

MCM-41 and *A*/MCM-41 are effective catalysts for oxidation reactions and are promising host systems for photoredox reactions. Previous studies have shown that MCM-41 and *A*/MCM-41 can achieve long-lived photo-produced charge separation. Incorporation of reducible transition metal ions into silica and aluminosilica porous materials further impedes back electron transfer by acting as a more stable electron acceptor.

Transition metals such as titanium, manganese, copper or vanadium have been incorporated into either framework or extra framework (ion-exchange) sites of MCM-41. Titanium ion

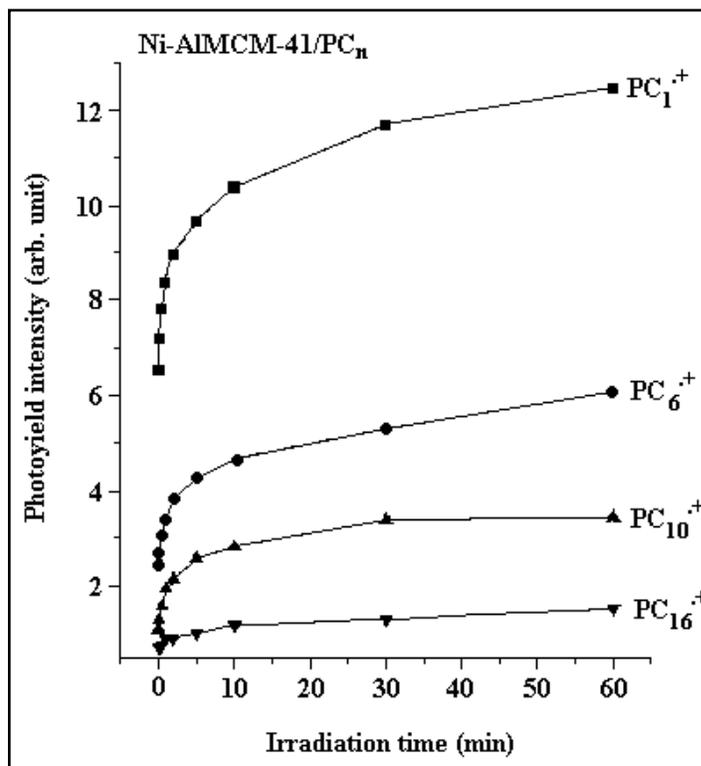


Figure 1. ESR intensity of  $PC_n^+$  in  $Ni-A/MCM-41/PC_n$  ( $n = 1, 6, 10$  or  $16$ ;  $Si/Ni = 99$ ) versus 320 nm irradiation time at room temperature.

[Ti(IV)] has been successfully incorporated into framework sites of MCM-41 and shows high photoionization efficiency for incorporated photoionizable molecules. However, photoionization of photoionizable molecules in *A*/MCM-41 ion-exchanged with different transition metal ions has not yet been studied.

In this work, *A*/MCM-41 with transition metal ions incorporat-

ed by ion exchange were prepared and denoted as Me-*Al*/MCM-41 [Me = Ni(II), Fe(III) or Cu(II)]. They are used as heterogeneous hosts for photoinduced electron transfer from *N*-alkylphenothiazines (PC<sub>*n*</sub>, *n* = 1, 6, 10 or 16 where *n* is the number of carbon atoms in the alkyl chain). The structures, pore sizes and surface areas of *Al*/MCM-41 with different amounts of *Al* were characterized by powder x-ray diffraction and N<sub>2</sub> adsorption before ion-exchanging with transition metal ions. The efficiency of photoionization of *N*-alkylphenothiazines incorporated into Me-*Al*/MCM-41 was monitored by electron spin resonance (ESR) and ultraviolet-visible diffuse reflectance spectroscopy. The experimental results show that the photoyields depend on the nature and the amount of metal ions in Me-*Al*/MCM-41 materials. The photoionization of *N*-alkylphenothiazines with different alkyl chain lengths was also studied and it was found that the alkyl chain length offers another dimension of control of the photoyield as shown in Fig. 1.

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“Mesoporous Materials.” Robert A. Welch Foundation, June 1, 1999-May 31, 2002, \$165,000.

“Photoinduced Charge Separation in Microheterogeneous Media.” Department of Energy, Feb. 15, 2000-Feb. 14, 2003, \$390,000.



Photo courtesy of Harris County Flood Control District

**Over 44,485 homes sustained flood damage, 3600 were completely destroyed and almost 11,000 received major damage totalling \$1.8 billion. Parkwood Estates (above), located in east-central Harris county, was inundated by water from Greens Bayou. Greens Bayou crested at 47.5’—15.9’ above the 100-year flood level. The Clear Creek second outlet gates were fully opened to facilitate the evacuation of flood waters (below).**

Source: Harris County Office of Emergency Management & Harris County Flood Control District



Photo courtesy of Harris County Flood Control District

**“Over 1 million people were simultaneously impacted by flash flooding.”**

Bill Read, National Weather Service

# Synthesis of Porous Materials with Environmental Significance

Jack Y. Lu and Amy M. Babb  
University of Houston-Clear Lake

NUMEROUS NEW POROUS MATERIALS that have great potential in environmental applications have been produced in Dr. Jack Lu's UHCL laboratory. Among the new materials synthesized last year, OMOF-1<sup>1</sup> has a remarkably stable spiral open-framework structure (Fig. 1). In addition to the zeolite-like structural features such as sturdy framework and porous channels with high stability, this novel spiral open-framework channel structure is even expandable. The inclusion polymers of this structure revealed that the spiral open-framework is highly stable in its original dimensions, capable of selective sorption, and expandable. The expandability along the spiral open channel direction is like a tension spring. The structure displays attractive reversible and selective-sorption capability. Thermal analysis revealed that the framework is stable up to 300°C.

$\{[Cu_2(IN)_4 \cdot 3H_2O] \cdot [Cu_2(IN)_4 \cdot 2H_2O]\} \cdot 3H_2O$  has an unprecedented interpenetrating structure with two covalent-bonded open-frameworks of different dimensionality (Fig. 2). The actual interlocked units between the three-dimensional and two-dimensional nets in the structure can be represented by Scheme 1 where each three-dimensional closed-circuit displaying a "table-frame" shape interlocked with four square grids of a two-dimensional sheet. In spite of the interpenetrating networks, a dozen of water molecules are included in a unit cell volume.<sup>2</sup>

$[Cu_3(N_2C_{12}H_{10})(IN)_6(H_2O)_2]^3$  is the first rational-designed triple-layer two-dimensional coordination polymer. This unprecedented two-dimensional triple-layer open-framework structure is stack-interlocked into a three-dimensional polymeric coordination network under hydrothermal conditions. The multiple-layer two-dimensional open-framework may have potential applications in many aspects such as molecular sorption and separation since it has attractive features, such as open channels in two-dimensional networks, from both three-dimensional and two-dimensional open-framework structures.

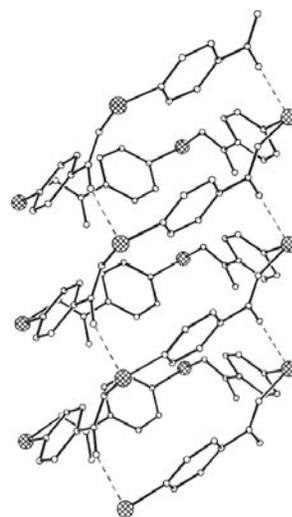


Figure 1. The spiral open channel structure of OMOF-1.

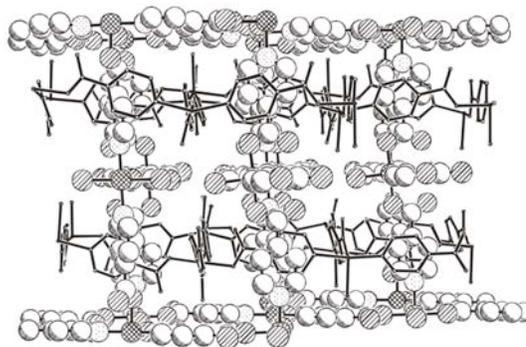
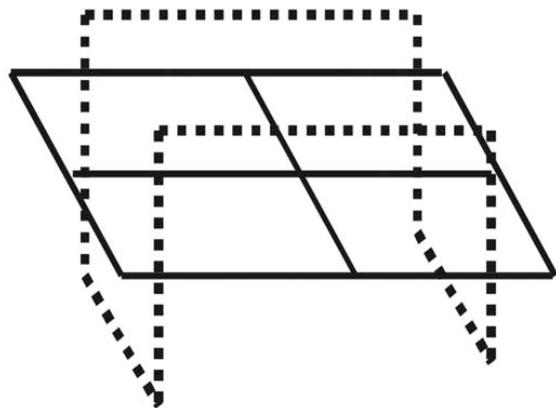


Figure 2. View of the interpenetrating structure with two covalent-bonded open-framework of different dimensionality in  $\{[Cu_2(IN)_4 \cdot 3H_2O] \cdot [Cu_2(IN)_4 \cdot 2H_2O]\} \cdot 3H_2O$ .



**Scheme 1.** A schematic representation of the inter-locked units in  $\{[Cu_2(IN)_4 \cdot 3H_2O] \cdot [Cu_2(IN)_4 \cdot 2H_2O]\} \cdot 3H_2O$ .

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Photo courtesy of Billy Underwood

**The University of Houston's Moody Towers residence hall (above) took in 10 feet of water. More than 120 students were relocated to Oberholtzer Hall.**

Source: Residential Life and Housing



Photo courtesy of Jon Schultz

**Damage to infrastructure including the medical center, water districts, colleges and universities, schools, roads, and bridges exceeded \$2.1 billion.<sup>†</sup> More than 90 of UH's 105 buildings suffered some damage from the storm. Electrical and phone systems were severely damaged throughout the campus. Some of the hardest hit buildings were the Law Center (above), the Fine Arts building, Wortham Theatre, the Conrad N. Hilton College of Hotel and Restaurant Management, and the University Center Satellite.<sup>\*\*</sup>**

Sources: <sup>†</sup>Harris County Office of Emergency Management

<sup>\*\*</sup>UHCN Campus News

# An Improved Process for the Elimination of Toxic Compounds in Landfill Gas

James Richardson and Mohammad Shafiei  
University of Houston

LANDFILLS are the most common means for disposal of municipal and industrial solid waste, with over 3,000 active landfills in the U.S.<sup>1</sup> Once considered benign, landfills are now recognized as a serious threat to human health and the environment since they generate landfill gas from the anaerobic decomposition of solid waste.<sup>2</sup> Typical emissions vary from 1-20 MMSCFD over the lifetime of the landfill (30-50 years). Although the major components of the gas ( $CH_4$  and  $CO_2$ ) can be utilized for energy, there are major concerns with up to 1000 ppmv of chlorinated hydrocarbons, principally chloro-substituted ethane and ethylene.

The purpose of this proposal was to explore the feasibility of using a novel process, developed at the University of Houston, to detoxify landfill gas. This process is based on catalytic steam reforming of hydrocarbons, which for trichloroethane, proceeds as follows:



In previous research, experiments on a wide range of chlorocarbons, such as aliphatic solvents, chlorinated aromatics, and PCB's were conducted.<sup>3-9</sup> The liquid chlorocarbon was vaporized, mixed with steam, and injected into a catalyst bed at space velocities from 5,000 to 500,000 hr<sup>-1</sup> and temperatures from 400 to 1000°C. Destruction levels of up to 6-nines were achieved, giving a product containing only  $H_2$ ,  $CO$ ,  $CO_2$  and  $HCl$ . The best catalyst was found to be 0.5wt% Pt/ $\gamma$ - $Al_2O_3$  but long-term tests revealed an irreversible deactivation resulting from the interaction between  $Pt$  and the support. This loss of performance made the catalyst unsuitable for industrial use.

The objectives were to (1) demonstrate the effectiveness of the process on a mixed feed of chlorocarbons similar to those found in landfill gas, (2) develop an improved catalyst with long-term

Table 1. Steam Reforming a Mixed Feed

Feed	
Chloroform	10.8
Carbon tetrachloride	25.1
1,1,2 trichloroethylene	2.2
1,1,2 trichloroethane	55.0
1,1,2,2 tetrachloroethane	7.0
Conditions	
700°C, GHSV = 10,000 h <sup>-1</sup> , $H_2O/C = 10$	
Product	
Conversion	0.99961
Carbon monoxide	0.168 C fraction
Carbon dioxide	0.832 C fraction

performance, and (3) design a process for landfill applications and conduct feasibility studies.

Table 1 demonstrates typical results with a mixed feed and verifies process is applicable to these conditions.

The key to establishing long life for the catalyst was to minimize carbon formation and chlorine adsorption on the support and to eliminate interactions between  $Pt$  metal and the support. Step-by-step research resulted in a successful catalyst, which is proprietary until patent protection is obtained by the University. The performance of this catalyst is shown in Fig. 1.

The catalyst exhibited no loss of activity or product composition for 35 days, when the test was terminated. Upon examination of the used catalyst bed, it was found that only 20 percent was slightly contaminated with carbon, implying the bed could operate for six months. This is within the limits for successful industrial implementation.

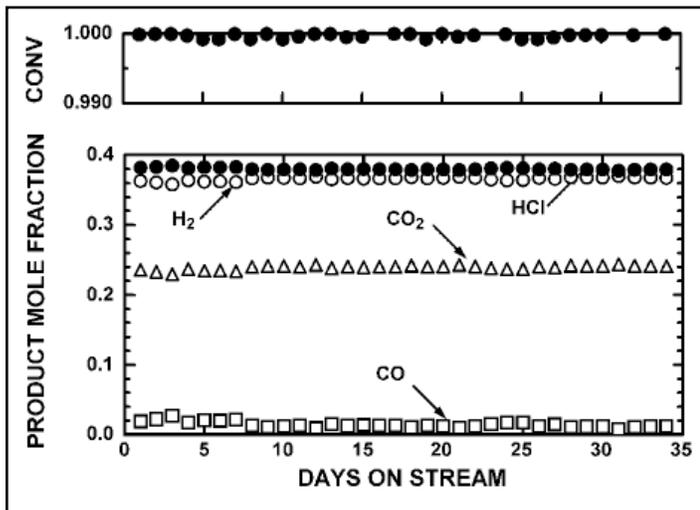


Figure 1. Long-term performance of 0.5wt% Pt on a proprietary support. Feed: trichloroethylene,  $H_2O/C = 10$ , GHSV = 8500 h<sup>-1</sup>.

A conceptual process for a landfill application is shown in Fig. 2. Preliminary calculations indicate the process can remove chlorinated hydrocarbons from landfill gas for \$0.25/lb C, less than competing technologies. The research team is currently exploring commercialization opportunities.

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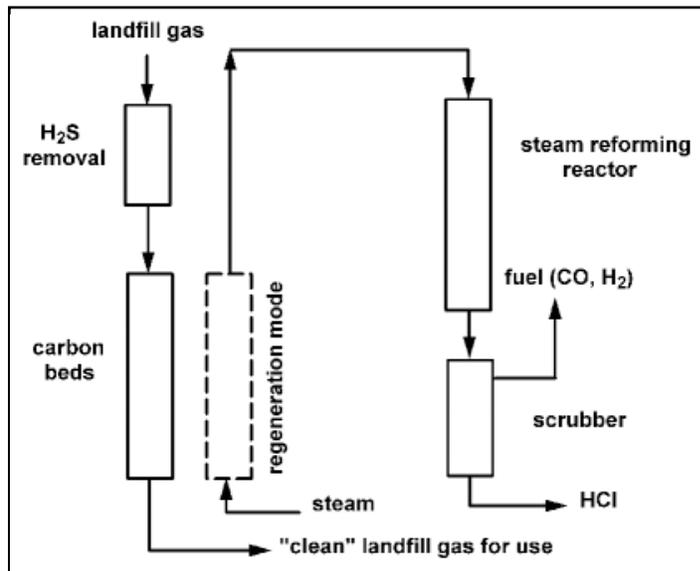


Figure 2. Conceptual process design for a landfill application.

