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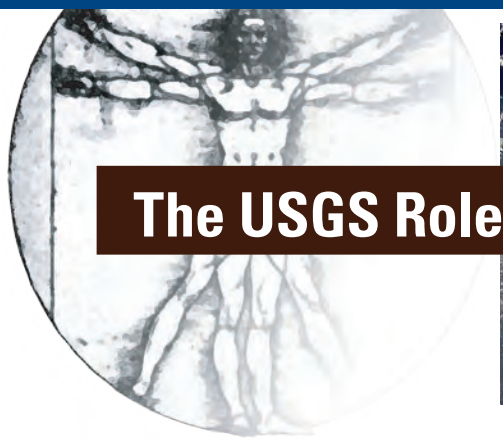
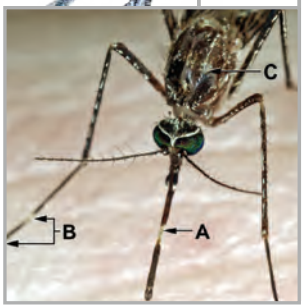


The USGS Role in Public Health Science

Earth Science and Public Health: Proceedings of the Second National Conference on USGS Health-Related Research



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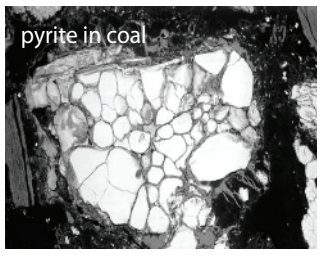

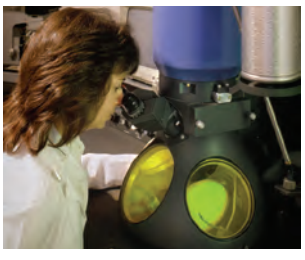

U.S. Department of the Interior
U.S. Geological Survey

Earth Science and Public Health: Proceedings of the Second National Conference on USGS Health-Related Research

Edited by Herbert T. Buxton, Dale W. Griffin, and Brenda S. Pierce

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
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U.S. Geological Survey
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U.S. Geological Survey, Reston, Virginia: 2007

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The abstracts in this volume that were written to by U.S. Geological Survey authors were reviewed and approved for publication by the Survey. Abstracts submitted by researchers from academia and from state and other Federal agencies are published as part of these proceedings, but do not necessarily reflect the Survey's policies and views.

Foreword

Human health so often depends on the health of the environment and wildlife around us. The occurrence of environmental contaminants and the emergence of zoonotic and vector-borne diseases are growing concerns worldwide. Chemical and pathogenic contaminants in drinking water, in recreational waters, in the air, dust, and soil we touch and breathe, and in the food we eat can be threats to public health that require innovative, science-based solutions. The Institute of Medicine Roundtable on Environmental Health Sciences, Research, and Medicine states *"In its broadest sense, the environment is one of the major determinants of human health and well-being. … Underlying the need for enhanced education of health professionals is the need for more research… that will further elucidate the linkages that exist between the environment and human health..."*

Throughout its existence, the U.S. Geological Survey (USGS) has provided scientific information vital for understanding and solving problems associated with our earth and living resources. Core capabilities in ecology and wildlife disease, hydrologic science, environmental geochemistry, geospatial analysis, and other fields enable USGS to be a significant partner in finding improved solutions to public health problems.

USGS involvement in human health occurs through strong partnerships with health and environmental organizations. These partnerships are essential for translating natural science information to public health applications. USGS scientists already are working closely with the public health community to pursue rigorous inquiries into the connections between natural science and public health.

This conference strengthened these partnerships and promoted interdisciplinary approaches to public health. The science presented in the workshop included many success stories of how scientific understanding and information has helped protect public health. Rapid monitoring methods and Internet-based models now enable beach goers to consider current bacteriological conditions before they leave for the day. Understanding of the geochemical factors that affect the mobilization of arsenic in ground water helps water managers protect drinking water supplies. Knowing the factors that affect the spread of West Nile Virus, including host animals and vectors, will help the public take appropriate precautions against being infected. Monitoring the flying patterns of migratory birds infected by Highly Pathogenic Avian Influenza assists health professionals prepare for potential disease outbreaks. Characterizing environmental disturbances after environmental disasters, such as Hurricane Katrina, help the public return safely to their homes.

These are only a few examples of the contributions being made by new collaborations among the natural and health sciences. As a whole, the research presented and discussed at this conference demonstrates the great potential for the integration of these sciences to solve complex societal problems.

Mark D. Myers, Director
U.S. Geological Survey
October 2007

Acknowledgments

The Geological Society of America and the Armed Forces Institute of Pathology are acknowledged for their co-sponsorship of this conference. We also are grateful to the invited speakers, Catherine Skinner, Jose Centeno, Sarah Noble, Robert Cook, Kathryn Mahaffey, Toni Glymph, and Marguerite Pappaionou. Their participation in this conference advanced the dialogue between the earth-sciences and human-health communities. The scientists who moderated and facilitated discussions during the breakout sessions are acknowledged for their important contributions, including capturing important results during the discussions, which are included in this report. Most importantly, we thank the scientists who presented their research and case studies at the conference and the effort they have made to make their science more useful to the human health community. The conference organizers (listed at the back of this report) also are acknowledged for their diligence and thorough attention to detail, which made the conference both interesting and enjoyable.

Contents

Earth Science and Public Health: Proceedings of the Second National Conference on USGS Health-Related Research

Edited by Herbert T. Buxton[1], Dale W. Griffin[2], and Brenda S. Pierce[3]

Introduction

The mission of the U.S. Geological Survey (USGS) is to serve the Nation by providing reliable scientific information to describe and understand the earth; minimize loss of life and property from natural disasters; manage water, biological, energy, and mineral resources; and enhance and protect our quality of life. As the Nation's largest water, earth, and biological science and civilian mapping agency, the USGS can play a significant role in providing scientific knowledge and information that will improve our understanding of the relations of environment and wildlife to human health and disease. USGS human health-related research is unique in the Federal government because it brings together a broad spectrum of natural science expertise and information, including extensive data collection and monitoring on varied landscapes and ecosystems across the Nation.

USGS can provide a great service to the public health community by synthesizing the scientific information and knowledge on our natural and living resources that influence human health, and by bringing this science to the public health community in a manner that is most useful. Partnerships with health scientists and managers are essential to the success of these efforts. USGS scientists already are working closely with the public health community to pursue rigorous inquiries into the connections between natural science and public health. Partnering agencies include the Armed Forces Institute of Pathology, Agency for Toxic Substances Disease Registry, Centers for Disease Control and Prevention, U.S. Environmental Protection Agency, Food and Drug Administration, Mine Safety and Health Administration, National Cancer Institute, National Institute of Allergy and Infectious Disease, National Institute of Environmental Health Sciences, National Institute for Occupational Safety and Health, U.S. Public Health Service, and the U.S. Army Medical Research Institute of Infectious Diseases. Collaborations between public health scientists and earth scientists can lead to improved solutions for existing and emerging environmental health problems.

This report summarizes the presentations and discussions held at the Second National Conference on USGS Health-Related Research, held at the USGS national headquarters in Reston, Virginia. The report presents 68 abstracts of technical presentations made at the conference and summaries of six topical breakout sessions. The abstracts cover a broad range of issues and demonstrate connections between human health and the quality and condition of our environment and wildlife. The summaries of the topical breakout sessions present ideas for advancing interdisciplinary science in areas of earth science and human health.

[1] USGS, West Trenton, New Jersey

[2] USGS, Tallahassee, Florida

[3] USGS, Reston, Virginia

Conference Purpose and Design

This conference was designed to provide a broad forum for discussion by bringing together policy makers, scientists, resource managers, and representatives of elected officials, Federal and state governments, and non-governmental organizations. The primary objectives of the conference were to build partnerships and share science so as to provide better information to policy makers, decision makers, and emergency officials. To meet these objectives, the conference focused on:

- Enhancing communication efforts across Federal agencies;
- Identifying common/similar science interests to leverage science research, results, and resources; and
- Establishing joint science investigations and cooperative partnerships.

Furthermore, the conference assisted USGS in (1) demonstrating the information and science that USGS provides to public health scientists and managers and how it is used; (2) improving relationships between USGS biologists, chemists, geographers, geologists, hydrologists, and other scientists and their partners in the public health sciences; and (3) helping increase the use of USGS information by the public health community.

The conference was organized in three major sessions. The first session was a general session with overview and keynote presentations on linkages between the natural environment and human health, and the human health insights gained from applying information and knowledge of earth and living resources to public health concerns.

The second session was organized in six individual topical areas that define the linkages between our natural environment and human health. These six topics are:

1. Exposure to Toxic Contaminants in Air, Dust, and Soil,
2. Chemical and Pathogen Exposure through Drinking Water,
3. Animals as Sentinels of Human Health,
4. Human Consumption of Bioaccumulative and Other Chemical and Pathogenic Contaminants,
5. Chemical and Pathogen Exposure through Recreational Waters, and
6. Zoonotic (animal to human) and Vector-Borne Diseases.

Each topical area was addressed by two speakers. One speaker was an earth, environmental, or wildlife scientist and the second was a public health scientist. Each pair of speakers presented perspectives and needs from their side of the environment-human health continuum.

The third and final session was composed of breakout sessions on each of the six topical areas. The breakout sessions encouraged discussion of opportunities for future collaborations across the environmental and human health disciplines to improve communication and cooperation and break down existing or perceived barriers to interdisciplinary research.

Conference Agenda and Speakers

The conference was held February 27th through March 1st, 2007, at the U.S. Geological Survey national headquarters in Reston, Virginia. The conference agenda follows.

Conference Agenda

Tuesday, February 27

1:00 – Opening Session
Robert E. Doyle, Deputy Director, U.S. Geological Survey
Timothy R. Petty, Deputy Assistant Secretary for Water and Science, U.S. Department of Interior
2:15 – Keynote Speakers
H. Catherine W. Skinner, Yale University – "Earth Materials and Health: Research Priorities for Earth Science and Public Health"
Jose A. Centeno, Armed Forces Institute of Pathology – "Integrating Earth Sciences and Public Health: Examples from a Successful Department of Defense – U.S. Geological Survey Collaboration"
3:45 – General Topical Poster Session
- Exposure to Toxic Contaminants in Air, Dust, and Soil
- Chemical and Pathogen Exposure through Drinking Water
- Animals as Sentinels of Human Health
- Human Consumption of Bioaccumulative and Other Chemical and Pathogenic Contaminants
- Chemical and Pathogen Exposure through Recreational Waters
- Zoonotic and Vector-Borne Diseases

Wednesday, February 28

8:00 – Exposure to Toxic Contaminants in Air, Dust, and Soil
Sarah K. Noble, NASA
Geoffrey S. Plumlee, USGS
9:45 – Chemical and Pathogen Exposure through Drinking Water
G. Rob Robinson, USGS (for Kenneth Cantor, National Cancer Institute)
Michael J. Focazio, USGS
11:00 – Animals as Sentinels of Human Health
Robert A. Cook, Wildlife Conservation Society
Rick F. Kearney, USGS
12:15 – Lunch
1:30 – Breakout/Discussion Sessions:
- Exposure to Toxic Contaminants in Air, Dust, and Soil
- Chemical and Pathogen Exposure through Drinking Water
- Animals as Sentinels of Human Health

4:00 – Scientific Poster Session

Thursday, March 1

8:15 – Human Consumption of Bioaccumulative and Other Chemical and Pathogenic Contaminants
Kathryn R. Mahaffey, USEPA
William H. Orem, USGS
9:45 – Chemical and Pathogen Exposure through Recreational Waters
Toni Glymph, Wisconsin Department of Natural Resources
Donna S. Francy, USGS
11:00 – Zoonotic and Vector-Borne Diseases
Marguerite Pappaionou, University of Minnesota
Erik K. Hofmeister, USGS

12:15 – Lunch
1:30 – Breakout/Discussion Sessions:
Human Consumption of Bioaccumulative Contaminants
Chemical and Pathogen Exposure through Recreational Waters
Zoonotic and Vector Borne Diseases
4:00 - Adjourn

Abstracts

The abstracts presented are organized in seven sections – a section on human health overview topics and one each on the six topical areas discussed throughout this report.

Human Health Overview Topics

Earth Materials and Health

H. Catherine W. Skinner
Yale University, New Haven, Connecticut

Many Earth Materials have been impugned as hazards and we have become much more aware, and cautious, about what we breathe, eat and drink. Fortunately or unfortunately, depending on personal outlook, we will and must continue to inhale and ingest. As earth scientists we continually investigate the distribution of natural materials, and the expanding amount of synthetic materials in our environment, and the processes by which they impinge on our well being. To understand the potential, as well as to seek preventative alternatives to some already defined health issues, I plan to share some perspectives from the recently published Report of a Committee (National Research Council and Institute of Medicine) convened to seek research priorities between earth sciences and public health.

The first and foremost conclusion of the Report was that interdisciplinary collaboration was essential. Starting with a health issue anywhere on the globe information can now be made rapidly available through international communications to a broad scientific community. It is a truism that early detection leading to prevention of hazardous situations and disease rather than control and treatment, affords the greatest advantages to the largest number of individuals. The early warning systems for tsunamis or the identification and mode of transfer of infectious disease such as malaria are well known. However, the silent, chronic hazards, those that cannot be seen, tasted or smelled, those that are low level, or intermittent, and expose unsuspecting and susceptible individuals remain to be adequately identified and assessed in spite of the vastly increased sensitivity of assay techniques, geochemical, geophysical and biomedical. Some progress has been made on a few contaminants/ pollutants which we hear and read about: arsenic in waters and foods, radon, or CO_2 and asbestos in the air. However, adequate remediation and preventative methodology even for these potential hazards are still under investigation or development and may not yet be adopted because of magnitude of the challenges and expense.

Geo- and medico-scientists are evaluating other potentially hazardous elements, compounds and man-made materials accumulating or already present in our environment but whose known biogeochemical signatures are not yet under geo- or bio-surveillance. The committee recommended expanded and, if possible continual, collaborative activities that would allow risks-assessment to be undertaken. Models that incorporate basic information of earth based materials and activities, the fate and transport of known or potentially hazardous materials, with possible particular human health impacts have been attempted. More accurate and sensitive data provided from the diverse geological and biological/epidemiological sources will be necessary for any comparison and application to these interdisciplinary problems to succeed and advance the benefit to global populations.

Human Health and our Natural and Developed Environments: The USGS Role in Public Health Science

Herbert T. Buxton
U.S. Geological Survey, West Trenton, New Jersey, hbuxton@usgs.gov

Concerns for public health problems caused by emerging infectious diseases and environmental contamination persist worldwide. Vector-borne and zoonotic diseases, water contamination, airborne contaminants, contaminants in the food chain, and other environmental threats require marshalling of all our scientific knowledge and know-how through new partnerships, approaches, and solutions that transcend traditional disciplinary boundaries. The USGS provides scientific information on the quantity and quality of our natural resources. However, this information has value well beyond the management of those resources. It can be essential to sustaining effective public health practices and policies.

As the Nation's natural science agency, the USGS has reached out to human health scientists and managers through the Institute of Medicine, Roundtable on Environmental Health Sciences, Research, and Medicine; the Interagency Zoonotic Disease Working Group; the Interagency Steering Committee for the Early Detection of Highly Pathogenic Avian Influenza in Wild Birds; the Committee on Environment and Natural Resources' Toxics and Risk Subcommittee; the World Organization for Animal Health; The UN Food and Agriculture Organization; and the Centers for Disease Control and Prevention's Indo-American Working Group on Environmental Health. The USGS is working with new partners: the National Institute of Environmental Health Science, the Armed Forces Institute of Pathology, the Agency for Toxic Substances and Disease Registry, the National Cancer Institute, the National Institute of Allergy and Infectious Diseases, the Centers for Disease Control and Prevention, and the Food and Drug Administration. In 2004, the USGS commissioned the National Research Council study to assess earth science research priorities supporting human health.