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Photo by Debbie Bush

**300 billion gallons of water fell over Harris County—enough to fill the Astrodome more than 5600 times.**

Source: Frank Gutierrez, Harris County Office of Emergency Management

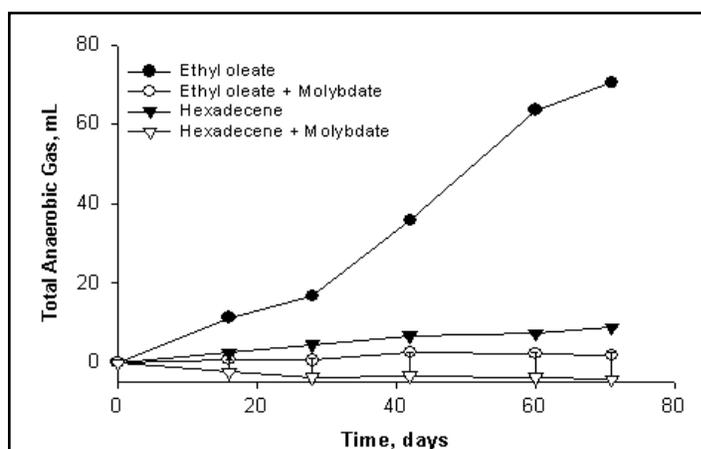
# Detecting the Biodegradation of Synthetic-Based Drilling Mud Fluids Using Cellular Fatty Acids Analysis of Microorganisms from Marine Sediment

Deborah J. Roberts and David C. Herman  
University of Houston

**S**YNTHETIC BASE FLUIDS (SBF) are a component of drilling fluids required in deep-sea drilling operations to cool and lubricate the drill bit, and to carry rock chips, or cuttings, to the surface. At the surface, most of the drilling fluid is recovered for reuse while rock cuttings contaminated with residual SBF are discharged into the marine environment. Recognizing the potential for environmental impact, the EPA has enacted regulations requiring all SBF used in the Gulf of Mexico to be certified as biodegradable.<sup>1</sup> In order to assess the environmental fate of SBF, it is critical to determine whether microorganisms indigenous to deep-sea sediment are capable of biodegrading SBF under ambient conditions. The goal of the current study was to investigate the applicability of total cellular fatty acid analysis to the evaluation of SBF biodegradation in marine sediment.

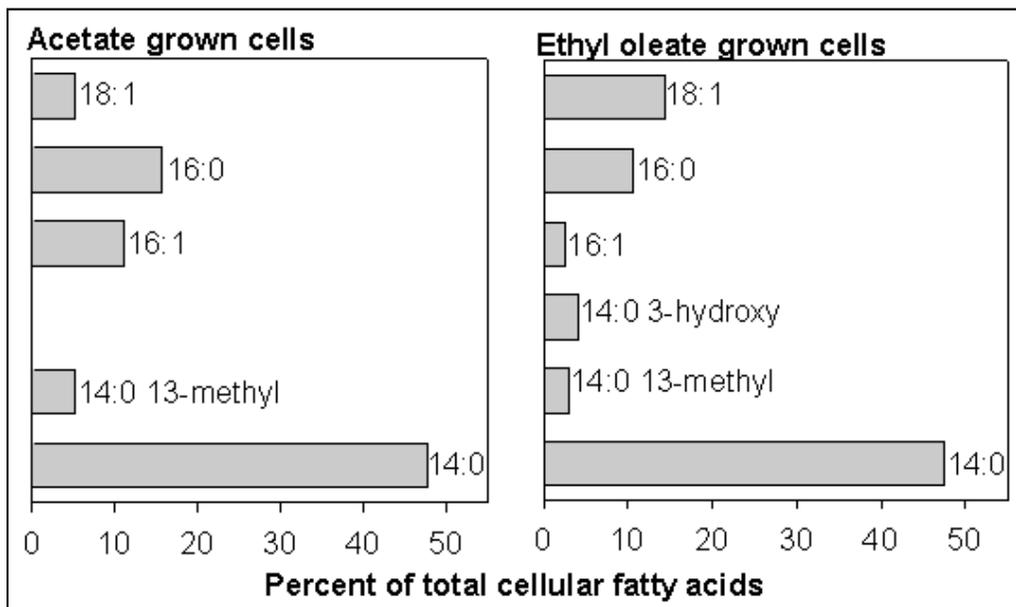
Sulfate reducing bacteria, which dominate anaerobic activity in marine sediment, are capable of biodegrading hydrocarbon substrates similar in composition to SBF.<sup>2-4</sup> The first objective was to determine if sulfate reducing bacteria were responsible for SBF biodegradation. A marine sediment was spiked with the surrogate SBF, ethyl oleate or hexadecene, in the presence or absence of a specific inhibitor of sulfate reducing activity, molybdate. The absence of anaerobic gas production in the presence of molybdate indicated the importance of sulfate reducing activity in the metabolism of SBF (Fig. 1). This study is continuing due to the long incubation period required for hexadecene biodegradation.

Microorganisms growing on hydrocarbon substrates can incorporate them directly into cellular fatty acids.<sup>5,6</sup> Therefore, the metabolism of SBF by sediment microorganisms may result in a cellular fatty acid composition that reflects the chemical structure of the substrate utilized. A distinctive cellular fatty acid profile from SBF-contaminated environments may provide an indication that the indigenous microorganisms are metabolizing SBF, thus removing them from the environment. A sulfate reducing mixed culture capable of growth on ethyl oleate was enriched from



**Figure 1. Anaerobic gas production from ethyl oleate- and 1-hexadecene-spiked marine sediment. Gas production in the spiked sediments is corrected for gas production in the control (non-spiked) sediments, and each point represents the mean ( $\pm$  standard deviation) of four replicate bottles.**

marine sediment. Total cellular fatty acid composition of ethyl oleate-grown cells was compared to acetate grown cells (Fig. 2). The relative abundance of six dominant fatty acids was similar, although there was an increase in octadecenoic acid (oleic acid) in the ethyl oleate-grown cells. Oleic acid is a product of ethyl oleate hydrolysis, and therefore, oleic acid would be readily available to the ethyl oleate grown cells. Attempts to establish an enrichment culture for hexadecene biodegradation is still in progress. This work will continue to investigate whether cellular fatty acid analysis can provide a unique signature for the identification of SBF metabolism in marine sediment.



**Figure 2. Total cellular fatty acid profiles of a sulfate reducing bacterial culture grown on acetate (1000 mg/L) or ethyl oleate (218 mg/L). Fatty acids identified were tetradecanoic acid (14:0), 13-methyl tetradecanoic acid, 3-hydroxyl tetradecanoic acid, hexadecenoic acid (16:1), hexadecanoic acid (16:0), and octadecenoic acid (18:1).**

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#### Funding

- "Biodegradation of Synthetic Based Drilling Muds in Marine Sediments." Gulf Coast Hazardous Substance Research Center, Aug. 2000, \$237,237; *submitted*.
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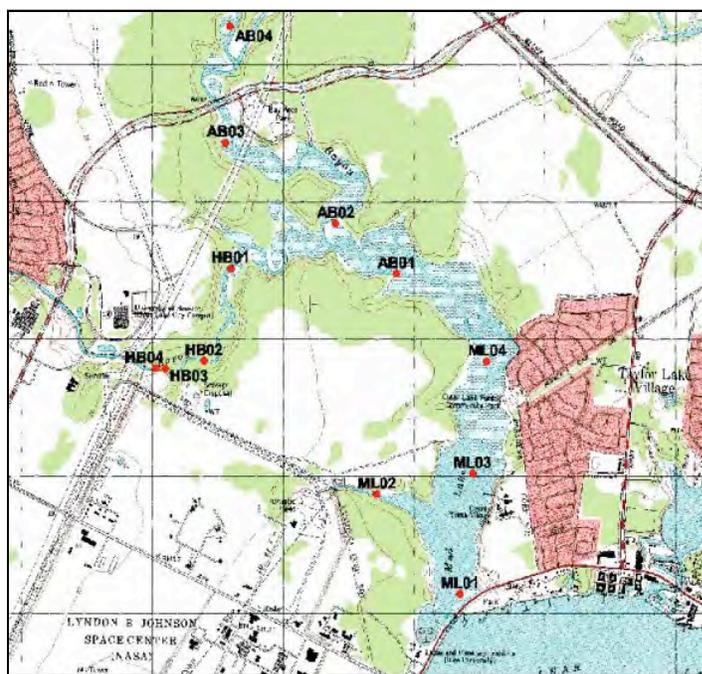
# Sediment Quality Triad Comparison of Armand Bayou, Horsepen Bayou, and Mud Lake, Harris County, Texas

Cynthia Howard and Charles Dingman  
University of Houston-Clear Lake

MANY CONTAMINANTS entering estuarine waters bind with salts or organic matter in the water column and are eventually deposited in the sediments. The Sediment Quality Triad (SQT) approach was developed by Peter Chapman<sup>1</sup> to evaluate the degree to which contaminants are responsible for the degradation of sediment health. The SQT approach is an effects-based technique that involves three components: sediment chemistry (measures of contamination), sediment toxicity testing (measures of biological effects and bioavailability), and *in situ* community parameters (benthic macroinvertebrate community structure).<sup>2</sup> The purpose of this project is to evaluate and compare the ecosystem health of Armand Bayou (a designated Coastal Preserve), Horsepen Bayou, and Mud Lake, using a modified SQT approach, and link these results to the current TMDLs (Total Maximum Daily Load criteria) and sediment quality guidelines for this area.

Twelve stations, four each along the reaches of Armand Bayou, Horsepen Bayou, and Mud Lake (Fig. 1), were established and have been sampled on three occasions. Samples were collected for the sediment chemistry component of the SQT using EPA standard protocols for heavy metals, total organic carbon, acid volatile sulfide, total PAHs, organochlorine pesticides, and PCBs. Additional sediment samples were collected for ten-day *Hyalloa azteca* amphipod and seven-day *Lumbriculus variegatus* oligochaete toxicity tests and for benthic macroinvertebrate community analysis.

Analyses for the SQT comparison completed to date are shown in Table 1. The data for the 12 stations are currently being analyzed using station parameter ranking, ratio-to-reference (RTR) and tabular decision matrix approaches.<sup>3</sup> Initial results indicate that the three water bodies are in relatively good ecological health, but are influenced by anthropogenic contaminants. Preliminary station parameter ranks for selected benthic community, toxicity and sediment chemistry parameters indicate that Horsepen Bayou is the least degraded and Mud Lake is the most



**Figure 1. Location of SQT sampling stations on Armand Bayou, Horsepen Bayou and Mud Lake.**

degraded of the three systems studied (Table 2). The final data sets will be evaluated using canonical correspondence analysis.

Initial results of the SQT sediment chemistry, toxicity, and biological community data were presented at the 21st Annual Meeting of the Society of Environmental Toxicology and Chemistry (SETAC) in Nashville, TN in November, 2000 and at the 5th State of the Bay Symposium in Galveston, Texas in January, 2001. Additional results were presented at the SETAC South Central Regional Chapter meeting in Stillwater, OK in

**Table 1. List of Sediment Quality Triad component analyses completed for SQT comparison of Armand Bayou, Horsepen Bayou, and Mud Lake.**

<u>SQT Component</u>	<u>Analysis</u>
Benthic community	Benthic macroinvertebrate abundance Benthic macroinvertebrate species richness Shannon Wiener species diversity Pielou evenness Horn's community comparison index
Toxicity	<i>Hyalella azteca</i> survival <i>Lumbriculus variegatus</i> survival and growth <i>Lumbriculus variegatus</i> reproduction Toxtrak® (Hach Co.) bacterial toxicity test
Sediment chemistry	Heavy metals (As, Cd, Cu, Cr, Ni, Pb, Zn ) by ICP Mercury by flow injection atomic absorption spectroscopy Acid volatile sulfide and simultaneously extracted metals Total and volatile solids Total organic carbon Pesticides by gas chromatography - mass spectroscopy PCBs by gas chromatography - mass spectroscopy Sediment particle size distribution



**Chuck Dingman, Environmental Science graduate student, conducts a mercury analysis on Armand Bayou sediments using the flow injection mercury system in the UHCL School of Natural and Applied Sciences.**

**Table 2. Relative rank scores for initial Sediment Quality Triad comparison analyses for Armand Bayou, Horsepen Bayou, and Mud Lake. Scores range from one (most degraded) to 12 (least degraded) according to each type of analysis. Overall rank score determined from sum of individual rank scores.**

System	Station Number	BENTHIC COMMUNITY				TOXICITY		SEDIMENT CHEMISTRY							Overall Rank Score
		Richness	Abundance	Diversity	Evenness	<i>Lumbriculus</i> Reproduction	<i>Lumbriculus</i> Biomass	As	Cd	Cu	Cr	Pb	Ni	Zn	
Armand Bayou	01	9	12	4	1	5	1	9	8	9	8	8	8	10	7
	02	5	8	8	12	3	8	9	7	7	7	7	5	6	7
	03	2	9	6	7	10	7	7	6	7	6	6	5	7	6
	04	5	3	7	8	7	3	8	4	6	2	5	4	3	5
Horsepen Bayou	01	12	4	12	4	1	11	12	12	12	12	12	12	12	12
	02	10	1	11	10	8	9	4	10	11	11	10	10	11	11
	03	8	2	9	11	12	12	5	11	3	9	11	10	8	10
	04	10	5	10	5	9	10	3	9	9	10	9	9	9	9
Mud Lake	01	2	6	2	9	1	2	11	1	2	1	4	1	1	1
	02	5	7	5	2	11	5	6	5	1	5	1	5	4	4
	03	1	10	3	3	4	6	1	2	5	4	3	1	2	2
	04	2	11	1	6	5	3	2	2	3	3	2	3	5	3

May, 2001, and the final project was presented at the SETAC 22nd Annual Meeting in Baltimore, MD in November, 2001.

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# Membrane Reactor for Synthesis Gas Production

Dan Luss, Hao Song, and Bharat M. Marwaha  
University of Houston-Clear Lake

THE LARGE AMOUNT OF AVAILABLE NATURAL GAS (mostly  $CH_4$ ) has generated considerable interest to converting it to valuable liquid chemicals and fuels. Among other economic advantages, such technologies would enable direct conversion of the vast amounts of remote deposits or stranded natural gas into transportable liquid hydrocarbons. Unfortunately, no commercial processes exist for direct conversion of natural gas to liquid hydrocarbons. This transformation may however be accomplished by an indirect route, *i.e.*, converting the natural gas first to synthesis gas (syngas), a mixture of  $CO$  and  $H_2$ , which can then be transformed into a wide range of fuels and chemicals by existing commercial processes, such as Fischer-Tropsch and methanol synthesis. The existing commercial processes of steam reforming and/or partial oxidation are old and capital intensive. Significant industrial and academic research attempts to develop more economical processes for syngas production. The success of these efforts will benefit Texas, where many of the companies serving the natural gas industry are located. The research team has developed a novel rugged membrane reactor for synthesis gas production.  $La_{0.5}Sr_{0.5}Ga_{0.2}Fe_{0.8}O_{3-d}$  made by SHS as the membrane material is used. The main problems associated with such a reactor is to provide a high selective flux of oxygen and at the same time to have a membrane which remains stable under the severe operating conditions. The team has been successful in developing a membrane which provides the highest oxygen flux among all those which remain stable. The team has developed a deposition procedure for producing a 150 mm thin film on a porous  $\alpha$ -alumina substrate. The thin film was dense and fairly uniform. This tube was glued to two non-porous  $\alpha$ -alumina tubes and placed in a quartz tube. The annular space was filled with a 0.1% Rhodium on alumina catalyst. By introducing methane into the annular space and air into the tube (the feed consisted of two moles methane for each mole of oxygen) at temperatures in the range of 650-850°C, the team obtained a 97 percent conversion of the methane and a 0.99 selectivity to  $CO$  and a  $H_2/CO$  ratio of 1.5:1.

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# Spatial and Temporal Variation in the Diversity of Phage at the University of Houston Coastal Center

Michael Travisano and Robert P. Goldman  
University of Houston

**B**ACTERIA play critical roles in ecosystem structure and function. Bacteria are found in virtually all environmental conditions and there are an estimated 1012 bacterial species on earth.<sup>1</sup> Not only are bacteria the most diverse and numerous organisms, they also make up the majority of biomass on Earth. Factors affecting microbial survival can have profound effects on ecosystems, given that changes in nutrient fluxes in microbial communities will have an impact on higher trophic levels.