In an effort to integrate and increase access to our human health related research, the USGS has developed the Internet site, *health.usgs.gov*. It presents our results in 6 topical areas of human health concern: (1) toxic contaminants in air, dust, and soils; (2) chemical and pathogenic contaminants in drinking water; (3) human consumption of bioaccumulative contaminants; (4) zoonotic and vector-borne diseases; (5) pathogen exposure through recreational waters; and (6) animals as sentinels of human health. These are areas we believe USGS can provide scientific knowledge and information that improves the understanding of environmental contributions to disease and human health. These are areas in which we seek partnerships with health agencies and scientists in applying such information to solutions.

Evaluating the Use of Stable Isotope and Uncertainty Analyses to Model Aquatic Environmental and Public Health Indicators

Michael S. Bank
Harvard School of Public Health, Department of Environmental Health, Boston, Massachusetts

Assessing the causes and consequences of aquatic ecosystem health often involves the use of models to aid in predicting which regions and ecosystems may be most sensitive to broad scale environmental pollutants (i.e., from atmospheric deposition). Mercury deposition and contamination in the United States is widespread and well-documented and continues to be a public-health issue of great concern for certain sectors of the global human population. Documentation of the pervasiveness of this contaminant is a first step toward understanding the potential environmental health and ecological implications of mercury pollution. Identifying broad scale distribution patterns of mercury bioaccumulation can convey to regulators that certain ecosystems may be degraded and require development of policies and regulations that may reduce mercury emissions, and ultimately, improve air and water quality. A more synthesized, heuristic, perspective on the mechanisms related to aquatic and terrestrial biogeochemistry linkages of fate, transport, and bioavailability of mercury in aquatic ecosystems will result from long term, multi-ecosystem monitoring programs coupled with process-oriented research questions. Through a series of place and process based case studies I present total and methyl mercury data from coastal freshwater ecosystems in the conterminous United States and evaluate the use of stable isotope and uncertainty analysis techniques for comparative modeling purposes. I evaluate variation in mercury bioaccumulation and distribution in aquatic ecosystems across a broad gradient of physical, climatic, biotic, and ecosystem settings to identify the environmental conditions and ecosystem types that are most sensitive to mercury pollution. The role of disturbance mechanisms and abiotic and biotic processes governing mercury distribution and bioaccumulation in the different ecosystem types will also be discussed.

Toxic Substances Hydrology Program Activities Related to Human Health

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The U.S. Geological Survey (USGS) Toxic Substances Hydrology (Toxics) Program provides objective and reliable scientific information needed to develop policies and practices that help reduce human exposure to toxic substances, mitigate environmental deterioration from contaminants, provide cost-effective environmental cleanup remedies, develop safe waste-disposal strategies, and reduce future risk of contamination. Contamination of surface water, ground water, soil, sediment, and the atmosphere by toxic substances is among the most significant issues facing the Nation. Contaminants such as excessive nutrients, industrial solvents, fuel oxygenates, metals, pharmaceuticals, and pathogens enter the environment--often inadvertently--through industrial, agricultural, mining, household, or other human activities.

The Toxics Program works in partnership with other Federal agencies (including public-health agencies, such as the Centers for Disease Control and Prevention, the Food and Drug Administration, and the National Institute for Environmental Health Sciences) to ensure that priorities for science needs are coordinated and satisfied. The Program contributes information that provides the scientific basis for decisions to minimize human and environmental health risks and consensus on contentious issues.

The Toxics Program conducts (1) intensive site-scale field investigations of subsurface contamination at local releases, (2) watershed- and regional-scale investigations of contamination affecting aquatic ecosystems from nonpoint and distributed point sources, and (3) research on the development of field and laboratory methods to study the fate and transport of contaminants in the environment. Many of these investigations relate either directly or indirectly to the protection of human health. Examples include:

- Investigating the occurrence and fate of pharmaceuticals and other emerging contaminants in the environment,
- Developing field and laboratory analytical methods to measure pesticides in sediment and water and methods to assess the impacts of pesticides on the quality of water resources,
- Conducting research on the factors controlling mercury methylation and accumulation in aquatic ecosystems, and on whether plans for reducing mercury emissions will result in corresponding reductions in the bioaccumulation of mercury by fish, and
- Conducting long-term research on the natural attenuation of contaminants in ground-water resources, such as solvents, fuel oxygenates, radionuclides, and nutrients

More information on the Toxics Program is available on the Internet at: toxics.usgs.gov.

GSA Geology and Health Division: Promoting Research, Education, and Practice in Sister Sciences

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[2]*Ontario Geological Survey, Sudbury, Ontario, Canada*

Global impacts of respirable dust particles transported by massive sandstorms blowing off the northwest African desert; naturally occurring arsenic which contaminates drinking water supplies in Bangladesh; particles of rock clinging to the body and clothes of a murder victim; landslides snuffing out lives and destroying property in California, the Philippines, and Honduras; trauma in survivors of Hurricane Katrina – these are but a few of the complex earth science and human health issues facing a large segment of the human population. This poster will highlight other complex environmental issues whose solution requires the collaboration of the sister disciplines of the geoscience and the health science communities.

To bring the resources of the geosciences and health sciences to bear on these human health threats, the Geological Society of America (GSA) has recently formed the Geology and Health Division. By drawing together researchers, educators, and practitioners in these sciences, the Geology and Health Division aims to:

- Promote interdisciplinary relationships,
- Encourage research,
- Facilitate presentations and discussion,

- Mentor students, and
- Enable networking within GSA and with other organizations.

The Division is organizing topical sessions at the GSA Annual Meetings, developing a specialty meeting on geology and health with the collaboration of the USGS, and actively building bridges to the international and health sciences communities. All GSA members are eligible to join the Geology and Health Division.

BS/MPH Degree Program: Geology and Human Health – Global to Self

William B. Size
Emory University, Atlanta, Georgia

A new integrative and interdisciplinary BS/MPH 5-year degree program at Emory University between the Departments of Environmental Studies and Environmental and Occupational Health, Rollins School of Public Health is described. Students pursuing a career in public health need a foundation in Earth systems and processes that impact human health, such as water pollution, heavy metals, soil chemistry, and biogeochemical cycling. The program specifics can be found at http://www.sph.emory.edu/eoh/bsmph5year.php. One course, Geology and Human Health – Global to Self, is used as an example of the integrative approach in the program. It begins with the relationships between the chemical composition of the human body with that of the Earth's crust and asteroids. The hydrologic cycle and global warming help explain the environmental and health effects of too much (floods), too little (drought), or too polluted (disease). Earth's metabolic pathways, or external geochemical cycles (P, S, C, and N) are compared with human body control systems (dynamic equilibrium or homeostasis). Respiratory, digestive, immune and nervous systems are examined in light of the pathways between the internal and external environment. The aging process in humans and the weathering process in rocks are visualized as basically one of oxidation. Natural catastrophes, such as earthquakes, tsunamis, and volcanic eruptions, are discussed in context with short term and generational health affects. The topic of what keeps us alive opens up discussions on energy flow and chemical cycling. This leads into paleopathology, ancient mass extinctions and the probability that it might happen again. Human health perspectives are also viewed in the mind/body practices of eastern medicine. The course concludes with the influence of geopolitics on risk assessment and world health.

Building Bridges for Collaboration between the Geosciences and Health Sciences: A Cross-disciplinary Training Conference

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[2]*Indiana University/Purdue University - Indianapolis, Indianapolis, Indiana*
[3]*U.S. Geological Survey, Reston, Virginia*
[4]*Loma Linda University, Loma Linda, California*
[5]*U.S. Geological Survey, Denver, Colorado*
[6]*University of Canterbury, Christchurch, New Zealand*

Purpose and Goals: Human health issues are increasingly viewed in the context of the natural world. That many diseases and injuries arise directly from exposure to natural or anthropogenic agents in the environment is well recognized. A deepening understanding of linkages between human health and the environment has been aided by collaboration between scientists and practitioners in the geosciences and the health sciences. However, communication and cooperation among these experts may be hampered by differences in vocabulary, models, research methods, etc.

USGS and the Geological Society of America (GSA) will convene a cross-disciplinary training conference in Reston, VA, on 4-6 December 2007. The purpose of this meeting is to outline the technical basis of the geosciences and of the health sciences to break through communication barriers, and to provide opportunities for professionals to work with their counterparts on case studies of environmental health hazards with geological and policy components.

Target audience: Scientists, practitioners, faculty, and students of the geosciences or health sciences, policy makers, resource managers, Congressional staffers, and employees of governments, universities, and non-governmental organizations are encouraged to attend.

Agenda: The meeting will consist of 5 different phases designed to introduce basic cross-disciplinary concepts, and provide opportunities to utilize newly-gained skills:

1 *Keynote addresses* by a geoscientist and a health scientist will establish the background and need for collaboration.

2. *Cross-disciplinary sessions* will introduce scientists and practitioners to concepts, vocabulary, models, methods, and key resources used by their counterparts.

3. Small interdisciplinary groups will discuss *"earth sciences and health" case studies* (e.g., Superfund sites, heavy metal contamination of drinking water supplies, development of new energy sources, and origin, effects, and characteristics of atmospheric particulates). Prime objectives will be the discovery and observation of the analytical approaches and processes utilized by counterpart professionals.

4. *Poster sessions* will illustrate case studies and suggest barriers and solutions to cross-disciplinary collaboration.

5. In the *closing session,* participants will be invited to make suggestions for the way forward in building bridges for col laboration across the disciplines.

Interdisciplinary Science in Support of Environmental Health along the United States – Mexico Border

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Water shortages, pollution, impaired air quality, increased soil salinities, pesticides, and heavy metals are examples of stressors degrading the environment and quality of life along the United States–Mexico border. The relationship between health and environmental quality challenges public officials, medical professionals, and resource managers on both sides of the border to provide for and maintain healthy communities. The U.S. Geological Survey (USGS) created an Internet Map Service (IMS) to facilitate understanding the relationship between environmental and human health. The goal of the *Border Environmental Health Initiative* (BEHI) IMS is to provide seamless integration of binational datasets at regional and local scales that link the condition of the physical environment with public health issues.

An interdisciplinary USGS team identifies the biologic, geologic, hydrologic, environmental, public health, and demographic datasets. This team collaborates with other Federal, State, and local agencies, non-governmental entities, and universities in the United States and Mexico. Project success and the reliability of the databases depend on these mutually beneficial partnerships.

The BEHI website offers: *Maps and Data*—binational datasets and tools to manipulate them. The interface allows users to select combinations of layers and customize their view for the entire border, a subregion, or a town. *Data Layer*—major themes of anthropology, hydrology, transportation, biology, geology, imagery, elevation, land use, and disease are detailed with description, metadata, and viewable extents. Following web protocols, users may incorporate available layers into their own geospatial analyses. *Static Map Library*—ready-made maps of common views and themes that can be integrated into custom presentations.

An anticipated outcome of this project is an increased opportunity to collaborate with scientific researchers in the public health, natural resources, and environmental protection fields to apply the BEHI datasets and the IMS to address specific public and environmental health issues. The vision of the USGS is that such collaborations could expand the breadth and depth of the datasets available and allow more sophisticated analysis of border health issues, ultimately leading to a healthier border environment.

Exposure to Toxic Contaminants in Air, Dust and Soil

A Fall of Moondust: Assessing the Heath Effects of Exposure to Lunar Soil

Sarah K. Noble
NASA, Johnson Space Center, Houston, Texas

NASA is now preparing to return humans to the Moon. Unlike our first wobbly steps on the lunar surface, which only lasted a day or two, this time around astronauts may be staying on the Moon for weeks or months at a stretch. Spacesuits will protect them while they are in the field, but at the end of the day, they will return to their habitat and bring dust in with them: on their suits, on their tools, and of course, the samples they want to study or bring back to Earth.
Because of the environment at the lunar surface, moondust has properties unlike anything seen in terrestrial soils or rocks. The lower gravity, the lack of wind or water, the absence of an atmosphere, the effects of irradiation, and micrometeorite impact all contribute to the unique characteristics of lunar soil. Is this unique material hazardous to humans? We don't yet know.
The Apollo astronauts complained that the lunar dust got in their eyes, and irritated their noses and throats, though it seems to have had no lasting effect on them. Toxicologists and lunar geologists have teamed up to tackle this problem and studies are now being planned and executed to help us understand the acute effects of exposure as well as any possible long term damage that lunar soil may cause. This information will allow engineers to more efficiently design suits, habitats, equipment seals and other vital components to keep our astronauts safe and healthy

Research by the U.S. Geological Survey on the Occurrences of and Human Exposures to Potential Toxicants and Pathogens in Air, Dusts, and Soils

Geoffrey S. Plumlee
U.S. Geological Survey, Denver, CO

It has long been recognized that air, dusts (and other atmospheric particulates), and soils can contain a variety of natural and anthropogenic toxicants and pathogenic microbes that are either known or speculated to result in adverse health impacts on individuals or populations exposed above threshold levels. A broad range of U.S. Geological Survey (USGS) research provides impartial information that can be used by public health experts to better identify and understand potential human health hazards posed by these toxicants and pathogens. This research is truly interdisciplinary and collaborative, and integrates USGS expertise in earth, biological, and geospatial-information science with appropriate expertise in toxicology, epidemiology, cellular biology, public health, and other biomedical disciplines. Typical collaborations involve scientists from academia and other Federal, State, or local agencies.

A variety of USGS research projects seek to understand the physical, chemical, biological reactivity, and (or) microbial characteristics of air, dusts, or soils that may result in toxicity or pathogenicity, and the mechanisms by which toxicity or pathogenicity occur. Examples of materials studied include: dusts containing asbestos and other fibrous minerals; coal dusts, fly ash, and combustion gases; volcanic ash and gases; mine wastes; natural soils and soils contaminated by anthropogenic activities; dusts generated by the collapse of the World Trade Center; flood sediments left in New Orleans by hurricanes Katrina and Rita; intercontinental dusts or dusts generated by earthquakes and landslides that contain toxicants or pathogens; and natural or anthropogenic gases containing radionuclides such as radon. Other USGS research measures regional variations in soil chemistry, bioreactivity, and microbial populations to provide insights into baseline distributions of contaminants and pathogens, and how these baselines vary as a function of bedrock geology, soil type, climate, vegetation, ecology, and anthropogenic impacts. Still other USGS research helps characterize and map the distribution of geologic source materials from which potential toxicants can be liberated, such as rock units that contain asbestos or heavy metals, or that release radionuclides. An important component of this USGS research is the modification of existing and development of new natural-science technologies to help detect, sample, characterize, and (or) map the occurrence of potential toxicants and pathogens in air, dusts, and soils.

Further details of many USGS research activities on this topic can be found by clicking on the "air, dust, and soil" link at the web site *health.usgs.gov*.

Respiratory Health among Navajos as Impacted by Coal Combustion

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The sparsely populated Navajo Nation is situated in the Four Corners region of the USA (Arizona/Colorado/New Mexico/Utah) where air quality is generally not influenced by vehicular traffic and industrial activity. Coal-fired electricity generation using locally mined bituminous and subbituminous coal is one of the only industries on the reservation. Despite the lack of typical risk factors, there is much unexplained respiratory disease among Navajos. Indian Health Service hospital records, adjusted for population, indicate that residents of the Navajo Nation in Shiprock, NM, are at more than five times the risk of respiratory diseases and complaints than residents of 76 other locales farther away from the power plants. Because of the general absence of alternative, economically-viable home heating fuel, many residents of the Navajo Nation use local coal for domestic heating and cooking. This study presents data suggesting that poor air quality contributes to excess respiratory disease burden in some areas of the Navajo Nation. The Shiprock area was selected for study because residents are exposed to poor air quality indoors and outdoors from atmospheric thermal inversions that trap combustion products from two nearby large capacity coal-fired power plants. Indoor and ambient air samples were taken to calculate particulate matter (PM2.5) concentrations, and to characterize the organic and trace metal composition of PM2.5. Ambient air exceeded US EPA standards for PM2.5, and indoor levels were similar. Indoor exposure to coal combustion emissions was found to be elevated in many homes because 25% of those surveyed burned coal in stoves not designed for that fuel. Many other residents burn coal in old, improperly maintained and inadequately vented stoves. Because many residents believe that the coal they receive for free is of inferior quality than the coal feeding the power plants, coal and ash samples were collected from both the power plants and from residents' homes. Chemical analysis demonstrated that there are no significant differences in potentially toxic trace metal concentrations (all below EPA established exposure limits for inorganics). To control for possible confounders, future studies should link collection of indoor air quality data to concurrent respiratory health data.

Long-distance Transport of Persistent Organic Pollutants and Trace Metals in Saharan Dust Air Masses

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The Saharan dust system, the largest in the world, begins with wind lifting eroded mineral soils from the surface of the African Sahara and Sahel, and carrying billions of tons of dust from Africa to the Caribbean, the Americas, Europe and the Near East every year. The quantity of dust transported varies interannually as a result of global climate, regional meteorology, surface material, and land use, with a documented increase in the amount of dust transported to the Caribbean over the past 40 years (e.g. Prospero and Nees 1986). We suggest that the composition of dust air masses has changed over the past decades as a result of human activities in the source regions and the areas over which the dust travels: burning of biomass and waste; use of pesticides, plastics, other synthetic organics, and pharmaceuticals; and increased industrialization. A series of related projects was initiated to test our hypothesis that Saharan dust air masses carry persistent organic pollutants [(POPs); organochlorine pesticides, polycyclic aromatic hyrdrocarbons, polychlorinated biphenyls, dioxins and furans], trace metals, and viable microorganisms thousands of kilometers to the Americas and Caribbean, and that these contaminants and eroded mineral soils adversely affect downwind ecosystems and human health. POPs and trace metals have been identified in air samples from the Sahel (Republic of Mali) and from dust events in the Caribbean (U.S. Virgin Islands and Trinidad). Air samples from source regions (Mali) contain a greater number of POPs and in higher concentrations than found in Caribbean air samples from dust events. All identified POPs are known toxins, carcinogens, immune-system suppressors, and/or endocrine disruptors in humans and other organisms, and are active at very low concentrations. Trace-metal concentrations were similar to average crustal composition, with slight enrichment of lead in Mali. Correlations between high concentrations of particles < 2.5μm and increased mortality from cardiovascular events have been reported in a growing body of literature (e.g., Dockery et al. 1993). Synergistic effects between the very fine particles in Saharan dust over the Caribbean (< 1 μm), first row transition elements on the dust surface, and POPs may compound and intensify organismal responses.

Airborne Microorganisms and African Desert Dust over the Mid-Atlantic Ridge, Ocean Drilling Program, Leg 209

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On a global scale, 'desert-dust storms' moves an estimated 2.2 x 10^9 metric tons of soil and dried sediment through Earth's atmosphere each year. Large dust events are capable of dispersing large quantities of dust across oceans and continents. The objective of this study was to determine if viable dust-borne bacteria and fungi could be recovered from the lower atmosphere at a mid-Ocean research site and how these isolates compared (species and concentrations) to those previously recovered during African-dust-events sampled in Africa and the Caribbean. Between the dates of 22 May and 30 June 2003, daily air samples were collected and evaluated for the presence of culturable bacterial and fungal-colony-forming units (CFU). A total of 26 bacterial and 74 fungal CFU were recovered on 24 of 40 sample dates. Many of the isolates were genetically very similar to isolates previously recovered in Africa and the Caribbean. A number are similar to known pathogens of humans and Florida plant life. Additionally, we report for the first time a statistically significant correlation ($r_s = 0.608$, $P < 0.001$) between daily atmospheric CFU counts at a mid-ocean research site (~15°N, 45°W) and daily desert-dust concentrations as determined by the U.S. Navy's Naval Aerosol Analysis and Prediction System (NAAPS) Global Aerosol Model.

The Western Canada Study: Assessing Risk to Cattle and Wildlife of Emissions from Natural Gas-Related Activities

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In 2000, the Government of Alberta took the initiative to organize The Western Canada Study on Animal Health Effects Associated with Exposure to Emissions from Oil and Natural Gas Field Facilities (henceforth called "the Study") to investigate allegations that reproduction in cattle and productivity in cow-calf operations had been adversely affected by emissions from oil and gas facilities. The Western Interprovincial Scientific Studies Association (WISSA) was set up to manage the study professionally but at arm's length. A Scientific Advisory Panel provided oversight to develop a strategy for the Study, to guide and monitor its implementation, for quality assurance, to ensure scientific integrity and to review data and assist in the interpretation of findings. The Study took six years, cost C$17 million (provided by the provincial governments, the Canadian Petroleum Producers Association and the Alberta Beef Producers). The Study was designed to accomplish two important goals: 1) to determine if emissions downwind from oil and gas facilities influence the reproduction and health of cattle and wildlife in western Canada and 2) to provide new and economically useful information for cow-calf producers on factors affecting herd productivity and herd health. A tandem wildlife study was implemented using European starlings as an indicator species. The overall pattern of findings demonstrated no adverse effect of downwind exposure on animal health, although the Study found some associations that need to be interpreted carefully and better understood. The Study is the largest and most comprehensive study undertaken to date of beef cattle productivity in North America. Important design features of this Study included the innovative management structure, a secondary goal of improving herd management, a hypothesis-driven study protocol, the unusually active role of science advisors, and the objective of this study to help resolve potentially a serious conflict between the oil and gas industry and cow-calf producers.

Health Effects from Indoor Air Pollution in Rural People's Republic of China Related to Domestic Combustion of Coal

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For much of the 21st century, coal will be a major energy source in the world. Air quality-related health issues in most developed countries mainly concern coal-fired power plants and research on various technologies used for mitigating the impact of gas

and particulate emissions will be developed and implemented. In contrast to this scenario, developing countries, such as China, India, and Indonesia, have extremely large populations, perhaps as many as one billion persons, who use coal in unvented stoves as an indoor energy source for heating, cooking, and drying food stuffs. The health impact of harmful indoor air quality can be extremely egregious and can add a significant health burden to rural populations. We have examined three occurrences of endemic disease from indoor air pollution in China caused by domestic combustion of coal. Discussion of these incidents will illustrate various disease etiologies, and strategies for coal geochemistry and mineralogy research. A small rural population in southwest Guizhou Province, has used mineralized coal in unvented stoves and this use has caused arsenic poisoning. Combustion in unvented stoves releases the harmful elements contaminating the air and the food stuffs typically dried after harvest. Chronic ingestion of high amounts of arsenic has caused various types of keratosis and skin cancer. Fluorosis is a serious health problem in China. Although contaminated ground water is the most common cause of excess fluorine in diet, approximately 10 million persons, mostly in Guizhou Province, are affected by fluorine poisoning from domestic combustion of coal (and clay as part of briquettes) in unvented stoves. The pathway is contamination of food, typically corn, by indoor coal combustion. Ingestion of these fluorine-rich foods has caused both dental and skeletal fluorosis. In rural Xuan Wei County, Yunnan Province, China, lung cancer mortality rates are among the highest in China. Various studies have shown that indoor air pollution, caused by smoky coal used in unvented stoves, is linked to this high lung cancer incidence. Detailed geochemical, mineralogical, and geological knowledge of the coal can be used to mitigate these health effects by understanding the source, pathways, and mechanisms of pollution.

Natural Sources and Natural Fluxes of Atmospheric Deposition of Trace Metals

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Knowledge of natural levels of trace metals (Pb, Cd, Tl, Bi, Zn, Cu, others) is the basis for judging whether modern observed trace metal environments are polluted. It is now well-established (e.g., from studies of peat bogs and ice cores) that pre-industrial fine dusts are “enriched” in trace metals: they contained more trace metals than can be accounted for by the amounts in the lattices of the dust minerals. USGS has determined the amounts of trace metal suites that are emitted worldwide annually by quiescently degassing volcanoes. By observing the amounts of trace metals deposited annually onto the surface of the earth (prehistoric ice strata in polar regions) USGS and Geological Survey of Japan have determined that those amounts of trace metals from volcano emissions account for the bulk of this trace metal flux to the surface (in excess of the smaller amounts that come with the minerals in dust). It appears that other proposed but unverified natural sources of trace metals (bursting of bubbles from ligand-rich ocean surface slimes, plant emissions, weathering residues in soils) are not needed to explain the observations.

USGS has determined that the modern annual deposition rate of trace metals with fine dusts (in excess of the metals in the dust mineral lattices) onto the surface of the southwestern U.S. is about ten times what would be expected if the region received its share of the annual worldwide volcano emission. But much of this trace metal excess may be expected to be recycled, as fine dusts are taken up over wide areas and redeposited by the atmosphere. The magnitudes of the fluxes suggest that soils have become enriched in trace metals over long periods of time by volcano emissions, apparently the dominant natural source. Modern enrichments of trace metals in atmospherically deposited, far-transported fine dusts appear to be similar to enrichments in pre-industrial dusts. On a regional basis, atmospheric deposition of trace metals still appears to be dominated by the long-term volcanic source of emissions to the atmosphere, but interacting with the accumulated reservoir of the trace metal enriched fine fraction of regional soils.

Estimation of Population Exposure to Ozone Using Shape Function Interpolation Methods

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The objective of the work is to generate a continuously changing map to visualize and estimate the human population exposure to ozone. A set of ozone data in the conterminous U.S., which records the ozone concentration levels at a set of monitoring sites during 1994 and 1999, is considered. The following three issues must be addressed.

First, we need to select numerous locations in the conterminous U.S. where the ozone values should be interpolated based on the set of measured ozone data. The existing methods of taking samples points are to take random points and to take evenly spaced

points in the area extent of interest. However, these existing methods do not consider the human population activities factor on the ground. In our work, we propose a new method to pick US census block centroids as sample locations to be interpolated, which generates more sample points in the areas with more intensive human activities. In our experiment, there are about 8,000,000 sample points selected in total.

Second, spatiotemporal interpolation methods are needed to interpolate the ozone values at the selected 8,000,000 sample locations from 1994 and 1999. Traditional GIS techniques are insufficient in handling such kind of spatiotemporal data. We adopt 3-D shape functions from finite element methods for the spatiotemporal interpolation of the ozone dataset and analyze interpolation errors.

Third, we need to generate a continuously changing map to visualize the interpolation results. Both the traditional GIS visualization method and the shape function visualization method will be explored. Using the traditional visualization method, a continuous map will be generated for each year based on the interpolation results at 8,0000,000 sample locations and some existing spatial interpolation method such as IDW and Kriging. The new shape function visualization method can generate a 3-D display with slices using shape functions.

Health Implications of Inorganic Mercury Exposure in Gorlovka, Ukraine

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An integrated human health/environmental study of mercury exposure is being conducted in Gorlovka (pop. 320,000), in eastern Ukraine, by a joint team of U.S. and Ukrainian researchers. Mercury exposure in Gorlovka results from a large abandoned mercury mining and processing operation, past production of extreme mercury-rich coal from the mercury mines, and current use of local coal from active coal mines nearby. Gorlovka presents a unique opportunity to assess health risks of long-term exposure to inorganic mercury and the feasibility of a broader epidemiologic study in the area.

Three groups of cohorts are being studied: 1) Gorlovka residents having occupational exposure to mercury; 2) Gorlovka residents lacking occupational exposure; and 3) residents of Artemovsk, a nearby control municipality without mercury enrichment. In the first group, blood and urine total mercury concentrations were determined for 29 people, primarily workers at a recycling facility occupying a small portion of the former mercury extraction plant. Results show mercury levels are highest for individuals with direct occupational exposure to mercury by recycling batteries and fluorescent lamps. A small number of people in group 1 who live in Gorlovka but do not work at the plant, had lower blood mercury levels than office workers at the recycling operation.

Soil samples collected along two transects through the mine workings show mercury contents in the 3 to 100 ppm range over an area of several square kilometers. One soil sample closest to the processing plant contains in excess of 27,000 ppm mercury in proximity to visible spilled mercury. In addition, soil and dust samples were taken from residential areas of Gorlovka, starting with those closest to the mercury mines. Indoor dust and tap water samples were taken from the homes of selected mercury workers and non-workers in each group, to assess their domestic exposure. Analysis of Gorlovka tap water indicates arsenic levels about five times the 10 ppb WHO standard, suggesting arsenic exposure may be a confounding health factor.

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Physiologically Based Extraction Studies of Baseline and Impacted Soils

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Assessing characteristics of soils that may influence human health includes baseline measurements of chemical composition, bioaccessibility of potentially toxic elements (such as chromium, lead, and nickel), and understanding processes controlling elemental distribution and migration. The continued impact of industrialization, mining, urbanization, and agriculture has the potential to significantly alter the geochemical composition of our soils. Without the establishment of background information on composition and processes, particularly for potentially harmful elements, assessing the influence of human impacts versus those of natural processes such as floods will be difficult. The USGS Geochemical Landscapes Project has as its long-term goal to provide a soil geochemical survey of the North American continent, which will provide baseline data and interpretation for soils at a continental scale.

Soils can influence health through: involuntary ingestion (hand-to-mouth contact or consumption of poorly washed vegetables); purposeful ingestion (geophagia); inhalation and passive ingestion of dusts generated from the soils; and dermal contact. As a result, it is important to understand processes controlling bioaccessibility of potential toxicants in soils along various exposure pathways. Physiologically based extraction tests are inexpensive *in vitro* tests designed to estimate the bioaccessibility of metals in soils, dusts, and other environmental materials by measuring geochemical reactivity of the materials in simulated body fluids. These studies are most useful when combined with detailed mineralogical studies of the material in question, so that the mineralogical hosts for toxicants can be determined. In conjunction with other studies for the Geochemical Landscapes Project, a subset of 20 samples from a north-south transect across the conterminous U.S. were sieved to two size fractions (<2 mm and <250 μm) and leached using a simulated gastric fluid. The <250 μm size fraction represents the particle size most likely to adhere to the hands of children. Analysis of this subset of 'baseline' samples shows no significant trends in metal bioaccessibility with regard to size fraction. In general, this baseline suite of soil samples showed relatively little enrichment in or bioaccessibility of potentially toxic heavy metals, especially compared to urban soils and atmospheric particulates, soils affected by mine wastes, and other soils influenced by anthropogenic activities.