Until recently, the impact of bacteriophage (bacterial viruses) on microbial communities has not been given much consideration, even though predation is believed to be important in structuring and maintaining diversity in metazoans.<sup>2</sup> Phage have been commonly thought to be minor components of microbial communities, having only negligible effects on bacterial populations. Early results in bacteriophage ecology in the laboratory<sup>3,4</sup> and the field<sup>5</sup> indicated that phage might only be responsible for a small fraction of bacterial mortality and, hence, not be a major factor in bacterial evolution and community structure. However, recent work has demonstrated that phage exceed the number of bacteria in some environments by an order of magnitude or more.<sup>6-8</sup> Moreover, studies in marine ecosystems have demonstrated that phage are probably responsible for 20-50 percent of bacterial mortality and are important in shaping microbial communities.<sup>6,9</sup>

In aquatic ecosystems, lysis of bacteria by phage allows for faster turnover rates of nutrients. Grazing of bacteria by eukaryotic predators sends organic material upward in the food chain and sequesters it for an unknown period of time from the bacterial community. It has been proposed that bacterial lysis by phage shunts organic material back into the lower trophic levels in the form of dissolved organic matter (DOM) and increases overall net productivity of the bacterial community.<sup>6,9</sup>

While there is evidence of phage-mediated nutrient cycling occurring in marine ecosystems, terrestrial bacteria-phage interactions are far less well understood. Terrestrial ecosystems differ

**Table 1. Host bacterial species used to isolate bacteriophage.**

<i>Bacillus cereus</i>	<i>Proteus mirabilis</i>
<i>Bacillus coagulans</i>	<i>Pseudomonas aeruginosa</i>
<i>Bacillus megaterium</i>	<i>Pseudomonas fluorescens</i>
<i>Bacillus subtilis</i>	<i>Pseudomonas putida</i>
<i>Escherichia coli B</i>	<i>Rhizobium leguminosarium</i>
<i>Escherichia coli C</i>	<i>Salmonella typhimurium</i>
<i>Escherichia coli K-12</i>	<i>Serratia liquafaciens</i>
<i>Klebsiella pneumoniae</i>	<i>Serratia marcescens</i>
<i>Micrococcus luteus</i>	<i>Staphylococcus aureus</i>
<i>Micrococcus roseus</i>	<i>Vibrio cholera</i>

markedly from marine and the role of bacteriophage in structuring bacterial communities is unclear. It has been estimated that a few grams of soil contain anywhere from 13,000<sup>10</sup> to 500,000<sup>1</sup> species of bacteria, which might support equally rich assemblages of bacteriophage. It is likely that soil phage are important in nutrient cycling in at least some soil communities. For example, lysis of nitrogen fixing bacteria might have large effects on their plant hosts.

To determine the effect phage might have on soil microbial communities, samples were taken from sites throughout the University of Houston Coastal Center. Sampling included both the native prairie and woodlands composed of invasive species. Sampling was done at least once a month and samples were processed either through a direct screening procedure or through an enrichment process.<sup>11</sup> Since phage are typically specific for one species (or even strain) of bacterium, it was necessary to screen against a wide range of bacterial species, and the research team used twenty host bacterial strains (Table 1). Two different phage were isolated from the drainage ditch that runs through the Coastal Center during May. They were isolated using enrichment on the host *E. coli C*, and no phage were isolated on any other of

the nineteen hosts. There are several possibilities for the lack of phage in our sampling. 1) There are very few phage in the soil and they are not important components of the microbial community in that environment. 2) Appropriate host bacteria may not have been used, and using more or different species will lead to success. For instance, *Streptomyces* and *Myxococcus* species are major groups of soil bacteria<sup>12</sup> and these were not used. These strains have been obtained for future work. 3) Soil phage may primarily be lysogenic. Lysogenic phage incorporate into the bacterial chromosome and are replicated during cell division without apparent harm to the host. Only under adverse conditions do these phage switch to the lytic cycle and replicate by killing their host. Another approach that may be taken in the future is to expose cells to UV radiation in an attempt to get the “dormant” phage to switch to lytic mode. 4) It is also possible that phage are adhering to soil particles and becoming inactivated.<sup>11</sup> It is not clear how to avoid this problem other than sampling from soils that are water saturated (after a rain) and presumably contain actively replicating bacteria and their phage. Future work may include sampling during or shortly after a storm.

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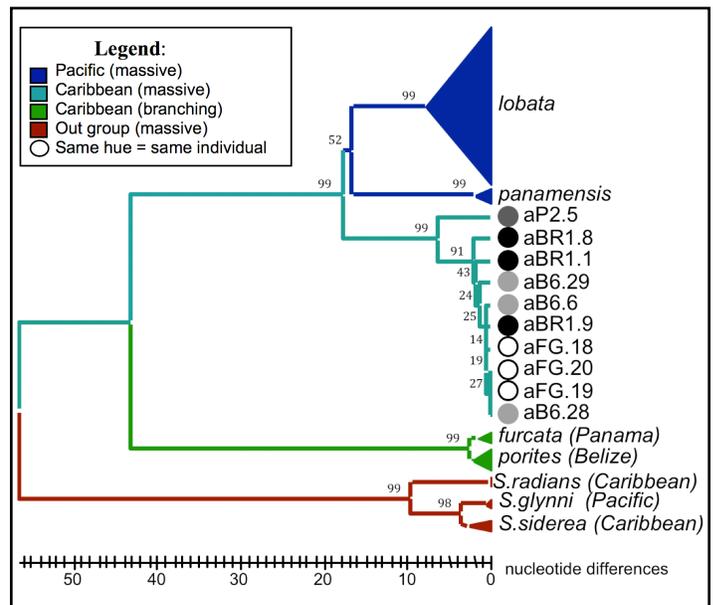
# Ribosomal DNA Variation in *Porites* spp.; The Relationship between the Texas Flower Garden Banks National Marine Sanctuary and the Caribbean Province

Gerard M. Wellington and Zac Forsman  
University of Houston

RESEARCHERS are examining the geographic variability of the nuclear ribosomal Internally Transcribed Spacers (*nrITS*) of the two species of *Porites* that occur in the Texas Flower Garden Banks National Marine Sanctuary (FGBNMS); the commonly occurring *P. astreoides* and the rare *P. furcata*. The research team is cloning and sequencing individuals from the East and West Banks, Florida, Dry Tortugas, the Bahamas, Bermuda, Belize, and Panama. An evaluation of the potential long-term effects of chronic disturbance, or global change, requires an understanding of population dynamics. Little is known about the relationship of the Texas Gulf Coast corals to the greater Caribbean province. If FGBNMS is an isolated population, it is less likely to recover from disturbance. This information is particularly germane to the Gulf of Mexico, given the heavy industrial usage in the form of transportation and processing of hydrocarbons in close proximity to the National Marine Sanctuary. The data derived from this study will also be combined with a Pacific data set, providing a rare opportunity to calibrate rates of molecular divergence with the well documented closure of the American Seaway 3 mya. *Porites* is the most commonly occurring genus present on both sides of the Isthmus. The rate calibration will be independently verified using a closely related genus (*Siderastrea*), that is also present on both sides of the Isthmus.

Although sequencing of molecular clones from the tissue collection has just begun, preliminary data indicates that there are geographic patterns. The molecular clones from a Flower Gardens individual are on average slightly more similar to those from an individual in Belize than to an individual from Brazil (see Fig. 1). Interestingly, the *P. astreoides* molecular clone from a Panama individual is quite different from all other *P. astreoides* molecular clones, and slightly more similar to Pacific species. In the Pacific, a similar geographic pattern is evident in the endemic *P. panamensis*; although it is morphometrically similar to *P. lobata*, it is genetically as similar to *P. astreoides* in the

Caribbean. Geographic patterns consistent with isolation by distance are also evident in *P. lobata* (data not shown). These striking geographic patterns warrant further investigation in order to correctly interpret population relationships.



**Figure 1.** UPGMA cladogram of *nrITS* of *Porites* species. Values above nodes indicate bootstrap values, triangle width is proportional the number of taxa sampled, triangle depth is proportional to the variability within a species. The three letter code refers to individual *P. astreoides* molecular clones. For example, aFG.18 was collected from The Texas Flower Gardens National Marine Sanctuary, molecular clone number 18 (B=Belize, P=Panama, BR=Brazil). The scale at the bottom indicates number of nucleotide differences.

# A Flexible Porous Wave Barrier for Enhanced Wetlands Habitat Restoration

Ken-Han Wang and A. Neil Williams  
University of Houston

LIVING MARINE RESOURCES located along the Texas coast constitute valuable and renewable resources that contribute to the food supply, economy, welfare, health, and recreational opportunities of the state. However, it is recognized that one of the greatest long-term threats to the viability of commercial and recreational fisheries is the continuing loss of marine, estuarine, and other aquatic habitats. One critical habitat for many fishery species and the fauna on which they prey are coastal wetlands. This habitat is under constant threat. Galveston Bay has lost more than 30,000 acres of coastal wetlands and seagrass meadows during the last four decades.<sup>1</sup>

The Galveston Bay wetlands habitats consist of salt, brackish, and freshwater marshes. Low salt marshes, like those found on the bay side of Galveston Island, are dominated by smooth cordgrass. They are greatly influenced by tides and are typically flooded and exposed once a day. These areas may also be exposed to significant wave action. Brackish marshes occur on somewhat higher ground, where salinity is lower and inundation less frequent. These marshes, which are found on the north side of East and West Bays, consist of marshlay, saltmarsh bulrush, and Gulf cordgrass. Again, these marshes may experience wave action during severe weather events. Freshwater marshes occur further inland or in the estuary where rainfall or river flow is too great to prevent regular intrusion by salt water. One of the main causes of marsh loss in Galveston Bay is erosion, and the primary method of habitat restoration for salt and brackish marshes involves replenishing the area with dredged sand followed by the introduction of cordgrass seedlings. Although the planting of these seedlings is a time-consuming, labor-intensive task, considerable success in wetlands habitat restoration can be achieved as the plants mature and fill-in the targeted area. However, not all projects of this type are successful, there is a critical period after planting (on the order of several months) during which the seedlings are vulnerable to wave action. Severe weather during

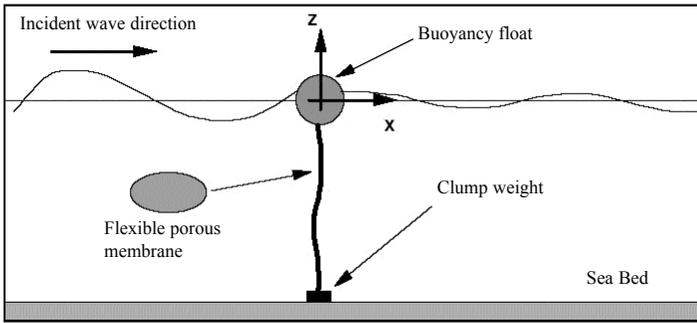
this time-frame can lead to the uprooting of the seedlings and the dispersal of the sand materials. After this time, as the plants grow stronger and more plentiful, and develop more extensive root systems, the risk of the wave-induced destruction of the new marsh decreases. Improved efficiency can be achieved in the wetlands restoration process by protecting the cordgrass seedlings from wave action by using a type of wave barrier during the initial months after planting.

## Proposed Wave Barrier

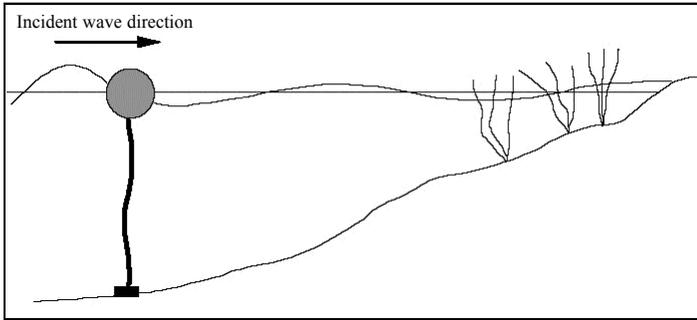
There are several types of wave barrier that can be used to provide temporary protection from wave action in the semi-protected coastal regions where wetlands are typically located. As well as being an effective wave barrier in the short-to-mid wavelength region, there are additional constraints to be considered in the present application: it must be a low-cost, zero-maintenance structure; it must be rapidly deployable with a minimum of specialized equipment; and it must allow water containing nutrients to circulate between its shoreward and seaward sides. The proposed wave barrier is shown in Fig. 1. It consists of a thin, flexible porous structure anchored to the seabed by a clump weight and kept under tension by a buoyant cylindrical float.

This structure satisfies all the conditions stated above (Fig. 2). It is anticipated that the membrane material will be of a fine mesh type similar to a screen door—readily available at low cost. This mesh structure will allow water containing nutrients to pass through the wave barrier. Deployment of the barrier can take place using a small boat with no specialized equipment or trained personnel.

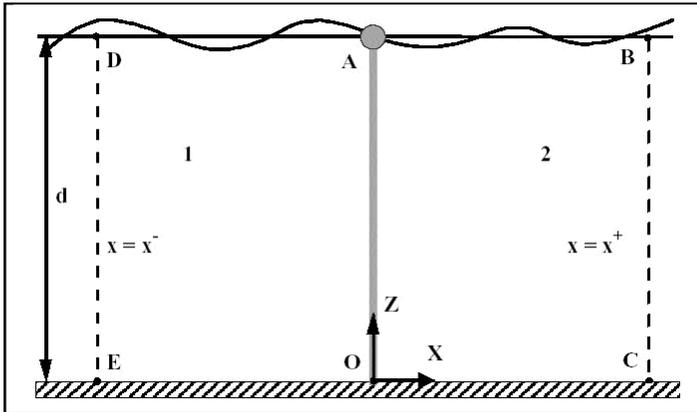
There have been several previous investigations, both theoretical and experimental, of flexible wave barriers. Sawaragi *et al.*<sup>2</sup> carried out a series of laboratory experiments to study the tensions on moored, floating membrane structures designed to act as silt curtains. Both wave and current loading on the structures was



**Figure 1. Schematic of Flexible Floating Wave Barrier (shown with zero buoy displacement)**



**Figure 2. Flexible Porous Wave Barrier Shown Protecting Cordgrass Seedlings during Habitat Restoration**



**Figure 3. Definition Sketch**

investigated. A theoretical solution for a bottom-mounted, submerged, membrane structure in waves was provided by Aoki *et al.*<sup>3</sup> The solution method for the membrane motions was based on the boundary element technique, using an appropriate Green function. Thompson *et al.*<sup>4</sup> presented an analytical solution for the dynamic response of a bottom-mounted, surface-piercing, flexible membrane wave barrier. The analytical estimates of wave transmission and structural response were compared with those obtained from laboratory experiments, both moored and unmoored configurations were tested.

Williams *et al.*<sup>5,6</sup> investigated a flexible wave barrier consisting of a compliant, beam-like structure, anchored to the sea bed and kept under tension by a small buoyancy chamber at the tip. Additional stiffness was provided by mooring lines attached to the buoyancy chamber. This type of structure provides an easily

deployable and relatively inexpensive wave barrier. Since, in certain circumstances it is desirable that a gap exists between the top of the breakwater and the ocean surface (for example, to allow for the passage of shallow draft marine craft), both submerged structures and structures which extended over the entire water column were studied. Over the course of these combined theoretical and experimental studies it was found that, for a given set of wave and structural characteristics, the bottom-founded structure was a more efficient wave barrier than its submerged counterpart. In fact, for the submerged barrier case, a relatively stiff structure was required to achieve acceptable wave reflection. Similar studies on moored flexible membrane structures, both surface-piercing and submerged, have been carried out by Kim and Kee.<sup>7,8</sup>

In a related study, Williams<sup>9</sup> studied wave reflection by a pair of flexible, floating barriers of the type discussed above was investigated. For simplicity, the structures were taken to extend over the full water column. It was demonstrated that by selecting an appropriate spacing between the barriers, acceptable wave reflection may be obtained even with relatively flexible structures. Wave reflection by a pair of flexible breakwaters was also considered by Abul-Azm.<sup>10</sup>

However, the use of bottom-founded, surface-piercing structure(s) may inhibit the exchange of water between the fluid regions either side of the barrier and, in certain situations, this exchange is essential to maintain water quality and/or to allow nutrients to flow into the protected area. One alternative, considered by Williams,<sup>11</sup> is to consider a surface-piercing, flexible structure similar to that discussed above but to limit the vertical extent of the membrane so that fluid exchange is permitted beneath the barrier. In this case, tension in the membrane is maintained by a clump weight at its free end. Another alternative, considered by Wang and Ren<sup>12</sup> is to maintain the bottom-founded, surface-piercing structural geometry (which has several advantages, for example it is much easier to anchor) but to make the membrane semi-permeable or porous in order to ensure water quality in, and enable nutrient flow to, the protected region. The flow through the thin porous flexible structure is assumed to obey Darcys' law, an approach that has been successfully applied to rigid thin-walled porous structures by several authors.<sup>13-15</sup>

### Theoretical Development

The geometry of the problem is shown in Fig. 3. The system is idealized as two-dimensional, Cartesian coordinates are employed, the breakwater is situated in at  $x = 0$  and the  $z$ -axis is directed vertically upwards from an origin on the sea-bed. The water is taken to be of uniform depth  $d$ .

The structure is subjected to a train of regular, small-amplitude waves of height  $H$  and frequency  $\omega$  travelling in the positive  $x$ -direction. The fluid will be assumed to be homogeneous, inviscid and incompressible and to undergo irrotational motion. The fluid motion is then described in terms of a velocity potential  $\phi(x, z, t) = \text{Re}[\Phi(x, z) e^{-i\omega t}]$ , where  $\text{Re}$  denotes the real part of a complex expression. The fluid velocity vector is then given by  $q = \nabla\phi$ . This velocity potential is required to satisfy Laplace's equation,

$$\nabla^2\Phi = 0, \quad (1)$$

everywhere in the region of flow. It is subject to the following

boundary conditions on the mean fluid free-surface, the sea-bed, the structural surface, and infinity, respectively,

$$g \frac{\partial}{\partial z} - \omega^2 = 0 \quad \text{on } z = d \quad (2)$$

$$\frac{\partial}{\partial z} = 0 \quad \text{on } z = 0 \quad (3)$$

$$\frac{\partial}{\partial x} = w(z) - i\omega v(z) \quad \text{on } x = 0^\pm, 0 < z < d \quad (4)$$

$$\lim_{x \rightarrow \infty} \frac{\partial}{\partial x} - ik = 0 \quad (5a)$$

$$\lim_{x \rightarrow -\infty} \frac{\partial}{\partial x} + ik = 0 \quad (5b)$$

where  $k$  is the incident wavenumber,  $g$  is the acceleration due to gravity, and  $v(z)$  is the complex amplitude of the displacement  $U(z,t)$  of the barrier, that is  $U(z,t) = \text{Re}[v(z)e^{-i\omega t}]$ ,  $w(z)$  is the complex amplitude of the normal velocity  $W(z,t)$  of the fluid passing through the porous structure from region one to region two, that is  $W(z,t) = \text{Re}[w(z)e^{-i\omega t}]$ . In Eq. (5b), the spatial component of the incident potential,  $\phi_1$ , is given by

$$\phi_1(x, z) = \frac{-igH}{2\omega} \frac{\cosh kz}{\cosh kd} e^{ikx} \quad (6)$$

The wavenumber  $k$  is related to the angular frequency of the wave through the dispersion relation  $\omega^2 = gk \tanh kd$ .

The fluid domain is divided into two regions, region one ( $x < 0$ ) and region two ( $x > 0$ ), with the complex velocity potentials in these denoted by  $\phi_1$  and  $\phi_2$ , respectively. The flow through the porous structure is assumed to obey Darcy's Law, and so the porous flow velocity  $W(z,t)$  is taken to be linearly proportional to the pressure difference between the two sides of the structure.<sup>13,16</sup> Writing the hydrodynamic pressures in each domain in terms of the respective velocity potentials through the linearized Bernoulli equation leads to the following expression for  $w(z)$ ,<sup>12</sup>

$$w(z) = \frac{b}{\mu} i\omega\rho \{ \phi_1(0, z) - \phi_2(0, z) \} \quad \text{on } 0 < z < d \quad (7)$$

in which  $\rho$  is the fluid density,  $\mu$  is the (constant) coefficient of dynamic viscosity and  $b$  is a material constant having the dimensions of length.

The structural response will be analyzed by assuming that the barrier behaves as a one-dimensional beam of uniform flexural rigidity,  $EI$ , and mass per unit length,  $m_s$ , subjected to a constant axial force  $T_o$  (the net buoyancy). The equation of motion of the structure acted upon by fluid pressure may be written in terms of the complex displacement amplitude  $v(z)$  as<sup>17</sup>

$$EI \frac{d^4 v}{dz^4} - T_o \frac{d^2 v}{dz^2} - m_s \omega^2 v = i\omega\rho \{ \phi_1(0, z) - \phi_2(0, z) \} \quad \text{on } 0 < z < d. \quad (8)$$

The boundary conditions include

$$v = 0 \quad \text{on } z = 0, \quad (9a)$$

$$\frac{dv}{dz} = 0 \quad \text{on } z = 0, \quad (9b)$$

$$\frac{d^2 v}{dz^2} = 0 \quad \text{on } z = d, \quad (9c)$$

$$EI \frac{d^3 v}{dz^3} = T_o \frac{dv}{dz} \quad \text{on } z = d. \quad (9d)$$

Equation (9d) results from relating the horizontal component of restoring force at the top of the barrier to the shear force in the beam.<sup>5</sup>

### Solution by Integral Equation Approach

The above problem for the fluid velocity potential is solved numerically utilizing the boundary integral equation method. First, two auxiliary vertical boundaries  $x = x^\pm$  are introduced, thus defining two finite fluid domains  $0 < x < x^+$ ,  $0 < z < d$  and  $x^- < x < 0$ ,  $0 < z < d$  (Fig. 3). These boundaries are located sufficiently far from the breakwater such that the corresponding radiation condition, given by Eq. (5a) or (5b), is valid on each. Applying Green's theorem in each of these regions to the velocity potential there and the free-space Green function of Laplace's equation, namely,

$$G(r_p; r) = \ln|r - r_p| \quad (10)$$

leads to the following integral equations

$$\varepsilon_p \int_{j} \phi_j(r_p) = \int_{j} \phi_j(r) \frac{\partial G}{\partial n}(r_p; r) - G(r_p; r) \frac{\partial \phi_j}{\partial n}(r) d \quad (11)$$

for  $j = 1, 2$ ,

in which  $\int_j$  is the boundary of each subregion and  $\varepsilon_p$  is the interior angle at the source point  $r_p = (x_p, z_p)$  which is restricted to lie on the boundary  $\int_j$ .

With reference to Fig. 3, after imposing the boundary conditions, the integral equations in each fluid domain may be written,

$$\varepsilon_p \int_{AO_1} \phi_1(r_p) - \int_{OE} \phi_1 \frac{\partial G}{\partial x} - G \frac{\partial \phi_1}{\partial x} dz + \int_{OE} \phi_1 \frac{\partial G}{\partial z} dx + \int_{ED} \phi_1 \frac{\partial G}{\partial x} + ikG dz - \int_{DA} \phi_1 \frac{\partial G}{\partial z} - \frac{\omega^2}{g} G dx = 2ik \int_{ED} \phi_1 G dz \quad (12a)$$

$$\varepsilon_p \int_{AO_2} \phi_2(r_p) - \int_{OC} \phi_2 \frac{\partial G}{\partial x} - G \frac{\partial \phi_2}{\partial x} dz + \int_{OC} \phi_2 \frac{\partial G}{\partial z} dx + \int_{CB} \phi_2 \frac{\partial G}{\partial x} - ikG dz - \int_{BA} \phi_2 \frac{\partial G}{\partial z} - \frac{\omega^2}{g} G dx = 0 \quad (12b)$$

A suitable Green function  $v_G(z; z_o)$  for the structural problem

which satisfies

$$\frac{d^4 v_G}{dz^4} - \frac{T_o}{EI} \frac{d^2 v_G}{dz^2} - \frac{m_s \omega^2}{EI} v_G = \delta(z - z_o) \quad \text{on } 0 \leq z \leq d. \quad (13a)$$

$$v = \frac{dv}{dz} = 0 \quad \text{on } z = 0, \quad (13b)$$

$$\frac{d^2 v}{dz^2} = 0 \quad \text{on } z = d, \quad (13c)$$

$$\frac{d^3 v}{dz^3} = \frac{T_o}{EI} \frac{dv}{dz} \quad \text{on } z = d. \quad (13d)$$

in which  $\delta(\cdot)$  is the Dirac delta function, may be obtained by the method of Laplace transforms<sup>5,6</sup> as

$$\begin{aligned} v_G(z, z_o) = & \frac{\alpha}{R_1 + R_2} \left( \cosh \sqrt{R_1} z - \cos \sqrt{R_2} z \right) \\ & + \frac{\beta}{R_1 + R_2} \frac{\sinh \sqrt{R_1} z}{\sqrt{R_1}} - \frac{\sin \sqrt{R_2} z}{\sqrt{R_2}} \\ & + \frac{1}{R_1 + R_2} \frac{\sinh \sqrt{R_1} (z - z_o)}{\sqrt{R_1}} - \frac{\sin \sqrt{R_2} (z - z_o)}{\sqrt{R_2}} \end{aligned} \quad (14)$$

valid for  $z > z_o$ , and expressions for  $\alpha$ ,  $\beta$ ,  $R_1$  and  $R_2$  are presented in the Appendix. Interchanging  $z$  and  $z_o$  on the right hand side of Eq. (15) yields an expression for  $v_G(z, z_o)$  valid for  $z_o > z$ .

By superposition, the complex displacement amplitude  $v(z)$  may be written

$$v(z) = \frac{i\omega\rho}{EI} \int_0^d v_G(z, \xi) \left\{ \phi^1(0, \xi) - \phi^2(0, \xi) \right\} d\xi \quad \text{on } 0 \leq z \leq d \quad (15)$$

and the structural boundary condition, Eq. (4), is now given by

$$\begin{aligned} \frac{\partial}{\partial x} \left( \phi^{\pm, j} \right) \Big|_{x=0} = & \frac{\omega^2 \rho}{EI} \int_0^d v_G(z, \xi) \left\{ \phi^1(0, \xi) - \phi^2(0, \xi) \right\} d\xi \\ & + ikG \left\{ \phi^1(0, z) - \phi^2(0, z) \right\} \quad \text{on } 0 \leq z \leq d \end{aligned} \quad (16)$$

for  $j = 1, 2$ , where  $G_0 = \rho\omega b/\mu k$  is Chwang's porous-effect parameter.<sup>13</sup>

The numerical solution of the integral equations, Eqs. (13a) and (13b), now proceeds by discretizing the integration contours into a large number of line segments, the interzonal points are numbered twice, and the boundary condition Eq. (16) is applied. In each segment, the velocity potential and normal derivative is taken to vary linearly between their nodal values. The resulting discretized system may be written in matrix form, and the velocity potentials at the nodes may be obtained by standard inversion techniques.

Once the potentials in each of the fluid domains have been calculated, various quantities of engineering interest may now be determined. The effectiveness of the structure as a wave barrier is usually measured in terms of the reflection and transmission coefficients  $\mathbf{R}$  and  $\mathbf{T}$ . On the auxiliary boundary  $x = x^+$ , the velocity potential may be written

$$\phi^2(x^+, z) = \frac{-igH_T}{2\omega} \frac{\cosh k(z+d)}{\cosh kd} e^{ikx^+ + i\gamma^+} \quad (17)$$

where  $H_T$  is the transmitted wave height and  $\gamma^+$  a phase angle. Similarly, on  $x = x^-$ ,

$$\phi^1(x^-, z) = \frac{-ig}{2\omega} \left( H_R e^{ikx^- + i\gamma^-} + H e^{ikx^-} \right) \frac{\cosh k(z+d)}{\cosh kd} \quad (18)$$

where  $H_R$  is the reflected wave height and  $\gamma^-$  its associated phase. The reflection and transmission coefficients are then given by

$$\mathbf{R} = \frac{H_R e^{i\gamma^-}}{H} \quad (19a)$$

$$\mathbf{T} = \frac{H_T e^{i\gamma^+}}{H}. \quad (19b)$$

The hydrodynamic load on the structure may be found as  $F(t) = \text{Re}\{\mathbf{F}e^{-i\omega t}\}$  where

$$\mathbf{F} = i\omega\rho \int_0^d \left\{ \phi^1(0, \xi) - \phi^2(0, \xi) \right\} d\xi \quad (20)$$

The complex amplitude of the structural displacement may be determined from Eq. (15), while the bending moment  $M(t) = \text{Re}\{\mathbf{M}e^{-i\omega t}\}$  and shear force  $Q(t) = \text{Re}\{\mathbf{Q}e^{-i\omega t}\}$  at the base of the structure are given by

$$\mathbf{M} = -i\omega\rho \int_0^d \frac{d^2 v_G(z, \xi)}{dz^2} \left\{ \phi^1(0, \xi) - \phi^2(0, \xi) \right\} d\xi \quad \text{on } z=0 \quad (21)$$

$$\mathbf{Q} = -i\omega\rho \int_0^d \frac{d^3 v_G(z, \xi)}{dz^3} \left\{ \phi^1(0, \xi) - \phi^2(0, \xi) \right\} d\xi \quad \text{on } z=0. \quad (22)$$

In the present formulation, the shear force has been taken on a cross-section normal to the axis of the deflected beam.<sup>5,6</sup>

### Wavetank Description and Test Setup

A series of laboratory experiments were conducted to validate the theoretical model and to further study the effectiveness of the proposed barrier under wave action. The experiments were carried out in the Civil and Environmental Engineering Wavetank Laboratory at the University of Houston. The wavetank is approximately 36.6 m (120 ft) long, 1.22 m (4 ft) high, and 1.22 m (4 ft) wide, with a steel bottom and glass sidewalls. Regular waves are generated in the tank by the oscillatory motion of a piston-type planar wavemaker. The complete experimental setup is shown in Fig. 3.1, a flexible porous membrane structure is located in the test section roughly half-way down the tank, it is anchored to the tank bottom and kept under tension by a buoyant cylindrical float. During the testing program, the free-surface profiles in front of, and behind, the wave barrier were measured by means of an array of resistance-type wave gauges. The measured data were recorded by a PC-driven eight-channel data acquisition system and stored on disk for postprocessing.

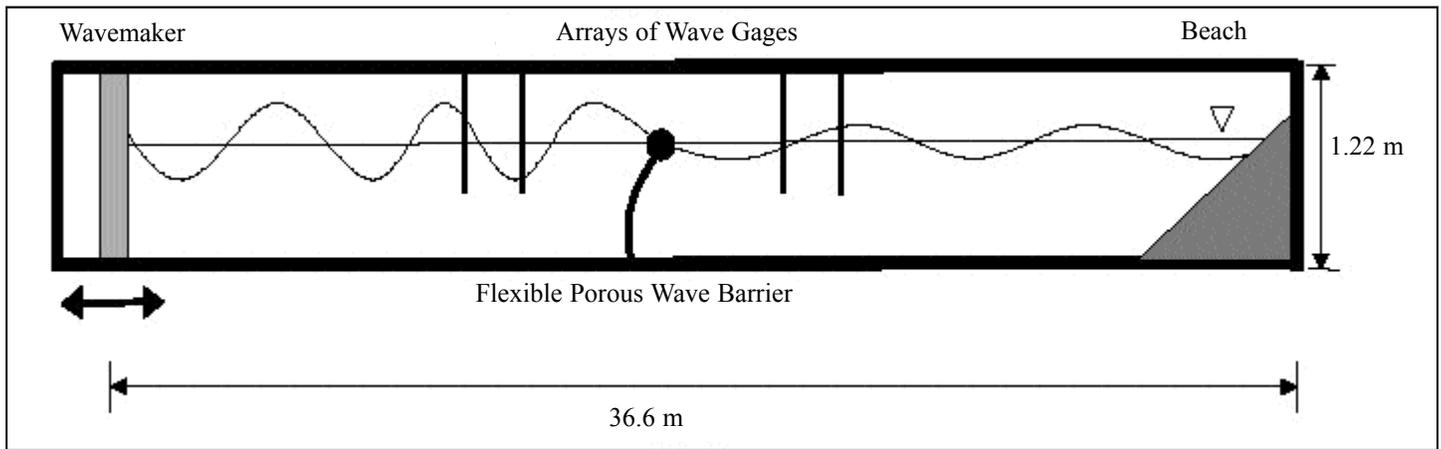


Figure 3.1. Experimental Setup in Laboratory Wavetank

Table 3.1. Mean Transmission Coefficients for NETS 1-3 for Water Depth 0.31 m.