Geologic Controls on Chromium and Nickel in Soils of the Sacramento Valley, California: Links to Human Health Issues

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Soil may affect human health through ingestion, inhalation, and dermal absorption. We studied soil samples in a latitudinal transect crossing northern California from Marin County north of San Francisco to the Nevada border. Chromium and Ni enrichments occur in soil derived from ultramafic belts. Nearly 2000 soil samples from archives, including 1300 surface soils and 100 soil profiles, were chemically analyzed. Chromium and Ni in these samples display distinctive patterns reflecting the underlying geology. Elevated concentrations of Cr and Ni (up to 6000 and 3000 ppm, respectively) occur in soils overlying ultramafic rocks in the Sierra Nevada foothills and are also associated with serpentinites in the Coast Ranges west of the Sacramento Valley. Chromium in ultramafic soil samples is predominantly in a refractory form, presumably as chromite ($FeCr_2O_4$); however, some Cr is associated with more labile phases such as iron oxides. Nickel is common in serpentine minerals and is more labile than Cr. Elevated Cr and Ni content (150-400 and 60-300 ppm, respectively) occurs in alluvial soils west of the Sacramento River, which was partially derived from sediments transported from ultramafic rocks in the Coast Range foothills.

We are investigating potential links between soil geochemistry and human-health issues as Cr and Ni-rich minerals undergo weathering. We have subjected a subset of samples to selective leaching by water, simulated gastric and serum-based fluid, which may be a proxy for fluids encountered during long-term exposure in the lung. These studies reveal the release of Cr and Ni to the solutions (0.01 -1 ppm and 0.06-150 ppm, respectively).

Geochemical data from groundwater and dust samples show elevated Cr and Ni content. Groundwater in the western Sacramento Valley has elevated Cr content (up to 50 ppb), while groundwater samples from the east side of the valley contain less than 15 ppb Cr. Dust samples collected near the cities of Sacramento and Stockton have elevated Cr content that is indicative of western Sacramento Valley soils. Although a direct causal link between our data and specific health outcomes cannot be inferred, the elevated incidence of lung cancer in our study area suggests further study is necessary.

A Planned Soil Geochemical and Microbiological Survey of North America: Continental scale pilot study in Canada and the United States

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Soils contain the elements that support and affect life, and their geochemical properties are critical to the health of individuals and nations. Currently, there is no common understanding of soil geochemical variation, and its origins for North America. Knowledge of this variation is important for human health protection from the standpoint of understanding natural and anthropogenic sources of potentially toxic elements and their exposure pathways, fluxes, and transformations.

The U.S. Geological Survey and the Geological Survey of Canada have completed a pilot study to test and refine sampling and analytical protocols for a planned soil geochemical survey of North America that would provide a continental-scale framework for defining the abundance and spatial variation of over 40 elements. In 2004, soil samples were collected from 265 sites along two continental transects: one from northern Manitoba, Canada to El Paso, Texas, and a second along the 38th parallel from the Atlantic Ocean to the Pacific Ocean. The transects crossed multiple geologic, climatic, physiographic, land use, soil order, and ecological boundaries. This imposed rigorous field testing of sampling protocols across a broad range of conditions. Each transect was divided into approximately 40 km segments. A 1-km-wide strip was randomly selected for each segment. Within each strip, the dominant soil type within the most representative landscape was chosen as a potential sample site. Duplicate samples were collected 10 meters apart to estimate local spatial variability at one in four sites. Samples from each site include: 1) soils collected by horizon (O-, A-, and C-horizons, where present) for multi-element analysis following a near-total four-acid digestion and for bioaccessibility determinations by a deionized water leach and a simulated human gastric fluid extraction; 2) A-horizon samples collected for soil moisture and microbiological characterization; and 3) topsoil collected from 0-5 cm for multi-element chemistry and determination of selected pesticides and other organic compounds. The *in situ* volumes of O- and A-horizon samples were measured so that element loadings can be calculated. Geochemical results from soil analyses will be integrated in a site-specific descriptive database to identify relations between trace soil constituents and geochemical processes across North America.

You're Standing on it! Parking Lot Sealcoat and Urban PAHs

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Polycyclic aromatic hydrocarbons (PAHs) are a ubiquitous contaminant in urban environments and are increasing in concentration in a majority of urban lakes sampled by the USGS National Water-Quality Assessment Program. Although numerous sources of PAHs to urban runoff have been identified, their relative importance remains uncertain. We show that a previously unidentified source of PAHs in urban environments, parking lot sealcoat, might dominate loading of PAHs to urban water bodies in the United States. Particles in runoff from six parking lots with coal-tar emulsion sealcoat had a mean concentration of PAHs of 3,500 mg/kg, 65 times higher than the mean concentration from four unsealed asphalt and cement lots. Contaminant yields projected to the watershed scale for four urban watersheds indicate that runoff from sealed parking lots could account for the major part of PAH loads in streams. Diagnostic ratios of individual PAHs indicate similar sources for particles from coal-tar emulsion sealed lots and suspended sediment from the four urban streams. PAH ratios in sediment cores from lakes undergoing rapid urbanization and coincident increases in PAH concentrations also indicate sealcoat as an important source of PAHs.

Worldwide Asbestos Consumption since the 1960s

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Although full or partial bans on the use of asbestos have been enacted by about 40 individual countries, asbestos continues to be used worldwide. Tracking asbestos use is important, allowing health researchers to identify areas where asbestos-related disease

may manifest itself. Particular attention is paid to usage after 1960, given the 20- to 40-year latency period for the occurrence of asbestos-related forms of cancer.

Between 1960 and 2004, roughly 151 million metric tons (Mt) of asbestos was used by industry worldwide. The leading consumer was the former Soviet Union, where Kazakhstan, Russia, and Ukraine had a combined total use of about 51.3 Mt. The next leading consumers of asbestos were the United States, with an estimated 14.1 Mt; China, with 10.9 Mt; and Japan, with 10.4 Mt. These countries accounted for 57% of world consumption between 1960 and 2004. Approximately 140 other countries used the remaining 43% over this same time period.

Annual Soviet usage peaked around 1990 at an estimated 2.15 Mt, followed by a large decline after the formation of the Commonwealth of Independent States (CIS). Despite this decline, the CIS remained the leading world consumer of asbestos at 780,000 metric tons (t) in 2004. In contrast, annual U.S. consumption peaked in 1973 at 803,000 t, after which usage declined in response to health and liability concerns, totaling only 3,450 t in 2004. China became a major consumer in the 1960s, when its annual consumption surpassed 100,000 t. In the mid-1990s, China became the second leading consumer of asbestos behind the CIS, having an annual consumption exceeding 500,000 t. Use in Japan peaked around 1980 and declined steadily; Japan became a minor consumer by 2004.

Worldwide asbestos use patterns changed from 1960 to 2004. In general, asbestos use in most countries of Europe, North America, South America, and Oceania declined. During the past 10 years, asbestos consumption has been maintained or increased primarily in certain countries in the CIS and Southeast Asia, such as China, India, Kazakhstan, Thailand, and Ukraine.

Community Deprivation, Minority Concentration and Human-Made Toxic Environment: A National Ecological Analysis in the US

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Objective: We examine whether deprived and minority concentrated communities are more likely to be exposed to human-made toxic environment in US.

Methods: We linked the 2000 census tract with the EPA Toxics Release Inventory (TRI) within ArcGIS and calculated the distance from the census tract centroids to the nearest TRI facility site. We used this distance as a proxy for environmental toxic exposure. US 2000 census data were used to construct the minority concentration index (e.g., percent of blacks, percent of Hispanics, percent of Asians), deprivation index (factor scores based on concentrated poverty, prevalence of households on public assistance, and percent of single-parent household) ethnic heterogeneity index (based on six racial/ethnic groups), and rurality (measured by percent of urban residents, percent of suburban residents). Zero-order correlation analyses were conducted to test associations between community characteristics and toxic exposure. We will further verify the patterns detected by the correlation analyses by performing random simulations and identifying spatial clusters of high risk communities across the United States.

Results: Preliminary results show that the median distance from census tract to a TRI facility site is 1.59 mile, the mean distance is 3.49 mile. The extent of exposure to toxic environment is positively correlated with rural locations, community minority and immigrant concentration, structural deprivation, and ethnic heterogeneity. All these association are significant ($p<0.0001$).

Conclusion: Our results are consistent with many local environmental equality studies. Minority, immigrant, and rural populations and people of lower SES are more likely to live nearby these toxic TRI sites.

Chemical and Pathogen Exposure through Drinking Water

Epidemiologic Studies of Drinking Water Contaminants

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Several drinking water contaminants, among them inorganic arsenic, disinfection byproducts, and nitrate, have been implicated as human carcinogens in epidemiologic studies. The evidence for cancer risk is strong and unequivocal for arsenic, consistent but somewhat weaker for disinfection byproducts, and more tenuous for nitrate. Central to the conduct of all epidemiologic studies, and especially studies of environmental contaminants, is accurate assessment of past exposures of the study participants. Even relatively low levels of misclassification of exposure can lead to bias in estimates of risk. Typically, when the error in estimating past exposure is similar among diseased and non-diseased study subjects, the ultimate effect is to bias observed risks toward the null. In conducting epidemiologic studies, collaboration with earth scientists with expertise that can contribute to assessing past exposures is of major importance. In this presentation, we will discuss the risk posed by arsenic and other water contaminants, and present examples from some recent studies.

Drinking Water Science in the U. S. Geological Survey

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Data and information collected and interpreted by USGS hydrologists have relevance to decision makers involved in drinking water management activities. Typical examples range from the continuous monitoring of ground-water levels to detailed assessments of source-water quality. As populations grow, more chemicals and pathogens find their way into water resources, and demands on safe sources of drinking water increase, societies will require more rigorous understanding of the subtle linkages between the quality of our drinking water and the potential, if any, for adverse human-health impacts. Scientists at USGS have long recognized this challenge and have begun to bridge the gap between the hydrologic and the human-health sciences in novel and creative ways (*http://health.usgs.gov/dw_contaminants/*) but arguably more can be done.

Some of these efforts include recent research to understand geologic sources and hydrologic transport of contaminants to drinking water supplies, new health-based benchmarks which provide additional human health context for water-quality data, and engineering-type analyses of drinking water treatment efficacy in removing poorly understood trace-organic compounds for which no drinking water standards exist. Although these studies and others like them are bringing scientists with diverse backgrounds together for the first time, answers to scientific questions about human health and exposure through drinking water will remain limited until more accurate exposure assessments and the potential for associated adverse human-health impacts are scientifically linked to environmental sources of drinking water contaminants. Some of these collaborative efforts are in the initial phases but new levels of long-term collaboration by experts potentially including earth scientists, epidemiologists, toxicologists, physicians, nutritionists, and others will be needed.

Future needs for interdisciplinary approaches to understanding human-health impacts due to exposure to a range of chemical and pathogenic contaminants through drinking water sources will be advanced through discussions to formulate the scientific questions that must be addressed by less traditional interdisciplinary collaborations. Existing government programs, such as the US Environmental Protection Agency's Contaminant Candidate List process and the Centers for Disease Control and Prevention's Environmental Public Health Tracking System and Biomonitoring efforts, will be discussed to explore fertile grounds for expanding existing collaborations and to serve as a starting point for discussions about appropriate opportunities for additional interdisciplinary research in the future.

Adsorption as a Control on Tungsten Concentration in Groundwater: Laboratory Experiments and an Example from Fallon, NV

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Tungsten (W) is used in a variety of industrial, commercial, and military applications. Despite these extensive uses, W is one of the least studied transition metals and remains unregulated by the USEPA. Information on its biological effects, toxicity, and environmental behavior is scarce. W was cast into the spotlight due to its elevated concentrations in drinking water at the site of a childhood leukemia cluster in Fallon, NV. Our work investigates the environmental behavior of tungstate, WO_4^{2-}. The objectives were to: 1) determine equilibrium constant(s) for WO_4^{2-} adsorption to ferrihydrite, 2) model WO_4^{2-} adsorption in the basin-fill aquifer in Fallon, NV, and 3) evaluate the hypothesis that adsorption controls groundwater W concentration.

Laboratory experiments were conducted to measure WO_4^{2-} adsorption to ferrihydrite, as a function of pH, ionic strength, and W concentration. Results were modeled with FITEQL 4.0 and Visual MINTEQ 2.50 to obtain equilibrium adsorption constants (log K) of 5.08 and 19.78, for the surface species $\equiv FeOHWO_4^{2-}$ and $\equiv FeOW(OH)_5$, respectively. These thermodynamic data were added to Visual MINTEQ to construct a geochemical model. Model inputs were the total values of W in water and sediment of the aquifer system. The concentration of WO_4^{2-} adsorbed to ferrihydrite in the aquifer was estimated from an extraction of the non-crystalline iron oxide fraction of the aquifer sediment.
Accuracy of the geochemical model was evaluated by comparing model estimates of dissolved W to groundwater chemistry. The best prediction was achieved by optimizing the model parameter for surface site density to 0.1226 mol sites/mol Fe. The model's ability to predict groundwater W concentration supports our hypothesis that equilibrium adsorption controls the concentration of W in the Fallon groundwater. This implies that a change in equilibrium conditions (e.g. pH or Eh) could release W from the solid to the dissolved phase. However not all W in the aquifer sediment was found associated with the ferrihydrite fraction. More work is needed to identify the speciation of the remaining W in the sediment, and to investigate its mobility as a function of changing aquifer conditions.

Early-warning Monitoring for Water Security: Evaluation of Water-Quality Variability in a Distribution System

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Accidental or intentional contamination of drinking-water distribution systems may be detectable as unexpected changes in easily measured (traditional) water-quality characteristics. This premise depends upon: (1) the nature and concentration of the contaminant, (2) the magnitudes of changes in water-quality characteristics caused by the introduction of various contaminants, and (3) the background variability of the water quality. The research addresses the background variability by investigating the spatial and temporal water-quality variability of a water-distribution system.

The U.S. Geological Survey (USGS), in cooperation with the U.S. Environmental Protection Agency (USEPA), Sandia National Laboratories, and a water utility, is researching the suitability of using continuous water-quality-monitoring stations to characterize the variability over time of selected water-quality characteristics. Self-contained, unattended instruments that measure physical and chemical characteristics of water at 15-minute intervals are used at source water and distribution system sites for this purpose.

The objective of the study is to obtain a detailed description of the spatial and temporal variability of water quality in a distribution system over a sampling period of several months to more than 1 year. A total of twelve monitoring stations were operated. Stations were located at a source-water intake and eleven distribution-system sites. The water-quality characteristics that were monitored include temperature, specific conductance, pH, oxidation-reduction potential, and free chlorine residual. In addition, an ultra-violet visible spectrophotometer and a total organic carbon analyzer were used at one site for several months.

Water-quality variability was evaluated temporally over three time increments--0.25, 1, and 24 hours--at all stations and spatially within the distribution system. The variability of source-water quality as a result of hydrological and meteorological variables, and the variability of distribution-system water quality as a function of source-water quality and location within the system were quantified. These results can complement results from controlled laboratory experiments being conducted by the USEPA at the Testing and Evaluation Facility in Cincinnati, Ohio. In these experiments, specific contaminants were added to water from a simulated distribution system (pipe loop), and responses of water-quality-monitoring sensors are observed. Together the studies may make it possible to distinguish between real contamination events and normal background variability.

Effects of Elevated Zn, Cu and Fe in Drinking Water on Learning and Memory

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Zinc is the fourth most abundant intercellular metal, and zinc deficiency is associated with reduced immune function and cognitive deficits. Iron is the most prevalent metal in the body and iron deficiency is a leading cause of mental retardation. However, our experiments have shown that enhanced Zn concentrations (ppm levels) in drinking water impairs memory in normal rats and mice and transgenic (Tg) mice pre-disposed to develop Alzheimer's disease (AD), also that iron impairs spatial memory in Tg mice.

Iron in drinking water is usually from natural sources *i.e.* the dissolution of Fe-bearing minerals and the oxidation of organic compounds. Although there are several natural sources of Zn in drinking water, anthropogenic contributions of Zn to the aquatic environment can be significant. In addition, dietary supplements can increase the total daily intake of these metals.

Our animal experiments have examined the long-term effect of Zn and Fe in drinking water on learning and memory. Initially, rats were raised on drinking water enhanced with Zn as $ZnCl_2$, $ZnSO_4$ or $ZnCO_3$ (and control). They were tested in the Morris water maze, a recognized test of spatial memory. Zinc as $ZnCO_3$ was the most detrimental to spatial memory. Because excess Zn depletes Cu levels in the body, rats also were raised on drinking water containing 10 ppm Zn (as CO_3) with or without the addition of 0.2 ppm Cu. The addition of Cu reduced the memory impairment of Zn alone. Another experiment examined both normal and Tg mice raised on either $ZnCO_3$ or Fe-enhanced water (5 and 10 ppm Fe as $Fe(NO_3)_2$). Both normal and Tg mice raised on enhanced Zn exhibited spatial memory deficits, whereas for Fe, only the Tg mice (pre-disposed to AD) showed spatial memory deficits. Using synchrotron XRF and laser-ablation ICP-MS techniques we have shown an increase of these metals in relevant brain structures. These results demonstrate that long-term sub-toxic metal ingestion in drinking water can induce cognitive deficits in rats and mice. Additional experiments are underway to extend the data on dose-response, to further investigate the nature of the cognitive impairments, and to explore the connection to the geochemical environment.

Potential Public Health Implications of Exposure to Arsenic from Private Drinking Water Wells in the United States

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As part of its public health mission to identify and evaluate the relationship between various environmental measurements and public health indicators, the Environmental Public Health Tracking Branch of the National Center for Environmental Health has been involved in documenting the existing data on U.S. drinking water sources and quality. Although some water quality problems exist in public water supplies, there is a large governmental (and private agency) infrastructure that is continually working to ensure that public drinking water sources are safe. This presentation addresses the potential exposures to contaminants in the drinking water of millions of Americans supplied via private (domestic) drinking water wells.

The public health evaluation of contaminant exposures via drinking water is based on the calculation of an exposure dose from contaminant concentrations and ingestion rates, and comparison of the calculated dose with doses expected to cause some health endpoint. Concentration and location data from specific private wells are essentially non-existent (although some states do maintain records of well permits, etc.) A recent study by the United States Geological Survey which compiled and assessed water

quality data on private wells identified arsenic, atrazine, and nitrate as contaminants that are widely present in private wells at concentrations of potential public health concern. This presentation will focus on the distribution and potential health effects from exposure to arsenic.

Potential exposure doses of arsenic are calculated using the frequency distributions of measured arsenic concentrations in major aquifer systems that are significant sources for private wells. Although arsenic exposure produces a number of adverse health effects, hyperpigmentation and keratosis of the skin seem to be the most sensitive endpoints (occur at the lowest doses). Comparison of the resulting probability distributions of potential exposure doses compared with doses likely to produce these health conditions indicates that adverse health effects from arsenic exposure are unlikely for the vast majority of Americans obtaining water from private wells. Future work will extend this evaluation to other contaminants and health effects and examine the epidemiological implications of these potential exposures.

Cyanotoxins in Midwestern Lakes

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Cyanobacteria (blue-green algae) produce a diverse group of toxins that target fundamental cellular processes and affect a wide range of organisms. Cyanobacterial toxins (cyanotoxins) have been implicated in human and animal illness and death in more than 50 countries worldwide, including at least 32 U.S. States. Human toxicoses associated with cyanotoxins most commonly have occurred after exposure through drinking water or from contact through recreational water activities.

The hepatotoxin microcystin is believed to be the one of the most common cyanotoxins. Because microcystin is a potential human-health risk, several studies were conducted to determine the occurrence of microcystin in Midwestern water resources. During the summers of 1999-2001 and 2004-05, 305 lakes in Missouri, Iowa, southern Minnesota, and eastern Kansas were sampled for microcystin. Most lakes were sampled 2-4 times in one or all years. Microcystin commonly was detected in the region with 78% of lakes sampled having detectable concentrations (≥0.1 μg/L) at least once. Microcystin concentrations ranged from 0 to 52 μg/L, with 20% of lakes having concentrations >1 μg/L and 3% having concentrations >10 μg/L. Microcystin concentrations >20 μg/L are considered to have a high risk for adverse health effects during recreational exposure. Seasonal studies were conducted on nine lakes during 2001-04. Peak microcystin concentrations occurred in June-December; 66% of the lakes had peaks in September or October. More recent studies have examined the presence of other cyanotoxins in Midwestern lakes.

Resource managers, drinking-water treatment-plant operators, lake associations and local officials increasingly are faced with making decisions about cyanobacterial blooms that affect public awareness, exposure, and health. Although anecdotal reports are common, few studies have documented the occurrence of toxins other than microcystin in cyanobacterial blooms throughout the U.S because few analytical methods are available. In addition, although the general factors affecting cyanobacterial bloom formation are well known, specific factors driving individual toxic occurrences are unclear. Understanding the range of cyanotoxins that are present and the biological, physicochemical, and hydrological factors affecting toxin occurrence are key to effective management of water resources and minimization of human-health risks.

North-to-South Position of Mississippi River States and their Health Rank

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The recent news that Minnesota ranks first in health and Louisiana last, suggested to the author that their connecting medium, the Mississippi River, might be a factor. Consequently, a correlation was sought between position of states along the Mississippi River and their health rank. Correlations were sought in similar categories such as position of states along the eastern U.S. seaboard and Missouri River. Accordingly, each state was ranked according to its north-to-south position. The position rank was then correlated with the health rank for the years 2004, 2005, and 2006 using the Spearman correlation test. Similar correlations were also made for states' position along the Mississippi River and their: a) temperature, b) per capita income, and c) ACT scores.

A strong correlation (r > 0.9) was found between position of states along the Mississippi River and their health rank for the years assessed. Strong correlations (r > 0.9) were also found for position of Mississippi River states and: temperature (r = 0.976), per capita income (r = -0.952), and ACT scores (r = -0.903). Correlations were less strong when comparing health rank to state positions along the eastern seaboard (r = 0.855) and Missouri River (r = 0.345). Thus, a state's north-to-south position, particularly along the Mississippi River, appears to be a risk factor for its health rank. Further study is indicated regarding possible causative mechanisms.

Pesticides and Pesticide Degradates: Their Occurrence and Removal in Drinking Water

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Although some pesticides such as atrazine are monitored in drinking water, little is known about the occurrence of unregulated pesticides in drinking water and even less is known about pesticide degradates. It is important to determine if these compounds are efficiently removed through drinking-water treatment. Analyses of source waters from 12 drinking water utilities in the mid-western U.S. in 2003–2004 for chloroacetamide herbicide degradates had at least one detection of 24 of 26 degradates and all four parent herbicides. Most degradates in drinking-water sources were present at concentrations similar to concentrations found for the parent herbicide (~10–100 ng/L); however, their summed concentrations contributed a significant fraction of the total level of pesticides and degradates. Further analyses of conventionally treated (coagulation/flocculation, sedimentation, filtration and chlorination) drinking-water samples indicated little to no removal of the degradates or parent herbicides, but activated carbon treatment achieved significant removals (~ 40 percent average) of all parents and degradates. Many other classes of pesticides and pesticide degradates could also be present in drinking water. Examples include the major degradate of ethylenebisdithiocarbamate fungicides (ethylenethiourea) and the triazole fungicide degradates (1,2,4-triazole, triazole acetic acid and triazole alanine), which have been recognized as posing a possible human-health risk.

Drinking-water treatment also has the potential to create transformation products during treatment processes. Experiments simulating the chlorination of water containing dimethenamid revealed that a more highly chlorinated product was formed. This transformation product is not formed in the environment, and its toxicity is unknown. One understudied herbicide that could be of concern in drinking water is diuron, which has the potential to form (directly or through its degradate dimethylamine) the known carcinogen N-nitrosodimethylamine through treatment of contaminated water. Additional studies that analyze the removal of parent pesticides and the removal and generation of their degradates through drinking-water treatment would contribute to a more complete assessment of human-health exposure to total pesticide residues from ingestion of drinking-water.

Assessing the Vulnerability of a Public Supply Well in the Karstic Upper Floridan Aquifer to Contaminants of Public Health Concern

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Multiple chemical indicators and geochemical and flow modeling techniques were used to assess the vulnerability of a public supply well (PSW) to contamination from nitrate, arsenic, radon-222, and organic compounds in the karstic Upper Floridan aquifer (UFA) near Tampa, Florida, as part of the U.S. Geological Survey National Water-Quality Assessment Program. Water samples were collected from the PSW and 13 monitoring wells that tap the Upper Floridan aquifer (UFA), and from 15 monitoring wells in the overlying surficial aquifer system (SAS) and intermediate confining unit that are located within the modeled ground-water contributing area for the PSW. Water samples also were collected from three discrete depth intervals (38-53, 43-53, and 48-53 m below land surface) in the PSW that were identified as highly transmissive zones during geophysical logging of the well bore. Water samples were collected from these depth intervals at a low pumping rate by placing a low-capacity submersible pump (<0.02 m^3/min) at the top of each interval. To represent higher-pumping conditions, a large-capacity portable submersible pump (1.6 m^3/min) was placed near the top of the open interval while water-chemistry samples were collected using the low-capacity submersible pump. The 48-53 m depth interval had distinctly different chemistry compared with the other two sampled intervals. Higher concentrations of nitrate, atrazine, radon, chloroform, arsenic (with higher As(V)/As(III) ratios), and lower concentrations of dissolved solids, strontium, iron, manganese, and nitrogen and sulfur isotope ratios were found in this highly transmissive zone in the limestone. Movement of water likely occurs from the overlying sands and clays of the oxic SAS

and intermediate confining unit (with elevated radon-222 and nitrate-N concentrations), into the anoxic UFA (lower radon-222 and nitrate concentrations). Differences in arsenic concentrations in water from the various depth intervals in the PSW (3.2-19 µg/L) were related to pumping conditions. Concentrations of age tracers (sulfur hexafluoride and tritium) in samples from the PSW during low and higher-pumping conditions were consistent with binary mixtures dominated by very young water (< 7 years), and indicate the high vulnerability of public supply wells in this area to contamination associated with highly transmissive zones in the UFA.

Reconstructing Historical Exposure to Volatile Organic Compound Contamination of Drinking Water Supplies at U.S. Marine Corps Base Camp Lejeune, North Carolina: An Epidemiological Study of Childhood Birth Defects and Cancers

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The Agency for Toxic Substances and Disease Registry (ATSDR) is conducting an epidemiological study to evaluate if in-utero or infant (up to 1 year of age) exposures to volatile organic compounds (VOCs) in contaminated drinking water at U.S. Marine Corps Base Camp Lejeune, North Carolina were associated with specific birth defects and childhood cancers. The study includes births occurring during the period 1968–1985 to women who were pregnant while they resided in family housing at the base.

No exposure data and very limited contaminant data are available to support the epidemiological study. As a result, ATSDR is using modeling techniques to reconstruct historical groundwater flow, fate, and transport characteristics of VOCs underlying the base. Numerical models used for this effort include: MODFLOW, used for simulating groundwater flow; MT3DMS, used for simulating contaminant fate and transport; and TechFlowMP, used for simulating three-dimensional multi-species, multi-phase mass transport. Using modeling techniques to accomplish historical reconstruction allow engineers and scientists to estimate concentrations of contaminants delivered through the drinking water-system as well as the frequency and duration of exposure to contaminants in drinking water. Such information, when provided to epidemiologists, facilitates the determination of quantitative estimates of historical exposure.

Based on field data and modeling results, tetrachloroethylene (PCE) contamination, exceeding the maximum contaminant level (MCL) for PCE of 5 micrograms per liter (µg/L), arrived at water-supply well TT-26 in January 1957 and at the Tarawa Terrace water treatment plant (WTP) in November 1957—significantly earlier than previously estimated. Maximum PCE-contamination of well TT-26 exceeded 850 (µg/L). PCE-contamination of treated drinking water, delivered from the Tarawa Terrace WTP, exceeded 180 µg/L. Although exposure to contaminated drinking water ceased after February 1985 when contaminated water-supply wells were taken out of service, exposure through inhalation of VOCs may have continued long afterwards.

Health Effects of Toxic Organic Substances from Coal in Drinking Water: Balkan Endemic Nephropathy (BEN) and Pandemic Nephropathy (PEN)

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Coal contains myriad organic compounds, some of which are toxic (e.g. polycyclic aromatic hydrocarbons, aromatic amines). Human exposure to toxic organic compounds from coal occurs through combustion and inhalation of particulates, or through leaching into drinking water supplies. One example of a disease linked to coal-derived toxic organic compounds in drinking water supplies is Balkan Endemic Nephropathy (BEN).

BEN is a kidney disease resulting in renal failure, with a high co-incidence of renal/pelvic cancer (RPC). BEN occurs only in clusters of rural villages in the Balkans. The geographic restriction of BEN is spatially correlated with the occurrence of Pliocene lignite deposits. The hypothesis being tested is that groundwater leaches toxic organic compounds from lignite located in hills surrounding endemic villages, and transports these compounds to wells/springs used as water supplies. Exposure to these toxic, coal-derived organic compounds for 20+ years may be a factor (combined with genetics) leading to BEN and RPC. Field and laboratory studies have demonstrated that: (1) drinking water from BEN villages has higher concentrations and numbers

of low and high molecular weight organic compounds compared to control sites; and (2) organic compounds in drinking water from BEN villages are similar to compounds in laboratory water leachates of lignites from BEN areas. Toxicological studies on human kidney cells have shown that organic compounds, extracted from BEN area lignites, and isolated from drinking water in BEN villages, stimulate excessive cell proliferation at low dose (possible carcinogenic properties), and induce cell necrosis at higher dose (nephrotoxic effect).

High rates of RPC are also found in the USA in States having low rank coal deposits and rural populations using groundwater for water supplies. Wells in aquifers containing coal in WY and LA contain significantly higher concentrations of organic compounds compared to control sites. Some of the types of organic compounds observed in well water from WY and LA closely resemble those observed from wells in BEN villages. These results and other observations have led to the development of the concept of Pandemic Nephropathy (PEN), or BEN-like diseases worldwide that appear to be linked to coal-derived toxic organic compounds in drinking water.

Volatile Organic Compounds in Samples from Domestic and Public Wells

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Occurrence of volatile organic compounds (VOCs) in ground water supplies sampled by the U.S. Geological Survey's National Water-Quality Assessment (NAWQA) Program indicates that domestic well samples had fewer compounds, lower detection frequencies, and smaller concentrations than public well samples. Chloroform, MTBE, and perchloroethene were the most frequently detected VOCs in samples from both well types. VOCs in domestic well samples represented compounds with multiple uses. VOCs in public well samples were predominantly solvents, the gasoline oxygenate MTBE, and trihalomethanes.

About one percent of domestic well samples and two percent of public well samples had VOC concentrations greater than the U.S. Environmental Protection Agency's Maximum Contaminant Levels (MCLs). Concentrations of 1,1-dichloroethene, trichloroethene, and perchloroethene were greater than MCLs in both well types. Additional VOCs with concentrations greater than MCLs in domestic wells included dibromochloropropane, 1,2-dichloropropane, and ethylene dibromide; whereas methylene chloride and vinyl chloride were additionally greater in public wells.