NET 1								
Period	Water Depth	Mass/unit length	$G_0$	$T_0$	EI	Wavenumber	$kd$	Texp-wave ht.
2.321	0.31	0.112	7.84	38.2	0.0	1.566	0.49	<b>0.93</b>
1.632	0.31	0.112	7.52	38.2	0.0	2.286	0.71	<b>0.92</b>
1.432	0.31	0.112	7.34	38.2	0.0	2.663	0.83	<b>0.96</b>
1.160	0.31	0.112	6.91	38.2	0.0	3.502	1.09	<b>0.95</b>
1.010	0.31	0.112	6.53	38.2	0.0	4.303	1.33	<b>0.92</b>
secs	m	Kg/m <sup>2</sup>	-	N	Nm	1/m	-	-
NET 2								
Period	Water Depth	Mass/unit length	$G_0$	$T_0$	EI	Wavenumber	$kd$	Texp-wave ht.
2.321	0.31	0.394	4.97	37.3	0.0	1.566	0.49	<b>0.91</b>
1.632	0.31	0.394	4.77	37.3	0.0	2.286	0.71	<b>0.88</b>
1.432	0.31	0.394	4.65	37.3	0.0	2.663	0.83	<b>0.95</b>
1.160	0.31	0.394	4.38	37.3	0.0	3.502	1.09	<b>0.95</b>
1.010	0.31	0.394	4.14	37.3	0.0	4.303	1.33	<b>0.96</b>
secs	m	Kg/m <sup>2</sup>	-	N	Nm	1/m	-	-
NET 3								
Period	Water Depth	Mass/unit length	$G_0$	$T_0$	EI	Wavenumber	$kd$	Texp-wave ht.
2.321	0.31	0.357	2.81	37.4	0.0	1.566	0.49	<b>0.85</b>
1.632	0.31	0.357	2.69	37.4	0.0	2.286	0.71	<b>0.89</b>
1.432	0.31	0.357	2.62	37.4	0.0	2.663	0.83	<b>0.90</b>
1.160	0.31	0.357	2.47	37.4	0.0	3.502	1.09	<b>0.83</b>
1.010	0.31	0.357	2.34	37.4	0.0	4.303	1.33	<b>0.83</b>
secs	m	Kg/m <sup>2</sup>	-	N	Nm	1/m	-	-

Table 3.2. Mean Transmission Coefficients for NETS 1-3 for Water Depth 0.44 m.

NET 1								
Period	Water Depth	Mass/unit length	$G_0$	$T_0$	EI	Wavenumber	$kd$	Texp-wave ht.
2.184	0.44	0.112	6.36	38.0	0.0	1.416	0.62	<b>0.87</b>
1.650	0.44	0.112	6.04	38.0	0.0	1.955	0.86	<b>0.87</b>
1.371	0.44	0.112	5.71	38.0	0.0	2.495	1.10	<b>0.90</b>
1.065	0.44	0.112	5.04	38.0	0.0	3.708	1.63	<b>0.88</b>
0.970	0.44	0.112	4.73	38.0	0.0	4.377	1.93	<b>0.89</b>
secs	m	Kg/m <sup>2</sup>	-	N	Nm	1/m	-	-
NET 2								
Period	Water Depth	Mass/unit length	$G_0$	$T_0$	EI	Wavenumber	$kd$	Texp-wave ht.
2.184	0.44	0.394	4.03	36.8	0.0	1.416	0.62	<b>0.87</b>
1.650	0.44	0.394	3.83	36.8	0.0	1.955	0.86	<b>0.86</b>
1.371	0.44	0.394	3.62	36.8	0.0	2.495	1.10	<b>0.87</b>
1.065	0.44	0.394	3.20	36.8	0.0	3.708	1.63	<b>0.90</b>
0.970	0.44	0.394	3.00	36.8	0.0	4.377	1.93	<b>0.82</b>
secs	m	Kg/m <sup>2</sup>	-	N	Nm	1/m	-	-
NET 3								
Period	Water Depth	Mass/unit length	$G_0$	$T_0$	EI	Wavenumber	$kd$	Texp-wave ht.
2.184	0.44	0.357	2.27	37.0	0.0	1.416	0.62	<b>0.88</b>
1.650	0.44	0.357	2.16	37.0	0.0	1.955	0.86	<b>0.82</b>
1.371	0.44	0.357	2.04	37.0	0.0	2.495	1.10	<b>0.84</b>
1.065	0.44	0.357	1.80	37.0	0.0	3.708	1.63	<b>0.81</b>
0.970	0.44	0.357	1.69	37.0	0.0	4.377	1.93	<b>0.79</b>
secs	m	Kg/m <sup>2</sup>	-	N	Nm	1/m	-	-

### Experimental Parameters

The porous membrane used for the construction of a wave barrier is a type of window screen. After a sequence of preliminary tests, three types of plastic screen, designated NET1, NET2, and NET3, were selected for further investigation. The estimated pore sizes for NET1, NET2, and NET3 were 1.414 mm, 0.9 mm and 0.5 mm, respectively. For the experimental program, regular wave trains with five different periods ranging from 1.01 sec to 2.32 sec were generated, each test was repeated five times and the results averaged. For each structure, the tests were repeated at water depths of 0.31 m, 0.44 m, and 0.67 m so that the effect of water depth on the performance of the wave barriers could be examined. The material constant,  $b$ , which is an essential variable for the determination of the porous-effect parameter  $G_0$  for each barrier, depends on the pore size and the water depth. The  $b$  values used in the present case were derived by linear scaling from those

measured in the experimental study of Twu and Lin.<sup>18</sup> The corresponding  $G_0$  values can be found in Tables 3.1-3.3.

### Experimental Results

The measured transmission coefficients for the barriers denoted NET1, NET2, and NET3 under various wave conditions and for water depths of 0.31 m, 0.44 m, and 0.67 m are summarized in Tables 3.1-3.3. Other parameters including the mass/unit length,  $m_s$ , the porous-effect parameter,  $G_0$ , the flexural rigidity,  $EI$ , and the net buoyant force,  $T_0$ , are also provided in order to facilitate the numerical computations.

### Numerical Results

The numerical results may be conveniently divided into two sections, namely a comparison with the measured data for the reflection coefficients presented in the previous section, and a paramet-

**Table 3.3. Mean Transmission Coefficients for NETS 1–3 for Water Depth 0.67 m.**

NET 1								
Period	Water Depth	Mass/unit length	$G_0$	$T_0$	EI	Wavenumber	$kd$	Texp-wave ht.
2.174	0.67	0.112	5.07	37.8	0.0	1.186	0.79	<b>0.90</b>
1.765	0.67	0.112	4.79	37.8	0.0	1.545	1.04	<b>0.90</b>
1.433	0.67	0.112	4.39	37.8	0.0	2.107	1.41	<b>0.91</b>
1.252	0.67	0.112	4.05	37.8	0.0	2.651	1.78	<b>0.87</b>
1.108	0.67	0.112	3.69	37.8	0.0	3.319	2.22	<b>0.86</b>
secs	m	Kg/m <sup>2</sup>	-	N	Nm	1/m	-	-
NET 2								
Period	Water Depth	Mass/unit length	$G_0$	$T_0$	EI	Wavenumber	$kd$	Texp-wave ht.
2.174	0.67	0.394	3.21	35.9	0.0	1.186	0.79	<b>0.91</b>
1.765	0.67	0.394	3.04	35.9	0.0	1.545	1.04	<b>0.92</b>
1.433	0.67	0.394	2.78	35.9	0.0	2.107	1.41	<b>0.88</b>
1.252	0.67	0.394	2.56	35.9	0.0	2.651	1.78	<b>0.86</b>
1.108	0.67	0.394	2.34	35.9	0.0	3.319	2.22	<b>0.82</b>
secs	m	Kg/m <sup>2</sup>	-	N	Nm	1/m	-	-
NET 3								
Period	Water Depth	Mass/unit length	$G_0$	$T_0$	EI	Wavenumber	$kd$	Texp-wave ht.
2.174	0.67	0.357	1.81	36.2	0.0	1.186	0.79	<b>0.85</b>
1.765	0.67	0.357	1.71	36.2	0.0	1.545	1.04	<b>0.84</b>
1.433	0.67	0.357	1.57	36.2	0.0	2.107	1.41	<b>0.87</b>
1.252	0.67	0.357	1.45	36.2	0.0	2.651	1.78	<b>0.80</b>
1.108	0.67	0.357	1.32	36.2	0.0	3.319	2.22	<b>0.76</b>
secs	m	Kg/m <sup>2</sup>	-	N	Nm	1/m	-	-

ric study that investigates the effect of varying the geometric and material properties of the barrier.

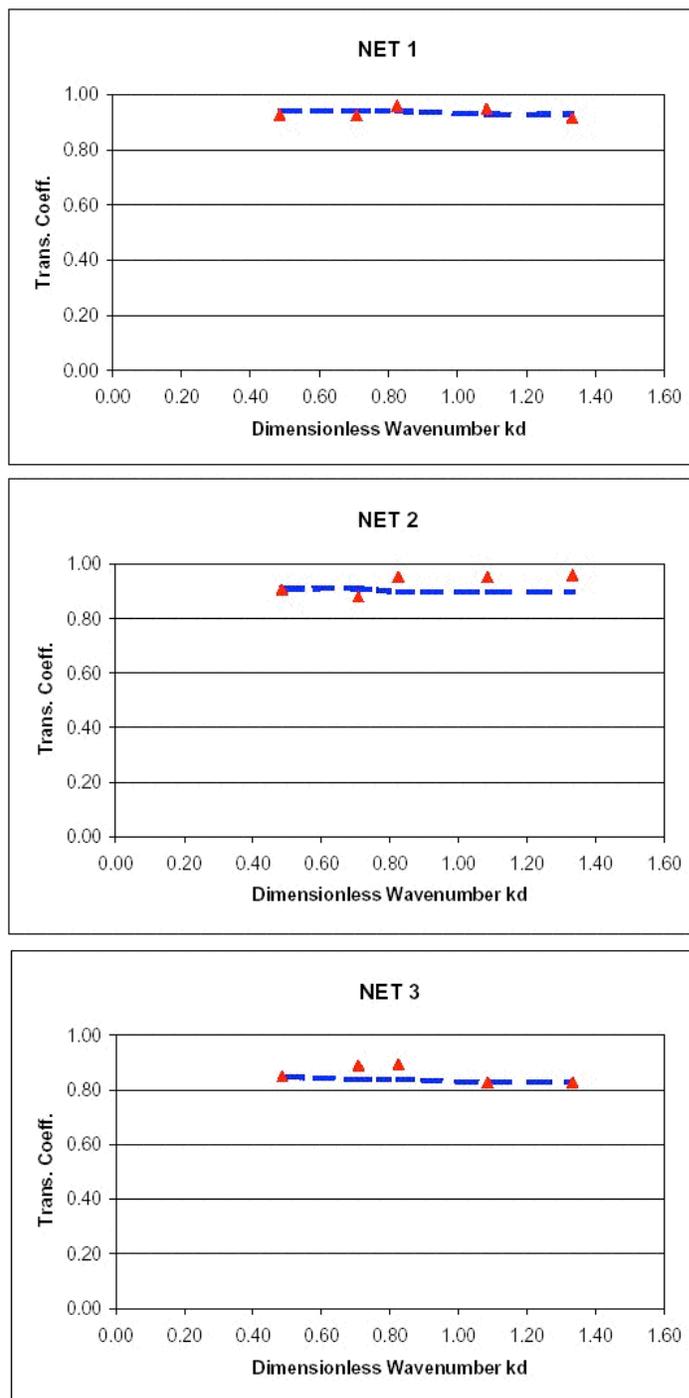
In obtaining the numerical results presented herein, the domain boundaries were each typically discretized into 240 line segments, 48 on the structural boundary, 72 each on the free-surface and sea-bed, and 48 on the auxiliary boundary at infinity. In several cases, a more refined element mesh was utilized in order to ensure that numerical convergence had been achieved. The auxiliary boundaries at  $x = x^\pm$  were placed three-four water depths away from the structure, sufficiently far to ensure that the evanescent wave modes could be neglected.<sup>19</sup>

### Comparison with Experimental Data

The comparisons between the measured and theoretical transmission coefficients are shown in Figs. 4.1-4.3. It can be seen that the agreement between theory and experiment is generally good. With the exception of one data point in Fig. 4.3, where the relative error is 13 percent, all relative errors between measured and theoretical transmission coefficients are seven percent or less. Overall, the best agreement is shown for NET1, then for NET2, and finally for NET3. There are no clear variations in the degree of agreement with change in water depth, neither are there any clear variations with wave frequency. Therefore, it is concluded that the numerical model developed herein provides an acceptable tool for the prediction of the gross behavior of the porous flexible wave barrier over a range of wave frequencies, water depths and structural properties.

### Parametric Study

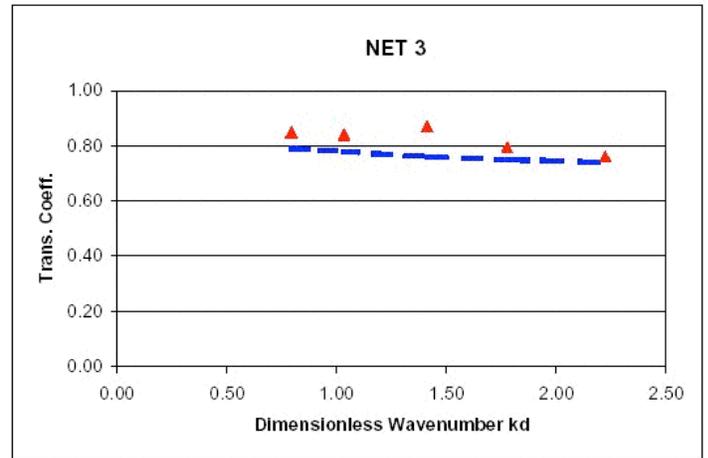
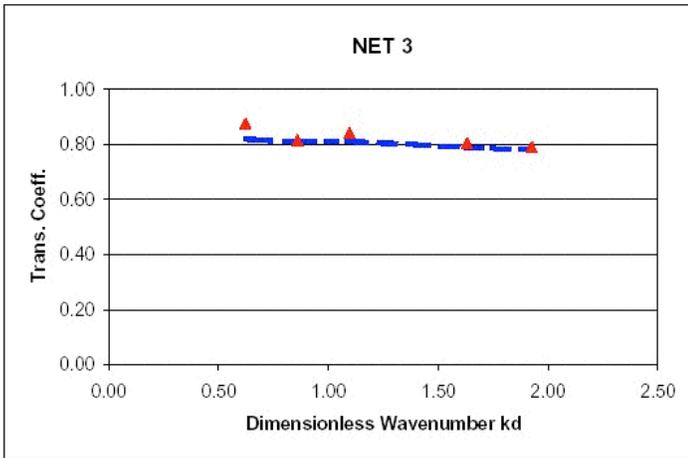
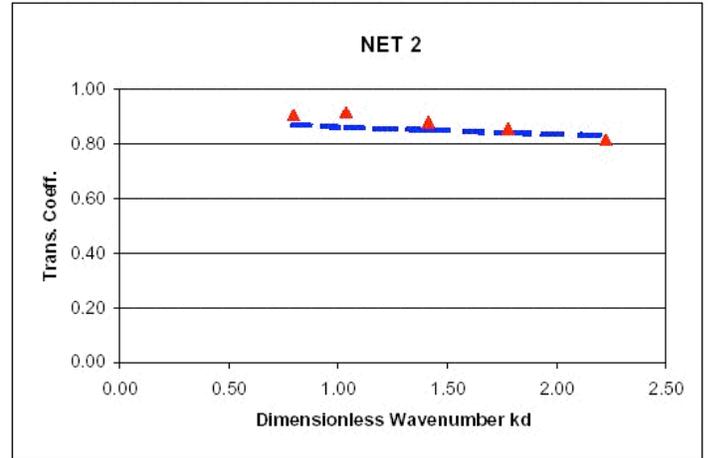
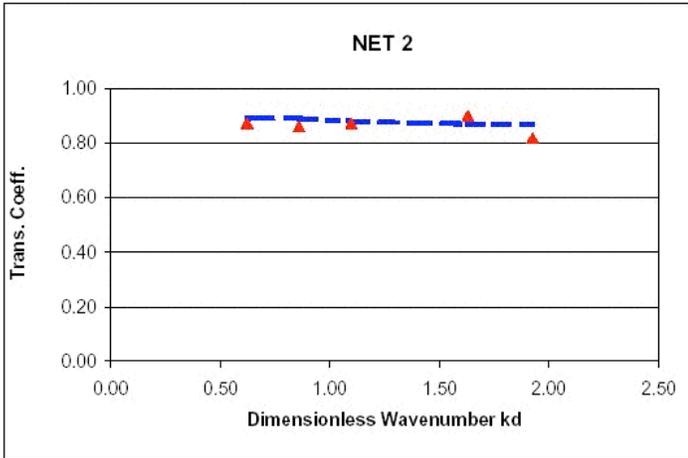
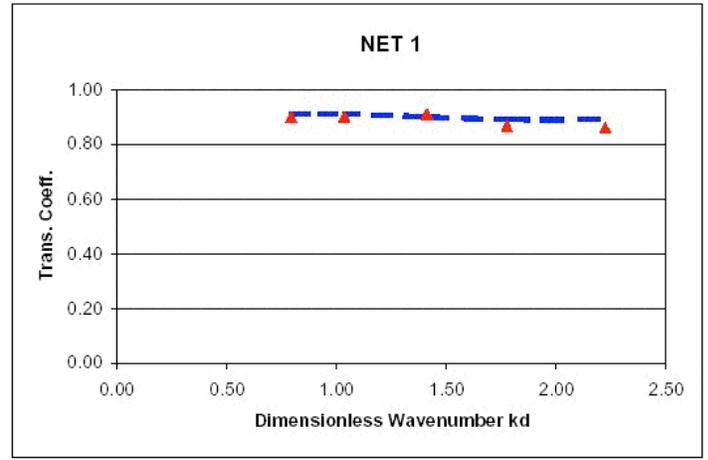
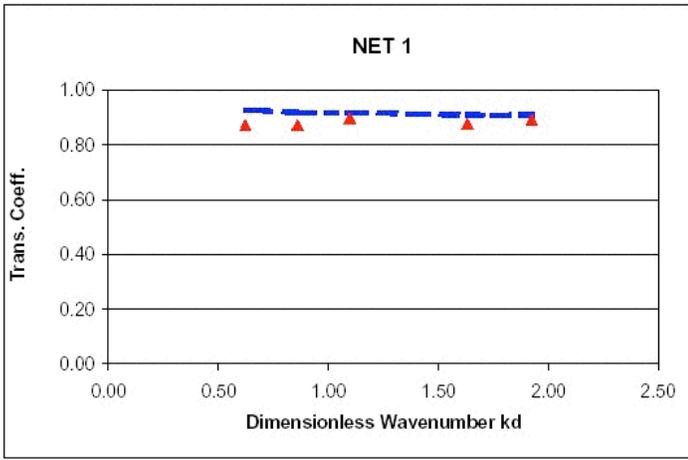
A parametric study has been carried out to illustrate the relationship between the various wave and structural parameters and to investigate the efficiency of various barrier configurations. The hydrodynamics of the system depend on several geometric and



**Figure 4.1. Comparison of Measured (symbols) and Theoretical (lines) Transmission Coefficients for NETS 1-3, for a Water Depth of 0.31 m.**

material parameters, the length of the structure—which is equal to the water depth,  $d$ , the porosity as indicated by the parameter  $G_0$ , the mass per unit length of the barrier,  $m_s$ , and the axial tension in the barrier,  $T_0$ . The influence of each of these parameters on the reflection coefficient will be investigated separately.