Findings indicate that water from public wells has greater vulnerability to VOC contamination than domestic wells despite deeper median depth of sampled public wells (303 feet) than domestic wells (104 feet). Larger withdrawal rates, proximity to developed areas, larger capture zones, and greater drawdown explain, in part, why VOC occurrence in public well samples was greater than in domestic well samples. Young, recently recharged ground water can be intercepted by both well types. Public wells may also intercept VOCs from multiple land uses and point sources because of their large contributing areas; and from ground water flowing along deeper, longer flow paths.

Volatile Organic Compounds in the Nation's Drinking-Water Supply Wells-What Findings May Mean to Human Health

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Ground water is used as a drinking-water supply for approximately half of the Nation's population. Untreated ground-water samples from about 2,400 domestic wells and 1,100 public wells were analyzed for 55 volatile organic compounds (VOCs) as part of the U.S. Geological Survey's National Water-Quality Assessment Program. Because domestic and public wells serve as drinking-water supplies, it is important to describe what the VOCs detected in these well samples may mean to human health. VOC concentrations were compared to Maximum Contaminant Levels (MCLs) and Health-Based Screening Levels (HBSLs) in a screening-level assessment to provide an initial perspective on the potential relevance of these concentrations to human health. VOC concentrations of potential human-health concern were defined as concentrations greater than MCLs or HBSLs; these concentrations occurred in about 1 percent of domestic-well samples and 2 percent of public-well samples. Fumigants accounted for about two-thirds of the VOC concentrations of potential human-health concern in domestic well samples. In public well samples, solvents accounted for about three-fourths of the VOC concentrations of potential human-health concern. Evaluating

the potential human-health relevance of VOC concentrations in domestic- and public-well samples is complex. NAWQA studies were not designed to evaluate the specific effects of VOCs on human health, and screening-level assessments are not a substitute for comprehensive risk assessments. Screening-level assessments, however, can provide an early indication of when concentrations approach levels of potential human-health concern and prioritize VOCs that may merit additional study or monitoring.

Animals as Sentinels of Human Health

Animals as Sentinels of Human Health

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Ever since men began carrying caged birds into coal mines to indicate the presence of poisonous gas, animals have been viewed as "sentinels" for environmental risks to human health. Recent efforts to develop early warning systems for natural and human-induced hazards have intensified the need to understand the relative advantages and disadvantages of using animals as sentinels. This presentation summarizes the current state of scientific knowledge regarding the use of wild animals to indicate potential biological, chemical, and physical threats to human health in the environment. It highlights USGS research, monitoring, and information delivery activities that involve the use of animals in assessing potentially hazardous environmental conditions and suggests future directions for USGS research in support of public health and other partners.

Cavity-Nesting Birds: Sentinels for Human Health

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Cavity-nesting birds, such as tree swallows and house wrens, have been widely used to assess contaminant exposure and effects. Birds of this type have traditionally been used in the wildlife health arena, but could also serve as a warning system for human health. Data from cavity-nesting bird studies can help to answer important questions, such as: (1) are contaminants in sediments at a particular location bioavailable? and (2) are contaminants affecting biological processes? Examples of recent exposure and effect studies with cavity-nesting birds include dioxins in Rhode Island, mercury in the historic gold mining regions of Nevada, and lead along the upper Arkansas River in Colorado. Cavity-nesting birds offer the following advantages over other avian species. Nest boxes can be placed in locations of interest to concentrate a study population at that site. This almost guarantees a study species and sufficient sample size. The birds feed within a 500 m radius of their nest so contaminant levels in their tissues are reflective of the local habitat. This small feeding radius makes them ideal to assess contaminant exposure over very small scales, but because of their broad distribution they can be used on a continental scale as well. The food web they represent is short and easily interpretable. Although the food web is focused on aquatic habitats, i.e. wetlands, creeks, rivers, and lakes, where many of our contaminants end up, they will nest in terrestrial habitats as well. Finally, cavity-nesting birds can be used to monitor the efficacy of clean-up activities. All of these qualities suggest that cavity nesting birds can be important sentinels for human health, a new canary for the global environment. Case studies will be presented to highlight the value and usage of these birds in both the wildlife and human health fields.

Exposure and Effects of Dioxins on Birds: A Case Study Using Tree Swallows

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Tree swallows (Tachycineta bicolor) were used to assess exposure and effects of 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) along a section of the Woonasquatucket River near Providence, Rhode Island. That section of the river is highly contaminated with TCDD as well as other dioxin and furan congeners. The U.S. Environmental Protection Agency was conducting an ecological risk assessment of the area. In 2000 and 2001 tree swallow nest boxes were put up at 2 contaminated sites and 1 upstream reference location, and the reproductive success and contaminant concentrations of swallows were quantified. Of the 7 dioxin and 10 furan congeners that were analyzed, all were detected in tree swallow egg samples at the contaminated sites. These

concentrations are some of the highest ever reported in bird eggs. TCDD was between 10 and 50 times higher at the 2 contaminated sites compared with the upstream reference location. Daily egg survival was significantly less at the contaminated sites compared to the reference location. Approximately 50% of the eggs hatched at the contaminated sites compared with between 75 and 90% at the reference location. Positive accumulation rates in 12-day old nestlings indicate local exposure to dioxins and furans. High concentrations of TCDD in food items verify a dietary route of exposure. Tree swallows can be used in this manner to identify and sample areas that may also pose a threat to humans. Tree swallows and similar species have been used at over 20 sites nationwide to assess contaminant exposure and effects.

Human Consumption of Bioaccumulative and Other Chemical and Pathogenic Contaminants

Bioaccumulative Substances in the Environment: Sources, Exposure Pathways, and Health Effects

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Bioaccumulative substances are defined as contaminants that persist in the environment and accumulate in living organisms, increasing in concentration up the food chain (maximum concentrations in high-end predators). Bioaccumulation is the degree of concentration of a chemical contaminant in an organism relative to the concentration of that contaminant in the organism's environment (such as water). Biomagnification is the process whereby the tissue concentrations of a chemical contaminant increase as it passes up the food chain through two or more trophic levels. A number of metals, organometallics, and organic chemicals are known to bioaccumulate and pose a human health risk. The substance enters the organism through dietary intake, epithelial tissue, gills (for fish), or other sources. For aquatic organisms, chemical uptake directly from water (across cell membranes) and dietary uptake are important routes of exposure. For terrestrial organisms, dietary uptake tends to be the most important exposure route. Human exposure to bioaccumulative contaminants is usually through consumption of plants, meat, and fish, but drinking water and exposure to nonfood solids (soil, dust, paint chips) can also be important, especially for metals such as lead and cadmium.

Persistent bioaccumulative toxic organic pollutants (PBTs) are organic chemicals that are resistant to degradation, have low water solubility and a strong affinity for organic material. They readily sorb to soil and sediment and partition into biological tissues. These contaminants can bioaccumulate to levels that pose a threat to human health and the environment. PBTs usually originate from anthropogenic activity (industrial chemicals, agricultural pesticides and herbicides, and combustion products), and most are synthetic chemicals. Some well known PBTs include: DDT, PCBs, PAHs, and dioxin. PBTs are linked to a range of adverse human health effects, including effects on the nervous system, reproductive and developmental problems, and cancer.

A number of metals are known to bioaccumulate. Familiar examples include forms of mercury, lead, and cadmium. Lead is particularly important as a health hazard for children, where it can cause neurologic problems (convulsions, learning disabilities), inhibit growth, cause hearing loss, and affect major organs. Human exposure to lead can be from drinking water (lead pipes or solder), paint manufactured prior to 1978, and contaminated soil. Mercury, especially methylmercury (MeHg), is possibly the most important of the toxic bioaccumulative substances in terms of its ubiquitous occurrence. The principal pathway for MeHg exposure in humans is consumption of contaminated fish. MeHg is formed when inorganic mercury from natural and anthropogenic sources (especially combustion processes) is deposited in aquatic environments. There, anaerobic bacteria (usually in sediments) convert inorganic mercury to MeHg, and the MeHg enters the food chain (often in organisms exposed to MeHg where it is formed). MeHg is a potent neurotoxin, and health effects in humans range from paresthesias and ataxia, to coma and death in severe cases. As with lead, the young (especially developing fetuses) are most affected by bioaccumulation of MeHg. The earth sciences can play an important role in providing information on exposure pathways, sources of, and biogeochemical processes leading to uptake of bioaccumulative substances in the environment.

Application of Municipal Biosolids to Dry-Land Wheat Fields – A Monitoring Program near Deer Trail, Colorado (USA)

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Since 1993, Metro Wastewater Reclamation District of Denver (Metro District), a large wastewater treatment plant in Denver, CO, has applied Table 1 Ceiling Concentration Limits, Class B biosolids to about 52,000 acres of non-irrigated farmland near Deer Trail, CO. In cooperation with the Metro District in 1993, the U.S. Geological Survey (USGS) began monitoring ground water at portions of this site. In 1999, the USGS began a more comprehensive study of the entire site to address stakeholder concerns about the chemical effects of biosolids applications. The study has recently been extended through 2010. Monitoring components of the comprehensive study included biosolids collected at the wastewater treatment plant, soil, crops, dust, alluvial and bedrock ground water, and stream bed sediment. Priority parameters identified by the stakeholders in 1999 for all monitoring components include the total concentrations of nine trace elements (As, Cd, Cu, Pb, Hg, Mo, Ni, Se, and Zn), plutonium isotopes, and gross alpha and beta activity.

The objective of each component of the study was to determine whether concentrations of priority parameters (1) were higher than regulatory limits, (2) were increasing with time, or (3) were significantly higher in biosolids-applied areas than in a similar farmed area where biosolids were not applied. To date, study results indicate that the chemistry of the biosolids was consistent during 1999-2006, and total concentrations of regulated trace elements remained lower than the regulatory limits. Plutonium isotopes were not detected in the biosolids. Leach tests using deionized water indicated As, Mo, and Ni were the most soluble priority parameters in the biosolids. Results show no significant difference in concentrations of priority parameters between biosolids-applied soils (after two applications) and unamended soils where no biosolids were applied. Results do not indicate significant differences in concentrations of priority parameters between crops grown in biosolids-applied areas and crops grown on control fields. Data from this study were used to compile an inorganic-chemical biosolids signature that can be contrasted with the geochemical signature for this site. The biosolids signature and an understanding of the geology and hydrology of the site can be used to separate biosolids effects from geochemical effects.

Paleozoic Stone Coal (Carbonaceous Shale) Use For Domestic And Industrial Combustion In Rural China: Environmental Consequences

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"Stone coal" or "bone coal", is a common term in China applied to organic carbon-rich shales and mudstones which can be used for combustion both domestically and in small industry. These rocks typically have more than 40% ash yield and are black shales that formed in anoxic to euxinic marine environments, distinct from the typical subaerial formation of peat and subsequent coalification processes. Stone coal samples, from Shaanxi, Hubei, and Guizhou Provinces, People's Republic of China have been examined to address the environmental problems associated with its use and weathering. These stone coals have very large reserves (over 1 billion tons) and play a significant role in the local energy budget of rural communities. Adverse health conditions resulting from combustion, disposal of ash, residual soil, and groundwater contamination have seriously affected some populations. The stone coals present three main environmental problems; (1) the residual soils are enriched in the metals contained in the stone coals and depending on their speciation and bioavailability, so are the crops grown on them; (2) the weathering of the stone coal contaminates the local ground water and/or surface waters with heavy metals; and (3) the local villagers and farmers use the stone coal as a source of fuel. The use as a fuel presents a number of problems. The atmosphere in their homes will contain Se and As, the more volatile elements, and the ash we will be extremely enriched with the balance of the heavy metal suite. Disposal of the ash on agricultural lands or nearby water supplies can contaminate both. We have focused our study on the mode of occurrence of Se, As, and other elements hazardous to human health. Scanning electron microscope, energy-dispersive analysis and electron microprobe wave-length dispersive spectroscopy were used to identify and determine the composition of host phases observed in the stone coals. The mode of occurrence of most of the environmentally-sensitive elements is in sulfides or their weathering products. Our studies are used by local and Provincial public health officials to help assess the hazards of stone-coal use and to develop plans for mitigation.

Mapping Mercury Sensitivity of Aquatic Ecosystems across the Contiguous United States

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About 20 years ago, researchers at a few locations across the globe discovered high levels of mercury in fish from remote settings lacking any obvious mercury source. We now know that for most locations atmospheric deposition is the dominant mercury source, and that mercury methylation is the key process that translates low mercury loading rates into relatively high bioaccumulation levels in aquatic food webs. Presently, 46 US states have advisories for elevated levels of mercury in sport fish, and as a result there is considerable public awareness and concern for this nearly ubiquitous contaminant issue. With recent promulgation of mercury emission regulations in the US and elsewhere, there is now a need for providing estimates of fish-recovery response times. This need presents a significant challenge to the scientific community because of the complex series of processes that rest between the contaminant source (atmospheric mercury deposition) and the human exposure vector (bioaccumulation in fish). The purpose of this study was to develop a predictive mapping tool that can provide an initial assessment of where we might expect to see areas of greater or lesser response to changes in atmospheric mercury load. The key factors regulating spatial variability are the net change in mercury loading, and the inherent ability of a specific ecosystem to convert a portion of the precipitation-deposited inorganic mercury to methylmercury, or mercury methylation. Methylmercury is the most toxic form of mercury in the environment and the form mercury that bioaccumulates in food webs, thus environmental data that are indicative of methylation potential and are available in a geospatial framework were targeted for this analysis to yield a national scale map of "mercury sensitivity". The final map is based on a national GIS coverage of surface water quality (pH, sulfate and dissolved organic carbon) and land use (wetland density). The abundance of wetlands (an important methylation hotspot) is one key factor used in the formulation of this "mercury sensitivity map". This paper will present the predicted national-scale trends in predicted mercury sensitivity across the US, and attempt to explore whether focused regional attention to methylmercury exposure is warranted.

How Sulfur Contamination and Atmospheric Mercury Deposition Influence Methylmercury Production and Bioaccumulation in the Everglades

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Mercury (Hg) represents one of the most important water quality issues facing restoration of the Everglades, as well as being an important environmental and human health issue worldwide. The concentration of methylmercury (MeHg) in biota is elevated throughout the Everglades, with levels of MeHg in gamefish among the highest in the nation. The objectives of USGS studies of Hg in the Everglades were to: (1) determine the biogeochemical processes influencing the production and bioaccumulation of MeHg, (2) provide to managers information needed to minimize the impacts of Hg on the ecosystem, and (3) transfer results of Hg research conducted in the Everglades to other environments.

The dominant source of Hg to the ecosystem is atmospheric deposition, while the major source of MeHg is new production in surface soils. Bioaccumulation of MeHg occurs mainly via the benthic food web, with patterns of bioaccumulation driven by differences in MeHg production rather than differences in bioaccumulation factors. USGS was the first to document ecosystem-scale sulfur contamination originating from the Everglades Agricultural Area. This sulfur contamination has a key influence on MeHg production in the Everglades by stimulating microbial sulfate reduction (the process responsible for production of MeHg from inorganic Hg). The influence of sulfur contamination on MeHg production is complex, however, because sulfide (a byproduct of sulfate reduction) inhibits MeHg production. Sulfur availability and speciation influence MeHg production in the Everglades. Mesocosm experiments confirmed the importance of sulfur and atmospheric mercury in fueling the biomethylation of mercury in Everglades' sediments, and have also shown the importance of DOC in facilitating transport of Hg and MeHg. Field and laboratory studies have also demonstrated that dry/wet cycles are important in stimulating MeHg production and bioaccumulation in the ecosystem. Restoration efforts need to continue reducing the atmospheric Hg load to the ecosystem, and also need to consider reducing sulfur loads from agricultural sources. Managers must also consider how restoration plans that include changes in water flow through the marsh might affect sulfate movement and wetting/drying cycles. Each of these factors appears to have an important influence on the production and bioaccumulation of MeHg in the Everglades ecosystem.

Chemical and Pathogen Exposure through Recreational Waters

The Need for Alternative Health Risk Indicators Due to Non-Fecal Inputs of E. coli and Enterococci from Papermill Effluents into Recreational Waters

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Elevated counts of *E. coli* and enterococci bacteria were measured at a recently completed county beach located on a river downstream from a northern Wisconsin papermill. The beach was closed to swimming during the entire summer of 2004 and 2005 and most of the summer of 2006. Samples taken upstream of the paper mill averaged 9 and 5 cfu/100mL, while counts in samples taken equidistantly downstream of the mill averaged 635 and 1,400 cfu/100mL. *E. coli* and enterococci were also measure in the paper mill effluent. Counts in the paper mill effluent ranged from 160,000 cfu/100mL to 46,000,000 cfu/100mL for *E. coli* and ranged from 140 cfu/100mL to 30,000 cfu/100mL for enterococci. In order to evaluate the health risk to recreational users of the river, a study was conducted by the Wisconsin State Laboratory of Hygiene to characterize the pathogenicity of the native bacterial flora within the mill, to evaluate pathogens in the paper mill effluent and to determine the fate of pathogens introduced to the paper mill effluent. The results showed that waterborne pathogens, represented by *E. coli* 0157 or *Salmonella* were not detected in any samples, pathogens introduced to mill processing water samples were inactivated within 14 to 24 hours and that the presence of indigenous flora provided a barrier against the inadvertent introduction of these pathogenic strains into the mill processing water.

Elevated levels of *E. coli* at the beach created a dilemma which required remediation between the paper mill, local citizens, and the local health department. The study conducted at the paper mill showed that high levels of *E. coli* and enterococci introduced into the river did not pose a significant health risk for recreational users. However, using the current bacteria indicators as a measure of health risks at beaches (*E. coli* and fecal coliform), implies that there is indeed a significant health risk. This dilemma poses a need to look at alternative ways to measure health risks at beaches in cases where there are non-traditional inputs of pathogen indicators into recreational waters.

USGS Beach Research—Current Activities and Future Prospects

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Beach closings and advisories that result from fecal contamination continue to be constantly in the news. Although USEPA is working to update beach monitoring methods, develop new standards, and establish better and quicker testing methods, considerable work remains to be done. In addition, many local agencies lack the resources and(or) expertise to identify fecal contaminant sources, much less control them.

The USGS has been working with USEPA and other cooperating agencies to address these issues. USGS scientists are developing models to improve predictions of beach water-quality conditions and are evaluating and optimizing real-time analytical methods for bacterial indicators. They have also been working to identify new microorganisms and chemicals that better indicate the presence of disease-causing microorganisms in recreational waters. Microbial source tracking techniques are being applied with spatial and temporal sampling to identify sources of fecal contamination. USGS scientists are also working to understand the accumulation of bacterial indicators and pathogens in beach sands, and their influence on recreational water quality. Understanding the coastal processes that influence bacteria concentrations, including submarine ground-water discharge, shoreline change, and ocean currents and waves, are also critical components of USGS beach science and management research.

Although the USGS continues this vital work in several coastal marine areas and the Great Lakes, resources are needed to integrate our efforts across disciplines and on a larger scale. Many of the techniques and methods used on the local level can be applied in a consistent manner by USGS scientists to better answer questions on the regional and national level.

Swimming Advisory Forecast Estimate (Project SAFE): A New Approach for Predicting E. coli Counts at Five Lake Michigan Beaches

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Predictive modeling for *Escherichia coli (E. coli)* concentrations at effluent-dominated beaches may be a favorable alternative to current monitoring standards. The ability to model numerous beaches simultaneously and provide real-time data decreases cost and effort associated with beach monitoring. From 2004-2006, five Lake Michigan beaches and the nearby Little Calumet River outfall were monitored for *E. coli*. Ambient lake, river, and weather conditions were measured or obtained from independent monitoring sources. Models were developed separately for days with prevailing onshore and offshore winds in 2004 due to the strong influence of wind direction in determining the river's impact on the beaches. Using regression modeling, it was determined that during onshore winds, *E. coli* could be adequately predicted using wave height, lake chlorophyll and turbidity, and river turbidity (R^2=0.635, N=94); model performance decreased for offshore winds using wave height, wave period, and precipitation (R^2=0.320, N=124). Variation was better explained at individual beaches. A model incorporating all three years of data included predictive parameters turbidity, rainfall, current direction, wave direction, and wind speed. Model results were provided to beach managers daily, and predictions were incorporated into management activities in 2006. Overall, the model was more effective at characterizing water conditions in real time than traditional methods, indicating that the predictive modeling may be a more reliable alternative to the monitoring approach employed at most recreational beaches.

Indicators of Shiga-Toxin Producing Escherichia coli in Ambient Water Monitoring Fecal Coliform Bacteria Cultures

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Background: Outbreaks of shiga-toxin producing *Escherichia coli* (STEC) have been linked with contact and consumption of contaminated recreational water. However, few data are available on the distribution of STEC in ambient waters and little is known about their relation to hydrology, land use, season and microbial water-quality criteria.

Methods: To evaluate the occurrence of STEC in ambient river water, 70 samples were collected from 14 urban, 27 agricultural and two forested sites in Michigan and Indiana. The samples were analyzed for fecal coliform bacteria, *E. coli* and enterococci using standard methods. The 100-ml fecal coliform culture was analyzed for 6 indicators of STEC using a variety of methods. Occurrence of the *E. coli* O157:H7 phenotype was assessed using CT-SMAC medium. The O157 antigen was assessed using a commercially available immunoassay as well as by polymerase chain reaction (PCR) for the rfb_{O157} gene. PCR was used to determine the presence of the *stx1*, *stx2* and *eaeA* genes. Land use and hydrology information was taken from U.S. Geological Survey data.

Results: There were multiple detections of STEC genes, antigens and phenotypes in river water samples. *E. coli* O157 was detected in five samples that were also positive for *eaeA* and *stx2* (four agricultural, one urban). Episodic increases in river discharge had significant affects on STEC detections in urban but not agricultural sites and STEC indicators were significantly different in May and July agricultural samples when compared with other land-use and sampling date combinations. Differences in STEC indicators were also found with respect to indicator concentration and land-use.

Conclusion: The use of fecal indicator enrichment cultures increased sensitivity and decreased matrix effects for the molecular methods used to detect STEC from ambient water. STEC were found in ambient surface water with complex site- and watershed-specific patterns. The occurrence of STEC is inconsistent with concentrations of indicator organisms, and shows a diverse relation with hydrology, land use and season.

Partitioning of E. coli within a Beachshed

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Recent research has highlighted the occurrence of *Escherichia coli* in natural habitats not directly influenced by sewage inputs. Most studies on *E. coli* in recreational water typically focus on discernable sources (e.g., effluent discharge, runoff) and fall short of integrating riparian, nearshore, onshore, and outfall sources. An integrated 'beachshed' approach that links *E. coli* inputs and interactions would be helpful to understand the difference between background loading and sewage pollution; to develop more accurate predictive models; and to understand the differences between potential, net, and apparent culturable *E. coli*. The objective of this study was to examine the interrelatedness of *E. coli* occurrence from various coastal watershed components along southern Lake Michigan. The study shows that once established in forest soil, *E. coli* can persist throughout the year, potentially acting as a continuous non-point source of *E. coli* to nearby streams; year-round background stream loading of *E. coli* can influence beach water quality. *E. coli* is present in highly variable counts in beach sand to depths just below the water table and distances at least 5 m inland from the shore, providing a large potential area of input to beach water. In summary, *E. coli* in the fluvial-lacustrine system may be stored in forest soils, sediments surrounding springs, bank seeps, stream margin and pools, foreshore sand, and surface groundwater. While rainfall events may increase *E. coli* counts in the foreshore sand and lake water, concentrations quickly decline to pre-rain concentrations. Onshore winds cause an increase in *E. coli* in shallow nearshore water, likely resulting from resuspension of *E. coli*-laden beach sand. When examining indicator bacteria source, flux, and context, the entire 'beachshed' as a dynamic interacting system should be considered.

Vancomycin-Resistant Enterococci and Cephalosporin-Resistant Escherichia coli Detected in Stream Waters

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Background: While the prevalence of vancomycin-resistant enterococci (VRE) and cephalosporin-resistant *Escherichia coli* (CREC) in hospitals has been well documented, the presence of these organisms in the environment has not been well studied. VRE or CREC in the environment may pose a health threat if the organism is pathogenic or could transfer antibiotic-resistance genes to pathogens. These genes are often carried on transferable genetic elements (plasmids or integrons) along with genes responsible for resistance to non-antibiotic toxins (mercury, detergents, or solvents). Waters contaminated with such compounds may contribute to the development, maintenance, and dissemination of antibiotic-resistant bacteria, including VRE and CREC.

Methods: Nineteen sites from urban and non-urban settings were samples and approximately 700 enterococci and 1000 *E. coli* were obtained. Seven sites were sampled twice. Clinical and Laboratory Standards Institute methods were used to determine resistance to vancomycin (enterococci), and cefoxitin, ceftriaxone (*E. coli*). *E. coli* were also evaluated for resistance to mercury. VRE genes (*van*A and *van*B) were detected by PCR.

Results: Intermediate-level VRE was detected in 8% of samples, and high-level VRE were detected at two sites. CREC was widespread with up to 56% of *E. coli* isolated from a single site resistant to cefoxitin; up to 54% resistant to ceftriaxone; and up to 46% resistant to both. Cephalosporin resistance was also found in combination with mercury resistance: 12% of isolates were resistant to one cephalosporin and mercury, 4% were resistant to both cephalosporins and mercury.

Conclusions: Antibiotic-resistant bacteria that have become a significant concern in the clinical setting can be found in stream waters. Streams may be a reservoir for antibiotic-resistant bacteria or for genes responsible for resistance that could be transferred to pathogens.

Nowcasting Bacterial Levels and Beach Advisories at Lake Erie Beaches

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Swim advisories issued by beach managers in Ohio are based on concentrations of the indicator bacterium *Escherichia coli* (*E. coli*). Because concentrations may change between the time of sampling and the reporting of results (18–24 hours), advisories issued on the previous day's *E. coli* may cause unwarranted loss of recreational access or may permit swimming when there is an unknown, unacceptable level of risk. Predictive models have been recognized as alternative tools to provide real-time assessments of recreational water quality.

Work is being done to develop and test models to predict *E. coli* concentrations at five Ohio Lake Erie beaches. For Huntington, where investigations are further along than at the other beaches, predictions based on a model have been available to the public through an Internet-based "Nowcasting" system since May 30, 2006. For 2006, the Huntington model yielded more correct responses and better predicted exceedance of the standard than did the current method for assessing recreational water quality (previous day's *E. coli* concentration). The other beach models were validated for the first time in 2006 and will be added to the Nowcasting web site in the future.

Human Fecal Pathogen Contamination in the Recreational Marine Waters of the Florida Keys

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Little is known about how water quality in offshore recreational environments, including coral reefs, may be impacted by microbes associated with human waste. To address this issue, samples were collected from surface water, ground water and coral mucus along a 6.7 mile transect off Key Largo in the Upper Florida Keys. Samples were collected semi-annually between July of 2003 and 2005 and were processed for fecal bacterial indicators and human enteric viruses (by molecular methods). Samples collected nearshore had the highest detection rate for indicator bacteria and enteric viruses and generally declined offshore; however, ground water samples at the two most offshore stations were positive for enteric viruses 75-100% of the time. When examined by sample type, coral mucus harbored both fecal coliform bacteria and enterococci at levels 10-fold greater than in the corresponding water samples. Enteric viruses were more likely to be detected in coral mucus and water column in the spring; however, they were more frequently detected in groundwater in the summer. Adenoviruses (AdV) were more widespread and appeared to be more persistent than the more labile enteroviruses (EV); 38% of all samples were positive for AdV and 6% were positive for EV. While work is ongoing to better characterize these viruses, data collected to date suggest a contaminated ground water source may be reaching the offshore reefs in the Upper Keys.

Detection of Genes Indicating Shiga-Toxin Producing Escherichia coli and Human Pathogenic Enterococci in U.S. Surface Waters

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Public health protection in recreational waters relies on enumeration of the fecal indicator bacteria *Escherichia coli* and/or enterococci. Little is known about the relation between fecal indicator bacteria and bacterial pathogens, and environmental dissemination pathways and locales for contact between bacterial pathogens and the public are poorly understood.

We studied 15 surface-water sites from 11 U. S. states, as well as urban and agricultural watersheds in Michigan and Indiana. Bacterial cultures that grow on standard fecal indicator test media from 100 mL of surface water were analyzed for 5 indicators of shiga-toxin producing *Escherichia coli* (STEC): O157 antigen, rfb_{O157} gene, and virulence genes *eae*A, *stx*1 or *stx*2. Most sites were also tested for the *esp* gene (associated with human-pathogenic enterococci). At selected sites where *stx*2 genes were indicated, the variants *stx*2c, 2d, 2e, or 2f were also tested.

The combination of O157 serotype+ *stx*2+*eae*A, of particular concern for human health, typically occurred in samples substantially exceeding recreational water quality bacterial criteria. However, the *eae*A gene (indicative of enteropathogenic *E. coli*) was detected in >95% of all samples tested, and the rfb_{O157}, *stx*2 and *stx*1 genes occurred individually in samples that met all water quality criteria. The *stx*1 gene was detected in <20% of samples, generally at sites with rural or agricultural land use. The rfb_{O157} gene was detected in <10% of samples, but the *stx*2 gene, that may occur in many STEC serotypes, was detected in >50% of all samples, and in several samples, more than one *stx*2 variant was detected. Specific combinations of genes were characteristic of particular sites, suggesting local as opposed to regional sources of contamination. The *esp* gene was typically detected at sites with urban land use.

STEC and human-pathogenic enterococci may occur in U. S. surface waters, and often in water that meets all bacterial water quality standards. Further studies, with more frequent sampling throughout the year, would be required to fully understand the complex hydrologic, geographic and temporal patterns observed.

Potentially Harmful Cyanotoxins in Drinking and Recreational Waters

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In freshwater, several species of cyanobacteria produce natural toxins. When a cyanobacterial bloom forms the potential for harm to domestic animals, wildlife and humans greatly increases. Human exposure occurs through ingestion of contaminated drinking water, accidental ingestion or inhalation during recreation, and inhalation of aerosolized toxins. The cyanotoxins are generally of two types: neurotoxins and hepatotoxins. The neurotoxins are fast acting, and ingestion of a large dose may cause paralysis of skeletal and respiratory muscles, which can result in death. Hepatotoxins affect the liver, disrupting the important proteins that keep the liver functioning. Both types of toxins are difficult to identify and require detailed laboratory analyses, which usually do not occur until after a poisoning event. More research is needed on this emerging issue. For example, organisms producing cyanotoxins look identical to those that do not, limiting the ability to prevent exposure of animals and humans. Monitoring organisms in water supplies is limited to identifying and quantifying the organisms that are present and determining if they have the potential to produce cyanotoxins. Simple, rapid tests for toxin detection are currently under development.