It is noted that the membrane porosity as characterized by the parameter  $G_0$  is a function of the incident wave properties. Therefore, in the parametric study it is more convenient to define the porosity in terms of a parameter  $R_0 = \rho b g d / \mu$ , which is inde-



**Figure 4.2. Comparison of Measured (symbols) and Theoretical (lines) Transmission Coefficients for NETS 1-3, for a Water Depth of 0.44 m.**

**Figure 4.3. Comparison of Measured (symbols) and Theoretical (lines) Transmission Coefficients for NETS 1-3, for a Water Depth of 0.67 m.**

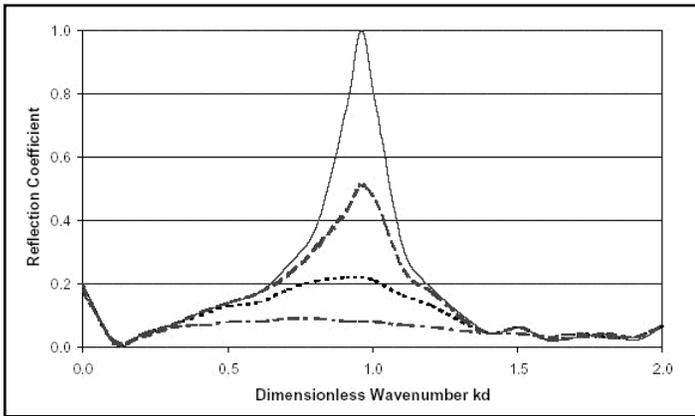
pendent of the incident wave characteristics and is related to the parameter  $G_0$  by

$$G_0 = \sqrt{\frac{\tanh kd}{kd}} R_0. \quad (23)$$

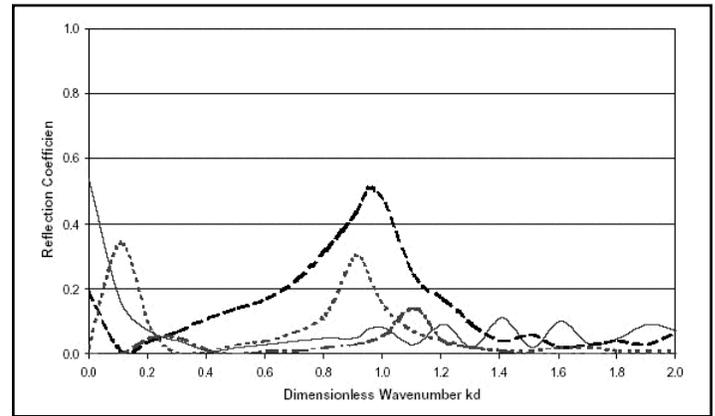
First, a prototype structure was selected for use in 1.5 m of water, i.e.  $d = 1.5$  m. The prototype structural properties were  $R_0 = 0.1$ ,  $m_s = 2$  Kg/m,  $EI = 40$  Nm, and  $T_0 = 100$  N/m. The parametric

study will concentrate on examining the effect on the reflection coefficient of perturbations from this base case. Numerical values will be presented for the variation of the magnitude of the reflection coefficient with dimensionless incident wave frequency,  $kd$ .

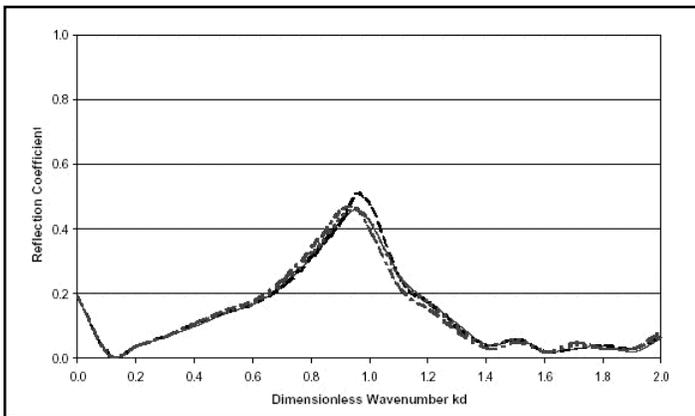
Figure 4.4 shows the effect of porosity on the reflection coefficients for three membrane structures. As intuitively expected, as the porosity is increased the reflection coefficient decreases. It can be seen that the response of the system is relatively narrow-banded, with acceptable wave reflection characteristics only



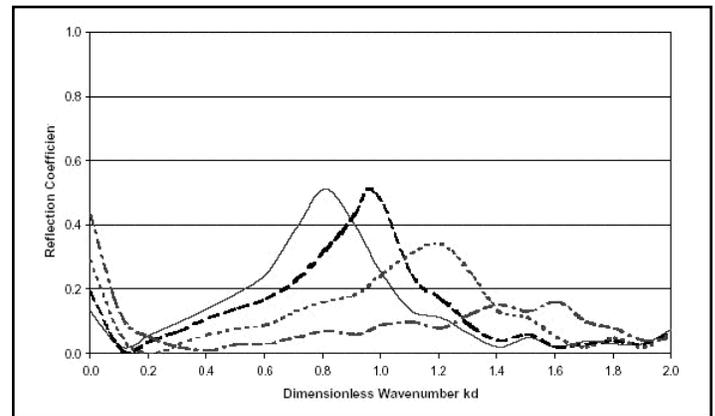
**Figure 4.4. Influence of Barrier Porosity on Reflection Coefficient for  $d = 1.5$  m,  $m_s = 2$  Kg/m,  $EI = 40$  Nm, and  $T_0 = 100$  N/m. Notations: ———  $R_o = 0.0$ ; - - - -  $R_o = 0.1$ ; ·····  $R_o = 0.3$ ; - · - ·  $R_o = 1.0$ .**



**Figure 4.5. Influence of Barrier Length (Water Depth) on Reflection Coefficient for  $R_o = 0.1$ ,  $m_s = 2$  Kg/m,  $EI = 40$  Nm, and  $T_0 = 100$  N/m. Notations: ———  $d = 1.0$  m; - - - -  $d = 1.5$  m; ·····  $d = 3.0$  m; - · - ·  $d = 4.5$  m.**



**Figure 4.6. Influence of Barrier Mass-Per-Unit-Length on Reflection Coefficient for  $R_o = 0.1$ ,  $d = 1.5$  m,  $EI = 40$  Nm, and  $T_0 = 100$  N/m. Notations: ———  $m_s = 1$  Kg/m; - - - -  $m_s = 2$  Kg/m; ·····  $m_s = 4$  Kg/m; - · - ·  $m_s = 20$  Kg/m.**



**Figure 4.7. Influence of Barrier Tension on Reflection Coefficient for  $R_o = 0.1$ ,  $d = 1.5$  m,  $m_s = 2$  Kg/m, and  $EI = 40$  Nm. Notations: ———  $T_0 = 50$  N/m; - - - -  $T_0 = 100$  N/m; ·····  $T_0 = 200$  N/m; - · - ·  $T_0 = 400$  N/m.**

being achieved in the immediate vicinity of the resonant peak. It is noted that the locations of the peaks (but not their magnitudes) are independent of membrane porosity.

Figure 4.5 shows the effect of barrier length (i.e. water depth) on the reflection coefficients for three membrane structures. It can be seen that as the length of the barrier is increased, the effectiveness of the barrier is considerably reduced. Therefore, it is concluded that the “base case” barrier is essentially tuned to the water depth,  $d = 1.5$  m.

Figure 4.6 shows the influence on reflection coefficient of varying the barrier mass density. Under the assumptions inherent in the current numerical model, varying the mass density is seen to have minimal influence on the efficiency of the structure as a barrier to wave action.

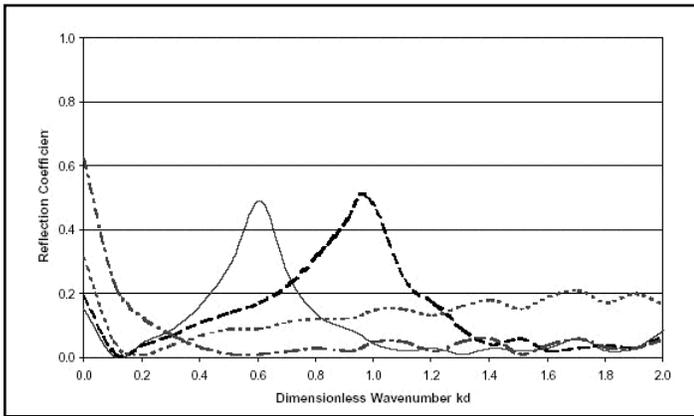
Figure 4.7 shows the influence on the reflection coefficient of varying the axial tension  $T_0$  for a range of dimensionless wave frequencies. This parameter is determined by the excess buoyancy of the float. Increasing the axial tension (float excess buoyancy) increases the natural frequency of the system, thereby shifting the peak in the reflection coefficient to a higher value of  $kd$ .

Therefore, the location of this peak may be by varying the axial tension (float excess buoyancy) in the membrane.

The influence of the bending stiffness  $EI$  of the barrier on the reflection coefficient is presented in Fig. 4.8. The results for the structures investigated fall into two pairs: the more flexible structures, with  $EI = 20, 40$  Nm, exhibit resonant behavior in the frequency domain of interest and, therefore, and each show a resonant peak of the reflection coefficient. The stiffer structures, with  $EI = 100, 400$  Nm do not possess a natural frequency within the frequency domain of interest and, although the low frequency behavior of these wave barriers is much improved over the flexible structure cases, there is no corresponding peak of the reflection coefficient in the mid-frequency range. Instead the reflection coefficient is essentially independent of frequency in the mid and high-frequency ranges.

## Conclusion

The hydrodynamics of a flexible wave barrier consisting of a vertical porous membrane kept under tension by a small buoyant float and anchored to the sea-bed has been investigated. A numer-



**Figure 4.8. Influence of Barrier Stiffness on Reflection Coefficient for  $R_o = 0.1$ ,  $d = 1.5$  m,  $m_s = 2$  Kg/m, and  $T_0 = 100$  N/m. Notations: \_\_\_\_\_  $EI = 20$  Nm; \_\_\_\_\_  $EI = 40$  Nm; \_\_\_\_\_  $EI = 100$  Nm; \_\_\_\_\_  $EI = 400$  Nm.**

ical model has been developed to assess the effectiveness of the structure as a barrier to wave action. In this model the fluid motion is idealized as linearized, two-dimensional potential flow and the equation of motion of the breakwater is taken to be that of a one-dimensional beam of uniform stiffness and mass per unit length subjected to a constant axial force. The boundary integral equation method is applied to the fluid domain, and the dynamic behavior of the breakwater is also described through an appropriate Green function. Numerical results have been presented which illustrate the effects of the various wave and structural parameters on the efficiency of the breakwater as a barrier to wave action. It has been found that the wave reflection properties of the structure depend strongly on the porosity, bending stiffness, axial tension (excess buoyancy) and barrier length (water depth), while the membrane weight is of much lesser importance. Small-scale physical model tests were carried out in the UH wavetank facility to validate the predictions of the numerical model. In general, good agreement was obtained between the theoretical and experimental reflection coefficients. It has been found that for certain structural parameter combinations a porous tensioned membrane may provide a reasonably effective barrier in the short- to mid-wavelength range.

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# The Color of Total Suspended Solids: A New Tool for Remote Sensing and Environmental Monitoring of Surface Water Quality

Chunlong Zhang, Jim Sui, Gabriel Zheng, Dean L. Muirhead, and W. Andrew Jackson  
University of Houston-Clear Lake, Water Resource Center, Texas Tech University

NATURAL and polluted waters come in many different colors. The most significant and variable contributor to water color is total suspended solids (TSS). TSS quantifies the mass of material retained on a glass fiber filter and includes phytoplankton, soil particles and bacteria; its color originates from the scattering and absorbance properties of inorganic and organic particles due to their size and refractive index. Water color is commonly regarded as an aesthetic concern; its quantitation as a tool for routine water resource management and its utility in water quality monitoring and remote sensing have been lacking.<sup>1,2</sup> Researchers at UHCL and Texas Tech University are seeking a correlation between TSS color and water quality of representative waters in Houston-Galveston and West Texas areas.

A quick and simple methodology for quantifying the color and optical properties of TSS has been developed. This method incorporated current standard analytical procedure for the measurement of TSS and employed the use of a hand-held Colortron spectrometer with computerized scanning and data output. Reflectance spectra (390-700 nm) have been examined under various sample volumes, oven temperature, and filters. GF/F glass-fiber filters (0.7 m) provided consistently higher TSS values than 934/AH glass-fiber filter (1.5 m, Whatman) for all the water samples; however, the TSS measured was not significantly different ( $p < 0.05$ ). TSS from different locations exhibited unique colors, representing particulate population and nutrient status of the water. Two distinct types of reflectance spectra were identified from representative water samples, and an example spectra of a water sample (Clear Lake, Houston) containing high algal population is shown in Fig. 1. Results also showed that increased mass loadings (i.e., TSS) resulted in the decrease in CIE Y (brightness) and slight increase in CIE y (saturation or color purity) (Fig. 2).

Figure 3 shows the reflectance spectra of TSS samples taken from an eutrophic lake from West Texas and three wastewater samples in Lubbock Wastewater Treatment Plant. Similar to the Clear Lake, the eutrophic Playa Lake showed absorption in the red and blue wavelengths by chlorophyll resulting in its green appearance. The other samples taken from the wastewater treatment plant showed different TSS color along with various wastewater treatment units. For example, green filaments were observed and recorded on two of the filter papers from the secondary effluent TSS samples. The reflectance spectra in Fig. 3 also clearly indicated the difference in the reflectance between primary effluent and secondary effluent. The latter has a brighter color that corresponded to a lower TSS concentration as well as smaller particulates in the sedimentation basin.

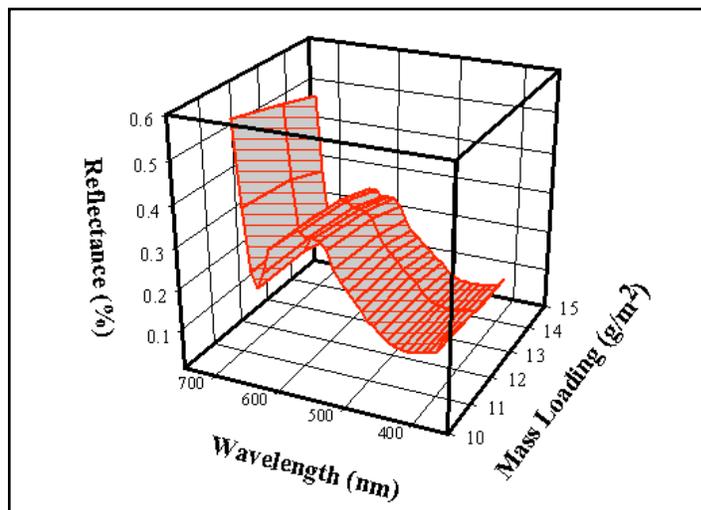


Figure 1. Reflectance spectrum of a water sample taken from Clear Lake, Houston (29°33.812N; 95°04.192W).

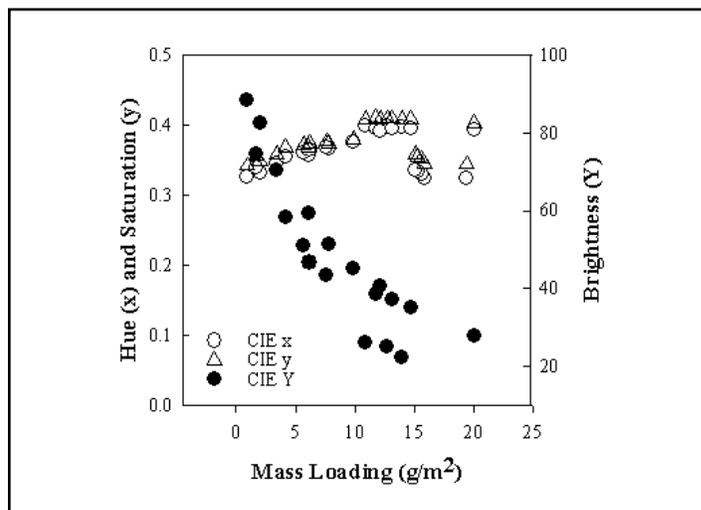
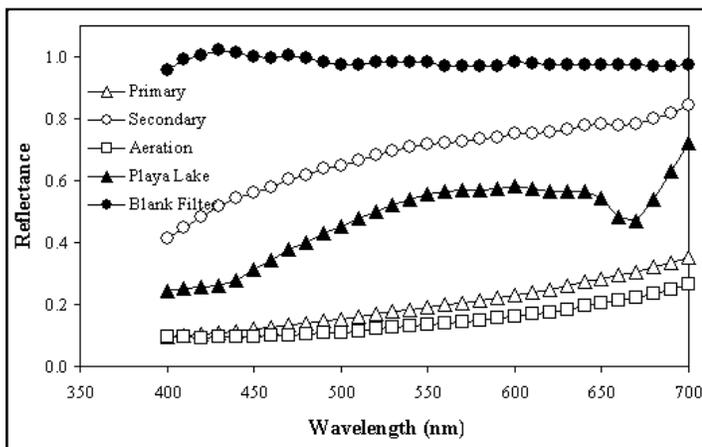


Figure 2. Color as a function of mass loading of water samples (Horsepen Bayou, Clear Lake, Ship Channel, and Kemah) in Houston, Texas area.

The TSS color serves as a snapshot of the biogeochemical status of a water body. This method may offer a convenient tool to monitor water pollution such as red tide, algal bloom, eutrophication and therefore the fingerprints of nutrient status. Unlike other



**Figure 3. Reflectance spectra of water in Playa Lake (Lubbock, TX) and wastewater in Lubbock Wastewater Treatment Plant**

numerical data, color provides a perceptual attribute to the status of a water body, which can be easily understood by the general public and even school children. Therefore, our results are also expected to have impact on public awareness on water quality issues and the improvement of environmental education to the general public. This work represents the first attempt to directly link color with the quality of water in Texas. More research is needed to establish the correlation between TSS color and algal growth (chlorophyll *a*), routine water quality parameters including turbidity, Secchi depth and conductivity, and satellite data for remote sensing. A website is planned to educate the public on the science of color and related water quality issues.

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# Are Spelean and Travertine Deposits Reliable Recorders of Climate?

Henry S. Chafetz and Penny M. Taylor  
University of Houston

U<sup>H</sup> RESEARCHERS sought to evaluate how closely surface travertine and cave deposits from the central Texas area record general climatic conditions and, more importantly, seasonal changes in conditions. Water and precipitate samples are being collected from sites in Colorado Bend State Park, near Bend, Texas, as well as at Natural Bridge Caverns near New Braunfels. Data related to the primary objective are still in the collection and analysis stage. Nevertheless, an interesting and significant relationship has been recognized between the water in the various pools within the cave systems and crystal habit of the carbonate minerals precipitating within these pools.<sup>1</sup> It is anticipated that this relationship will be useful in paleoclimatic analyses.

Calcite precipitation at the air-water interface in spelean pools produces floating rafts of interconnected, low-*Mg* calcite crystals with habits that range from equant (length to width = 1:1) to tabular (1:5) (see Figs. 1 and 2). Data from sample pairs (rafts and water) provide evidence that individual crystal habit is related to saturation state of the water at the site of precipitation. Saturation state ranges from 1 (equilibrium) for waters precipitating equant crystals to 22X saturation for tabular precipitates.

Temporal changes in stable isotopic ratios and increasing concentrations of ions within individual pools indicate that the processes driving calcite precipitation are evaporation and  $CO_2$ -degassing. During a three-month sampling period (regional drought conditions), the water level in one pool near the cave entrance dropped (~5 cm),  $PCO_2$  decreased (0.01 to 0.001 atm),

oxygen and carbon isotopic values became higher (2 and 6, respectively), and dissolved ions became concentrated (*Na*, *Mg*, *K*,  $SiO_2$ , *Cl*,  $SO_4$ ,  $NO_3$ ). In another pool, far from the entrance, during a 2-month sampling period,  $PCO_2$  decreased (0.23 to 0.06 atm),  $\delta^{18}O$  and  $\delta^{13}C$  values became slightly lower (0.2 and 0.4, respectively), and ion concentrations changed little.

Equant crystals, with no crystallographic defects, precipitate from water with saturation states close to equilibrium. Tabular crystals are disequilibrium precipitates from supersaturated water. Crystal defects in the tabular crystals include inter-crystalline pores, rounded faces, and nearly circular holes (diameter = 5-10 mm) on faces. The holes apparently result from rapid crystallite growth around foreign objects on the water surface (e.g., biotic or abiotic particles, or escaping gas bubbles). Crystal habits range due to preferential growth along one axis, a phenomenon related to the saturation state of the water.

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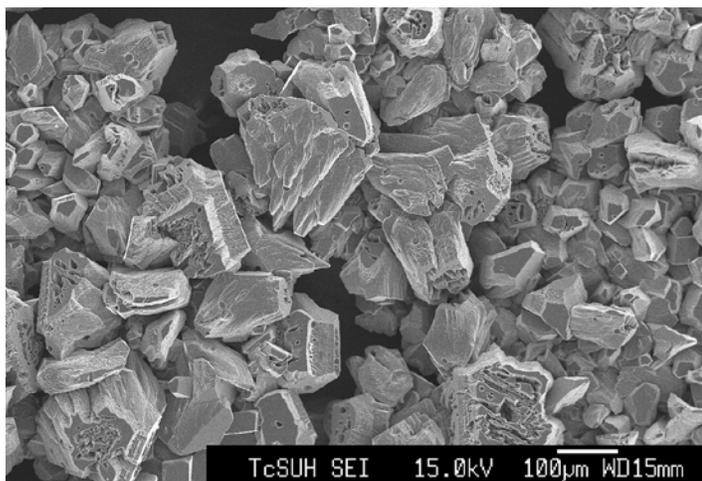


Figure 1. SEM photomicrograph of equant calcite crystals comprising rafts that precipitated in waters slightly supersaturated ( $Isat = \sim 1$ ).

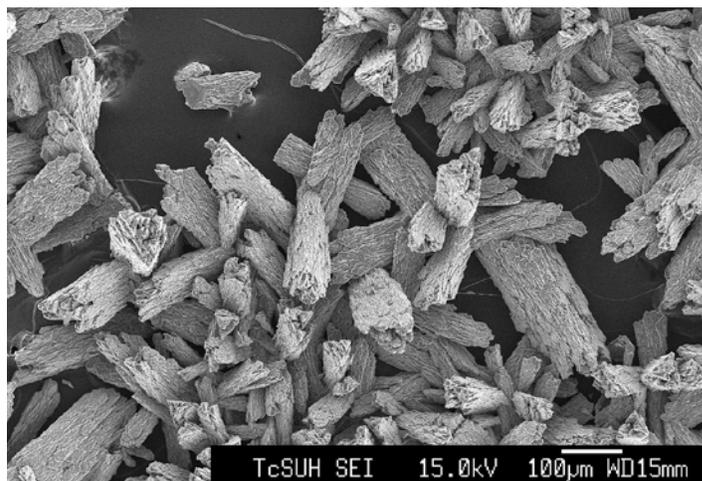


Figure 2. SEM photomicrograph of tabular calcite crystals comprising rafts that precipitated in waters 6.3x saturation.

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**Penny Taylor, taking *in situ* water chemistry measurements in Gorman Cave.**

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# A Preliminary Ethnographic Study of Asthma Among School-Aged Children in Houston, Texas

Janice Harper, Tracy Smith, Karen Plessinger, Tom McKinney,  
Anna Pokluda, and Nicolas Somoana  
University of Houston

**S**UBSTANTIAL RESEARCH into the relationship between asthma and the environment has been conducted by Janice Harper and her research team. The team has established collaborative relationships with organizations and individuals in the Houston area and initiated an ethnographic study in a low-income community with high rates of asthma and other health problems.

*Research.* Substantial literature on the history, etiology, epidemiology, theories of causation and triggers, and social concerns related to asthma and related respiratory problems; legislation and reporting of air quality issues in Houston and Texas; and ongoing asthma research and community health projects throughout the nation has been collected.

*Collaborative relationships.* Affiliations with a number of organizations and individuals regarding this research project have been established. Houston-ACORN, a grassroots community action organization, has agreed to provide assistance with community outreach and training student assistants. A local branch of the Kelsey-Sebold health clinic has agreed to refer residents with respiratory problems to the researchers to discuss their illness and treatment, and to encourage staff physicians to work with researchers. Dr. Kay Bartholomew, of the University of Texas School of Public Health, and the Principal Investigator of a long-term asthma project, has agreed to share data from her project and discuss future collaboration. Attending the "Environmental Air Toxics: Role in Asthma Occurrence?" conference sponsored by the Mickey Leland National Urban Air Toxics Research Center enabled Professor Harper to meet researchers throughout the state and nation to learn of related research and programs. Most importantly, this conference illuminated the lack of community-level data regarding asthma occurrence, a gap that was repeatedly brought to light at the conference.

*Ethnographic research.* Ethnographic research of residents of South Park, a low-income community in the Houston area has begun. Residents are primarily African-American and Hispanic, homeowners, and active in their community. Efforts by residents to engage the city of Houston in repair of roads, drainage ditches, and other community concerns have met with years of resistance and inaction. The neighborhood is surrounded by freeways, con-

tributing to high levels of air pollution. In addition, three years ago a concrete crushing plant was established adjacent to the neighborhood, and very close to a local elementary school. Residents are concerned that the pervasive dust from the plant is exacerbating respiratory problems. In addition, alongside the eastern boundaries of the community are several factories, releasing a number of chemicals known to trigger asthma attacks. Door-to-door surveys have indicated that asthma prevalence is high; on some blocks, every home on the street has one or more household members with severe respiratory problems.

*Refinement of research problem.* Initially, the research team set out to study asthma among children in school settings. Reluctance on the part of the Houston Independent School District to collaborate with this project led to the revision of the project. The project will now include an ethnographic study of the South Park community, which will be followed by research of a nearby higher income community such as West University. After establishing herself in the communities, Professor Harper hopes to resubmit a request for research clearance with HISD. The project will also include environmental assessment of the air, water, and ground contamination in the area, to determine the multiple avenues of exposure to asthma triggers.

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# Greening the UHCL Campus: A Model Project

Brenda Weiser and Christina Blankenship  
University of Houston-Clear Lake

**T**HE PURPOSE of this study was to develop and implement a plan to green the University of Houston-Clear Lake (UHCL) campus. The researchers aimed at creating a green campus that could be modeled by other campuses in the Houston-Galveston area.

The primary objectives of this study were to (1) research and identify assessments conducted at other universities and determine the appropriate assessment for UHCL, (2) develop a plan to green the UHCL campus, and (3) provide opportunities for students, staff, and faculty to develop knowledge regarding positive environmental practices and to actively participate in the greening the campus plan.

Other university assessments were examined and topics identified, including energy conservation, composting, transportation, carpet, lawn maintenance, and recycling, to possibly implement at the university.

Surveys were administered to students, staff, and faculty to measure awareness of the current UHCL recycling program, to determine the willingness to participate in a recycling program, and to determine if participants would be willing to pay a recycling fee. Responses indicated a marginal campus recycling awareness. In addition, students were willing to pay a \$1.00 or less recycling fee per semester and instructors were willing to pay a recycling fee attached to their parking fee. Comments about recycling on these surveys suggested that a greening campus plan should focus on the visibility, the location, and the number of recycling bins to increase campus-wide awareness of recycling efforts.

Recycling, energy conservation, transportation, and student participation were the areas selected to address/implement this first year.

## **Recycling**

After surveying various buildings, it was determined additional recycling bins were needed. The Facilities Management group assisted with determining the placement of additional recycling

bins for plastics and cans in the various buildings. In addition, the Facilities Management team constructed and placed additional bins in appropriate areas.

## **Energy Conservation**

UHCL currently uses LED replacement lights in all exit signs, providing 96 percent energy savings and a 25-year life expectancy. Fluorescent lighting is used instead of incandescent, using 25 percent less energy. The Bayou Building's roof has been replaced with a reflective white roof to help conserve electricity. UHCL also purchases reformulated oil and lubricants and has retrofitted 75 percent of the UHCL vehicles for propane and gas.

Plans to purchase light switch cover stickers for classrooms and offices (as a reminder to turn off lights when not in use) are being implemented at this time.

## **Student Participation and Transportation**

Recommended actions for student participation included: (1) installing a drop-off-recycling center on the far most north side of the student parking lot; (2) providing a database of students, faculty, and staff for car-pooling; and (3) placing bicycles at the Bayou, Arbor, and Delta buildings to be utilized by individuals to travel between the various buildings.

## **Other Recommendations**

The university should hire a part-time environmental coordinator to assist in the implementation of a greening the campus plan. This position could be funded by the savings the campus would realize with conservation and recycling efforts, an additional green fee, or grants.

The greening of the UHCL campus is critically dependent on the cooperation of its faculty, staff, students and contractors. The greening process needs leadership from all groups to succeed.

# Improving Environmental Policy by Facilitating Public Involvement

Priscilla Weeks and Lisa Gonzalez  
University of Houston-Clear Lake

INDIVIDUALS AND COMMUNITY GROUPS affected by environmental policies often find the forest of regulations and agencies to be trackless and foreboding. As environmental policy facilitators, EIH's Public Participation and Outreach Program (PPOP) serves the public by discerning needs, improving communication between public and private groups, and providing independent technical resources. PPOP's ultimate goal is to improve the democratic decision making process surrounding the formation and implementation of public environmental policies in the Houston-Galveston region. To meet this goal, PPOP specializes in translating scientific and regulatory languages into an idiom that can empower citizens. This expertise is applied through two modes: reaching out to the public directly to inform and educate, and increasing public participation in policy design and execution.

In 2001, a new public participation project was initiated with a chapter of Mothers for Clean Air located in the Fifth Ward of Houston. Concerns about the cleanup of the neighborhood's MDI Superfund site prompted the group to apply for an EPA technical advisor grant. PPOP manages this grant for the chapter. PPOP also aides the group in articulating its members' concerns about the cleanup process and acts as a liaison between the chapter and the Environmental Protection Agency (EPA) and Texas Natural Resources Conservation Commission (TNRCC).

The newest public participation project focuses on the quality of the Houston metropolitan area's air, which is out of compliance with EPA ground level ozone standards. TNRCC already has a state implementation plan (or SIP) designed to return Houston to compliance, but the SIP is designed to evolve as modeling techniques improve and public input increases through a series of SIP updates scheduled for 2002 and 2004. In August 2001, PPOP and the University of Houston formed a group charged with developing consensus-based strategies for these updates. TFORS (Task Force for Ozone Reduction Strategies) brings together representatives of citizen groups, industry, local governments, environmental groups, academics, and regulatory agencies. The group is

committed to designing control strategies in conjunction with the Air Quality Modeling Group (AQM) at the University of Houston's main campus. PPOP serves as a group facilitator and funds TFORS in conjunction with the University of Houston. By the end of August, the TFORS group had just defined its initial goals. Much more is planned for 2002.

PPOP also continued facilitating two TMDL (Total Maximum Daily Load) groups overseen by the TNRCC and the Houston-Galveston Area Council of Government (H-GAC). The goal of a TMDL group is to achieve consensus on a series of recommendations for improving the water quality of a particular waterway. Most group members are stakeholders concerned about policy formation. Typical stakeholders include individual concerned citizens as well as representatives from regulatory agencies, environmental organizations, corporate and industrial concerns, and various branches and levels of government. One TMDL group is focused on fecal coliform bacteria levels along segments of Buffalo and White Oak bayous. The other group considers the dioxin levels in the Houston Ship Channel. PPOP's role in these TMDL projects is to manage the consensus process at stakeholder meetings and further the exchange of information between stakeholders, the TNRCC, and scientists.

Also ongoing is a similar facilitation process for the Galveston Bay Freshwater Inflows Group (GBFIG). Members include staff from relevant natural resource agencies, water district managers, and representatives from environmental, fisheries, industrial, municipal, and agricultural interests. The group has been meeting since 1996 to devise strategies to maintain adequate freshwater inflows to Galveston Bay by reviewing relevant scientific and technical information.

Public outreach is the other significant category of work for PPOP. The Galveston Bay Estuary Program (GBEP) contracted PPOP in 2000 to manage the revision of the second edition of its 1994 publication *The State of the Bay: A Characterization of the Galveston Bay Ecosystem*. Most revision work occurred in fiscal

2001. With an estimated 230 pages, the publication is designed to describe the Galveston Bay estuary to a nontechnical audience. This edition represents a significant update. Major topics include the history of human use of the estuary, descriptions of local ecosystems, important geophysical and hydrological processes, the environmental quality of biotic and abiotic resources, the status of animal and plant populations, and the effects of the Bay on public health (such as seafood safety and air quality). These topics are framed in the terms of GBEP's Galveston Bay Plan. Several themes span these topics, such as the development of public and private partnerships to conserve and restore the Bay's resources.

Another ongoing form of public outreach is the creation of a series of public education display boards available for instructors, civic groups, private organizations, and conferences. These display boards incorporate current research around particular issues. As appropriate, the boards emphasize citizen action and participation as a means of addressing environmental problems. In 2001, a display board on the history of resource use around Galveston Bay and another on the TMDL process was created. These boards have been used as a basis for web-based displays along the same topics. Forthcoming topics include Houston air quality and the restoration of submerged aquatic vegetation (such as seagrasses) around Galveston Bay.

Finally, other noteworthy events at PPOP in 2001 include the addition of several key new staff members and the expansion of physical tools (such as computers and workspace) that will allow PPOP to operate effectively.

For 2002, PPOP will continue to promote the public's involvement in environmental policy. Several of the projects described above will continue, including work with Mothers for Clear Air and air and water quality projects. A few projects will draw to their end, as when *The State of the Bay* publishes. Many projects will enter new phases, such as the quickening of TFORS's pace. And several projects will be launched, including a new GBEP-affiliated invasive species venture and the collating of Galveston Bay environmental quality data from numerous agencies for posting on the Internet. The new year holds much promise.

**Project descriptions and displays can be found on the Public Participation and Outreach Program Web page:**  
<http://www.eih.uhcl.edu/outreach/>

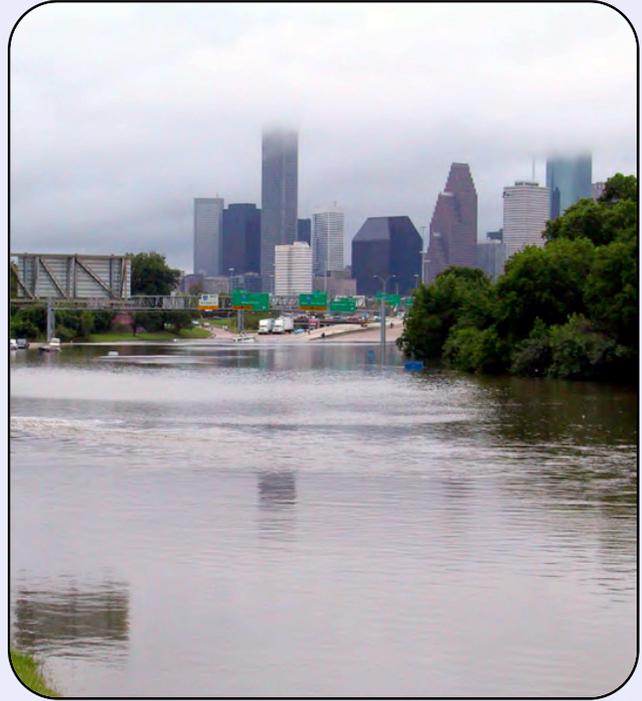


Photo courtesy of Dan Wallace

### **Tropical Storm Allison Online**

Drainage Forum: The Allison Experience  
University of Houston College of Engineering  
<http://www.egr.uh.edu/forum/>

Tropical Storm Allison Recovery Project  
FEMA and HCFCD Cooperative  
<http://www.tsarp.org>

The Great Flood of 2001  
The Houston Chronicle  
<http://www.chron.com/content/chronicle/special/01/flood/>

Tropical Storm Allison Floods  
National Weather Service Houston/Galveston  
<http://www.srh.noaa.gov/ftproot/hgx/html/projects/allison01.htm>

The Big One: Tropical Storm Allison at the  
University of Houston's O'Quinn Law Library  
<http://www.uh.edu/libraians/jschultz/TheBigOne.html>

# Air Education in Houston: Changing Our Image

Brenda Weiser and Sally Wall  
University of Houston-Clear Lake

**H**OUSTON is one of the largest cities in the nation. The greater Houston-Galveston area is the home of petroleum and chemical plants, headquarters for many multinational companies, the space program, and leading medical facilities. In addition, this flat, coastal area is home to millions of people and a variety of sub-tropical ecosystems. Unfortunately, Houston now battles Los Angeles for the title of the city with the worst smog and has been portrayed as a dirty, unhealthy place.

In metropolitan areas such as the greater Houston area, many children live in an urban setting and do not have an understanding about the environment and environmental issues. There is very little air quality education conducted in our classrooms. Thus, these students learn about air, air quality, and issues relating to air pollution from the local television stations and the Internet. Opportunities may exist for students to visit a plant or have guest speakers present information to them, but few ever experience this.

Ultimately, children are growing up without experiencing the environment around them or understanding the issues related to the place they live. Though the Houston-Galveston area is unique, many educators and community residents never consider the natural environment, environmental issues, or the different cultures associated with the urban and suburban settings. Generations of children are being raised with limited exposure to the environment and the opportunity to investigate environmental issues. Students of today are the decision-makers of tomorrow. They need a better understanding of their environment and local environmental issues and how to assess the many reports as they relate to environmental issues such as air quality.

The Houston-Galveston area consists of 28 percent of the teacher population in Texas distributed among 54 school districts. In addition, over 22 percent of the state's students live in the Houston-Galveston area. In the seven counties around the Houston area, many of these students represent an under-served population. Twenty-two percent of the students in the area are

African-American and 35 percent of the students in the area are Hispanic. Approximately 45 percent of the students in the Houston-Galveston area are economically disadvantaged and about 15 percent of these students have limited English proficiency.

Many teachers recognize their students' disconnection from the environment and environmental issues. Some teachers attempt to teach about the environment and environmental issues but most do not have the appropriate expertise and resources. Very few materials have been developed that can be used in the classroom to emphasize the importance of the environment for our health and economy. Even fewer materials teach how to think critically about environmental issues.

A majority of pre-service educators graduate and obtain teacher certification without any formal instruction in environmental education (EE). According to Rosalyn McKeown-Ice, only nine percent of teacher colleges require elementary education majors to take a practicum in EE and only seven percent of the teacher colleges require a practicum for high school teachers<sup>1</sup>. In addition, very few schools require their teachers to teach about the environment or incorporate EE into their curriculum<sup>2</sup>. Thus, teachers do not feel comfortable leading a discussion on environmental issues nor do they have the necessary background to teach about the environment. Like the majority of students being prepared to enter the teaching profession, teachers in the Houston-Galveston area lack the appropriate education to incorporate environmental education within their curriculum or to address environmental issues in classroom discussion. As a result, there is increasing interest in professional development on environmental issues, including air quality and energy, and in learning how to incorporate such knowledge within the formal classroom.

The Environmental Institute of Houston at University of Houston-Clear Lake conducts teacher professional development for both formal and non-formal educators across the Houston-Galveston area. Many of these professional development opportunities involve a six to eight hour workshop and use leading

environmental education materials, such as Project Learning Tree, Project WILD, and Project WET. All of these programs were developed using broad-based writing teams and a national evaluation process and are recognized model programs in the field of environmental education. These programs represent both sides of issues, are based on sound science, and are easy to use by the educator.

However, there is not a national environmental education program that has undergone a national evaluation process and is recognized by the leaders in environmental education that focuses strictly on air education. There are many small activity packets, pamphlets, and resources available to teachers but these are not easy to identify nor easy to obtain. Therefore, the Environmental Institute of Houston is striving to establish an air education curriculum designed for Texas educators that will address issues relating to the air issues in Texas.

This curriculum will provide educators with needed background information and materials to incorporate air education into their courses. The curriculum will address specific topics including what is ozone and how does it form; how does one contribute to everyday air pollution; conservation practices that impact the air quality; green spaces and air quality; and environmental health issues as they relate to air.

To accomplish this task, an educator was hired to research and evaluate existing air education curriculum/materials to meet the needs of Texas educators. In addition, the educator developed new activities. These activities will be pilot tested and field tested by local educators. Revisions will be made to the activities based on the input from the pilot and field test teachers. The materials will be bound and distributed to educators through workshops and summer institutes conducted by UHCL. In addition, the activities will be correlated to the appropriate Texas Knowledge and Skills and the correlations will be provided to the teacher.

The target audience for the air curriculum/materials will be the teachers of middle school Science, Integrated Physics and Chemistry, and the Algebra I classes. Initial conversations with representatives from Houston ISD, Clear Creek ISD, Pearland ISD, and Cypress-Fairbanks ISD indicated a need to create workable integrated lesson plans focusing on middle school Science, Integrated Physics and Chemistry, and Algebra I. However, the curriculum/materials being adapted and developed will be flexible so that other science, math, and social studies teachers can use them.

By providing accurate, balanced educator workshops, teachers are encouraged to incorporate air education into their classrooms and the students learn how to think and not what to think regarding air pollution, air quality, and related issues. This benefits the students, teachers, and the community as others learn about air and air quality, and related environmental issues.

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Photo courtesy of Julia Morgan

**1,656 Harris County businesses sustained damages totalling \$1.1 billion.**



Photo courtesy of Julia Morgan

**Over 70,000 cars were flooded during Tropical Storm Allison.**

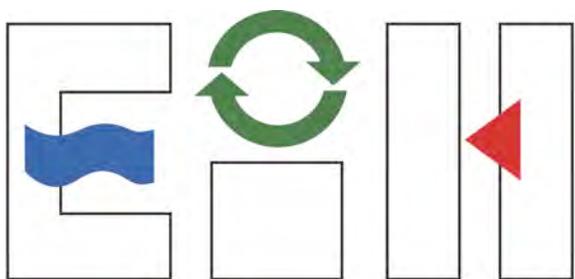
Source: Harris County Office of Emergency Management



**Buffalo Bayou, looking upstream from Main Street on June 9, 2001.**

Photo courtesy of Robert Eury

<b>Investigator</b>	<b>Title</b>	<b>Department</b>	<b>Phone</b>	<b>E-mail</b>
Amy M. Babb	Research Assistant	Environmental Science, UHCL	713-520-8856	
Michael Benedik	Associate Professor	Biology & Biochemistry, UH	713-743-8377	benedik@uh.edu
Steven R. Blanke	Assistant Professor	Biology & Biochemistry, UH	713-743-8392	sblank@uh.edu
Christina Blankenship	Research Assistant	Environmental Science, UHCL	281-283-3950	blankenshipc@cl.uh.edu
Henry S. Chafetz	Professor	Geosciences, UH	713-743-3427	hchafetz@uh.edu
Charles F. Dingman	Graduate Student	Environmental Science, UHCL	281-461-0414	ihss@vonl.com
Zac Forsman	Research Assistant	Biology & Biochemistry, UH		zac@uh.edu
Robert P. Goldman	Research Assistant	Biology & Biochemistry, UH	713-743-2628	goldman_rp@yahoo.com
Janice Harper	Assistant Professor	Anthropology, UH	713-743-3790	harper@uh.edu
David Herman	Research Assistant	Civil & Env. Engineering, UH	713-743-4283	david.herman@mail.uh.edu
Cindy Howard	Associate Professor	Biology & Env. Science, UHCL	281-283-3745	howardc@cl.uh.edu
W. Andrew Jackson	Assistant Professor	Civil Engineering, Texas Tech U.	806-742-3523	andrew.jackson@coe.ttu.edu
Dakshina Jandhyala	Doctoral Candidate	Biology & Biochemistry, UH	713-743-8378	ajand@UH.EDU
Jack Y. Lu	Assistant Professor	Chemistry, UHCL	281-283-3780	lu@cl.uh.edu
Dan Luss	Professor	Chemical Engineering, UH	713-743-4305	dluss@uh.edu
Bharat M. Marwaha	Research Assistant	Chemical Engineering, UH	713-743-4341	bmarwaha@Bayou.uh.edu
Tom McKinney	Research Assistant	History, UH	713-838-7801	tmack2k1@ev1.net
Dean L. Muirhead	Research Associate	Water Resources Center	806-742-3597	
Karen Plessinger	Research Assistant	Anthropology, UH	713-743-2780	kplessinger@uh.edu
Anna Pokluda	Research Assistant	Anthropology, UH	281-286-5265	enderlil@aol.com
James T. Richardson	Professor	Chemical Engineering, UH	713-743-4324	jtr@uh.edu
Deborah Roberts	Associate Professor	Civil & Env. Engineering, UH	713-743-4281	djroberts@uh.edu
Mohammad Shafiei	Research Assistant	Chemical Engineering, UH	713-743-4300	msshafiei@uh.edu
Tracy Smith	Research Assistant	Anthropology, UH	281-370-2109	tsmith21@uh.edu
Hao Song	Research Assistant	Chemical Engineering, UH	713-743-4336	shao@bayou.uh.edu
Jim Sui	Research Assistant	Environmental Sciences, UHCL	281-481-5886	suix@cl.uh.edu
Penny M. Taylor	Doctoral Candidate	Geosciences, UH	713-743-3417	ptaylor@uh.edu
Michael Travisano	Assistant Professor	Biology & Biochemistry, UH	713-743-2627	mtrav@uh.edu
Sally Wall	Air/Energy Curr. Spec.	Env. Institute of Houston, UHCL	281-283-3045	wall@cl.uh.edu
Keh-Han Wang	Associate Professor	Civil & Env. Engineering, UH	713-743-4277	khwang@uh.edu
Brenda Weiser	EE Prog. Manager	Env. Institute of Houston, UHCL	281-283-3960	weiser@cl.uh.edu
Gerard M. Wellington	Professor	Biology & Biochemistry, UH	713-743-2649	wellington@uh.edu
A. Neil Williams	Professor	Civil & Env. Engineering, UH	713-743-4269	awilliams@uh.edu
Rong Yang	Graduate Student	Biology & Biochemistry, UH		ryang@uh.edu
Chunlong Zhang	Assistant Professor	Env. Science & Chemistry, UHCL	281-283-3746	zhang@cl.uh.edu
Gabriel Zheng	Research Assistant	Environmental Sciences, UHCL	281-286-7648	zhengg@cl.uh.edu



Environmental Institute of Houston

University of Houston  
University of Houston-Clear Lake  
2700 Bay Area Blvd.  
Houston, Texas 77058-1098

Director—Phone: (281) 283-3950  
Editorial—Phone: (281) 283-3948  
E-mail: [eih@uhcl.edu](mailto:eih@uhcl.edu)  
<http://www.eih.uhcl.edu>