A drinking water study was conducted on 5 facilities that utilize Lake Champlain, Vermont. Using mouse bioassays, ELISA assays and LC/MS, microcystins, a class of hepatotoxins, were commonly found in raw water but not in finished water. Microcystins were also found in North Carolina and Florida lakes and streams that are used for recreation and drinking water sources. Anatoxin-a, a potent neurotoxin, was also identified and attributed as the cause of death for two dogs that drank lake water in Lake Champlain.

There is an increasing awareness of health-related cyanotoxins at water treatment facilities. Removing these toxins from drinking water supplies has met with only limited success. The USEPA has added cyanobacterial toxins to the Candidate Contaminate List, which may result in new regulatory measures for cyanotoxins in surface waters. With increasing eutrophication, drinking water sources and recreational waters are at risk from toxic cyanobacteria.

Impact of Bird Use on the Water Quality in Managed Wetlands

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The South San Francisco Bay Salt Pond Restoration Project has a major goal of habitat restoration – particularly habitats that support resident and migratory birds. Another goal is to provide public access and recreation in the project area. Parts of the Alviso ponds, a publicly accessible section within the project area, are currently home to year-around bird residents and large numbers of seasonal waterfowl.

Bird feces carry fecal indicator bacteria [FIB; total coliforms (TC), *Escherichia coli* (EC), and *Enterococcus* (ENT)] identical to FIB in human waste. Although FIB are not pathogens, epidemiological studies show that exposure to FIB during recreation in water correlates with increased risk of gastrointestinal and respiratory illnesses. A number of diseases can be transmitted from birds to humans, for example salmonellosis (etiologic agent *Salmonella* spp.). *Salmonella* has been isolated from bird feces collected in some California wetlands.

Because there are large bird populations in the Alviso pond system and some of the Alviso ponds now discharge to sloughs, there is potential for discharged water to be of reduced quality, as indicated by FIB. Also, recreation in or around the ponds creates a potential route of human exposure to FIB and pathogens through incidental ingestion or inhalation of slough or pond water.

The relationship between winter and summer bird use of two Alviso ponds and FIB concentrations in these ponds and adjacent sloughs is being examined. Results show that the California water-quality standards for recreational marine contact for TC, EC, or ENT were exceeded in 95 to 100 percent of the slough samples and 0 to 28 percent of the pond samples during the winter, and 80 to 100 percent of the slough samples and 40 to 88 percent of the pond samples during the summer. Bird use of the ponds was ten times greater during the winter, although water samples showed greater FIB exceedances in the summer. The pathogen *Salmonella* was isolated from 4 of 7 slough samples and 3 of 28 pond samples combined for both seasons, and eight different serotypes were isolated and identified, each of which has been implicated in human disease in California.

Potential Exposure to Trematode Parasites in Biscayne National Park through the Non-native Gastropod Melanoides Tuberculatus

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A non-native gastropod *Melanoides tuberculatus* (Family Thiaridae; common name Red-Rimmed Melania) has been identified in Biscayne National Park (BNP) in densities up to 383 live/m^2 1.7 km from shore. As a known carrier of parasites harmful to both human and animal populations, *Melanoides* poses a number of potential threats to the habitat of Biscayne Bay and is a serious concern for BNP managers. This study is 1) examining the history of introduction into the park (via sediment cores and DNA analyses); 2) determining whether parasites are present in the snail population in BNP; 3) mapping the geographic distribution of *Melanoides* and the parasites within the park; and 4) examining their effect on native animal populations. In addition, through experimental work and field observations we will attempt to determine what environmental factors (e.g. salinity, temperature) may control its distribution, in order to determine what strategies the Park might use to eradicate the species.

Melanoides tuberculatus is the intermediate host to human parasites *Clonorchis sinensis*, *Opisthorchis spp*. (liver flukes) and *Paragonimus westermani* (lung fluke). *Paragonimus* is a documented cause of human disease in the U.S. (Mariano et al., 1986; DeFrain and Hooker, 2002). *Melanoides* also is a known carrier of *Centrocestus formosanus*, a trematode that produces lesions on fish gills. The complex lifecycle of the trematodes involves passing from the definitive host (humans) via untreated fecal material, to the first intermediate host (snails) to a second intermediate host (crustaceans or fish). The source of infection for the next definitive host is consuming raw or poorly cooked crustaceans or fish. These issues are a significant concern in south Florida where all components of the trematode life cycle are in place. In addition, the recreational use of Biscayne National Park, via fishing, swimming, etc. increases the likelihood of exposure if parasites are present.

Zoonotic and Vector-Borne Diseases

Public Health Aspects of Vector Borne and Zoonotic Diseases: The Relationship Between Disease Occurrence and the Earth Sciences, and Contributions by USGS to Disease Prevention and Control

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Worldwide, 14 million deaths occur each year from infectious diseases, which frequently are transmitted from animals to humans by arthropod vectors, or have rodent vectors as reservoir hosts. This presentation will provide an overview of Vector-borne and Zoonotic (VB &Z) diseases, their causes, and approaches for effective prevention and control. By the end of the presentation, the audience will 1) know the most important VB &Z diseases to global health, 2) understand the driving forces leading to an increase in these diseases, and 3) understand how USGS expertise and tools contribute to preventing and or controlling VB &Z diseases of global public health importance.

Malaria, diarrheal diseases, HIV/AIDS, and tuberculosis are among VB &Z diseases causing substantial morbidity and mortality worldwide. In addition, several human VB &Z disease outbreaks, including avian influenza, rabies, Ebola fever, West Nile Virus, SARS, and Nippah Virus, have had considerable health and economic consequences in industrialized and developing countries. These diseases frequently are caused by interactions among humans, domestic animals, and wildlife populations. The driving forces behind these interactions include an increasing human population; human encroachment into wildlife habitat; changing climates and ecosystems; increasing international travel and trade; human-made and natural disasters; increased rapid movement of people and animals; globalization of the food supply; and human behaviors (e.g., consumption of bush meat). Preventing and or controlling VB &Z diseases requires early detection and response; rapid outbreak investigation; integrated disease surveillance in wildlife, domestic animals, and humans; monitoring arthropod vector and rodent reservoir populations; and research on the epidemiology of disease, risk factors, and effective interventions. USGS scientists are important members of the public health team, offering expertise in wildlife health and disease, epidemiologic investigation, diagnostic pathology, virology, parasitology, etc. The USGS also has developed and supports several important tools for disease surveillance and response, including web-based applications for data entry, geographic mapping, tracking and analysis of disease patterns, vectors, and res-

ervoir hosts; a Field Manual of Wildlife Diseases: General Field Procedures and Diseases of Birds; a new publication on Disease Emergence and Resurgence: The Wildlife-Human Connection, and more.

Vector-Borne and Zoonotic Diseases: USGS's Role in Public Health

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In the last ten years, the US Geological Survey (USGS) has made great strides in providing neutral and factual scientific information of value to health professionals across the disciplines of wildlife and domestic animal health, ecosystem health, and public health. In particular, USGS, by serving Department of Interior agencies, and through cooperation and collaboration with federal entities such as the U.S. Department of Agriculture (USDA), the Environmental Protection Agency (EPA), the Centers for Disease Control and Prevention (CDC) and the National Institutes of Health (NIH), state and tribal partners, such as the Association of Fish and Wildlife Agencies and the Native American Fish and Wildlife Society, and public and private entities, such as the Wildlife Conservation Society, the Consortium for Conservation Medicine, the Gaylord Nelson Institute for Environmental Studies, and Yale University's Canary Database, Envirovet, has helped provide linkage among the scientific community and in the public realm with regard to health for all living creatures.

Recent publications [1-3] demonstrate that from one-half to two-thirds of human pathogens are zoonotic[4] in origin, and that zoonotic diseases of wildlife are among emerging and resurging infectious diseases of humans and domestic animals. Factors promoting the transmission of infectious diseases among animals and humans include: (1) the exponential rise in human population growth; (2) increasing interactions among people and domestic and wild animals; (3) the ever-expanding growth in international travel; (4) increasing rapidity with which people and animals move across boundaries; (5) globalization of food supplies and food processing; (6) climate change; (7) ecosystem modifications; and (6) escalation in numbers of insect vectors, such as mosquitoes and ticks, capable of transmitting infectious diseases.

On September 26, 2003, the U.S. Geological Survey in partnership with CDC, the University of Wisconsin-Madison and the International Association of Fish and Wildlife Agencies provided an in-depth briefing to Congress entitled "Science, Society, Solutions -- Preparing for the Next Disease: The Human-Wildlife Connection -- What's Next?" This briefing discussed a number of emerging and resurging zoonotic diseases around the world, including: influenza, West Nile virus, ebola, monkeypox, Lyme disease, tularemia, leptospirosis, rabies, yellow fever, brucellosis, colibacillosis, hantavirus, nipah virus, and SARS. West Nile virus and Lyme borreliosis are just two such vector-borne emerging diseases

This session will emphasize vector-borne and zoonotic diseases from both the USGS and public health perspectives. Dr. Erik Hofmeister, a veterinary researcher at the USGS National Wildlife Health Center in Madison, WI will speak from the USGS perspective and Dr. Marguerite Pappanioanou, a public health specialist from the University of Minnesota will speak from the public health perspective. Questions and answers followed by a facilitated break-out session will follow.

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[2]Woolhouse MEJ, Taylor LH, Haydon DT. Population biology of multi-host pathogens. Science. 2001;292:1109–12.
[3]Friend, M. 2006. USGS Circular 1285. Disease Emergence and Resurgence: The Wildlife-Human Connection. U.S. Department of the Interior, U.S. Geological Survey. 388 pp.

Forecasting the Space/Time Spread of West Nile Virus

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Forecasting depends on autocorrelation; events $z(x, t)$ at an instant t and point x tend to occur in runs and clusters-–and similar diseases often occur in similar organisms (consider human and simian immunodeficiency virus). This poster uses United States county-level reports of 2003 West Nile Virus cases among humans and birds to illustrate these ideas. The epidemic was concentrated in the New York and upper Midwest regions, and human reports came from counties also reporting bird cases. A time series analysis shows that reports all occurred around the same time of year, with avian cases preceding human. Binning counties by week of first report demonstrates that most of the counties reported avian cases several weeks before human cases. This

conjunction is used to estimate relative risk: the extent to which knowledge of an avian report increases the probability of later human reports. For example, bird cases reported in a county during the week of 2003 July 18-24 are used to forecast later occurrences of human cases: relative risk is positive but declines from 4.4 to 2.0 using a simple model that explains about 25% of the variance. Finally space/time autocorrelation is illustrated with an animated map of the graph of human reports among adjacent counties. By integrating data from spatial, temporal, and taxonomic dimensions we can use the autocorrelation of epidemics to improve forecasts over those made in only one dimension.

Contributions to Understanding Transmission, Spread, and Persistence of West Nile Virus

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Emerging infectious diseases that are virulent to both wildlife and people depend on partnerships between wildlife biologists and public health scientists to carry out epidemiological research. Biologists identify which wildlife species play key roles in transmission of a disease to human populations and what are the ecological pathways of transmission. We assessed the importance of Eastern Screech Owl as a reservoir species for West Nile Virus through experimental infection studies after mortality patterns suggested that raptors were unusually susceptible. Our results ruled out this species as a significant reservoir, because the owl was susceptible, but did not produce viremia levels high enough to consistently infect mosquitoes (*Avian Diseases 50: 252-258*).

Biologists monitor the spread of an infectious disease though populations and subsequently a population's immunity to re-infection, which assists public health authorities in alerting and protecting human populations nearby. We determined that West Nile Virus antibodies were prevalent in a screech owl population 3 years after exposure, and we demonstrated that immunity to West Nile Virus is transferred from adult owls to their young through the egg (*Avian Diseases 50:454-455*).

Biologists draw on ecological expertise to anticipate the likely geographic patterns of spread of an infectious disease, and they identify the ecological factors that facilitate spread and persistence of the disease. We recognized the risk posed in California by a particular avian species that could spread West Nile Virus widely because it is more disease-resistant than closely-related species. We tested its reservoir competence in order to provide early warning if it should be monitored and controlled, because this species is exceptionally vagile and far-ranging. We determined that the enhanced disease resistance of the brown-headed cowbird did not take the form of tolerating high viremia levels that could be spread through many habitats and populations (*J. Wildlife Disease, in press).*

Efficient Surveillance and Management of Vector-Borne Diseases in Natural Areas

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Management programs for vector-borne diseases in national parks and wildlife refuges are designed to protect public health while minimizing negative effects on natural systems. The more efficient the management program, the fewer people get sick, and the less the need for broad scale environmentally damaging interventions. Highly efficient management requires knowledge of both vector ecology and pathogen transmission dynamics to develop accurate surveillance tools and well-targeted control methods. Numerous management techniques are available, but theoretical advances are needed on ways to efficiently integrate these techniques.

Probabilistic models of pathogen spread through natural populations suggest that efficient integration of techniques requires knowledge of the effects on vector abundance and pathogen prevalence of incremental increases in the level of each intervention. Fluctuations in vector numbers have a more or less linear effect on vertebrate disease incidence when pathogen prevalence in vectors is low (e.g., for most mosquito-borne arboviruses such as West Nile Virus) but not when pathogen prevalence and vector numbers are high (e.g., for Lyme disease spirochetes in endemic natural areas). Therefore, effectiveness of management depends on initial conditions of vector abundance and pathogen prevalence. Furthermore, interventions that lower vector numbers and incidence of human disease might or might not similarly affect incidence in wildlife, depending on local transmission dynamics. Finally, the structure of the transmission cycle (numbers and phenologies of competent vector and reservoir species)

influences growth and stability of local pathogen prevalence. Efficiently integrated and well-targeted management of vector-borne diseases can protect public health while minimizing negative effects on nontarget organisms.

Multi-temporal Remote Sensing of Soil Moisture and Vector-borne Disease Potential in the Rio Grande Delta, South Texas/North Tamaulipas, US-Mexico Border Area

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A dengue fever outbreak near Matamoros, Mexico during the Fall, 2004 became an epidemic during the Summer, 2005 as a result of heavy rainfall and flooding associated with the landfalls of Hurricane Emily and Tropical Storm Gert. Dengue fever is a vector-borne disease spread by mosquitoes, which breed in areas of high soil moisture often containing pools of stagnant water. In this study, normalized difference vegetation index (NDVI) combined with surface radiant temperatures was used to model soil moisture availability (Mo), which measures relative amounts of moisture in the soils not available for evapotranspiration by vegetation. A previous study applying this method found mosquito infection rates throughout the Nile Delta, Egypt to be highest in areas where modeled Mo values range between 20 – 60%, with 0% Mo defining dry areas and 100% defining water-saturated areas, wetlands and perennial bodies of water.

For the Rio Grande Delta area, both Landsat-7 ETM+ and ASTER measured NDVI images (15 – 30 meter spatial resolution) and surface radiant temperature images (60 – 90 meter spatial resolution) were used to map the distribution of Mo values throughout wet and drought periods between 06/00 and 09/05. The results show that the most persistent areas of high (> 60%) Mo corresponds with “resacas”, or abandoned meanders, along the Rio Grande floodplain and delta, which often persists even through drought periods. In particular, pre- and post- Hurricane Emily ASTER images show an increase in flooded areas around ephemeral lakes and resacas along the Rio Grande floodplain. Within the Pleistocene Beaumont formation, areas of moderate to high Mo within the 20 – 60% range of high mosquito-breeding probability correspond with impermeable muds from remnant interdistributary, abandoned channel-fill, and overbank flood deposits. One such area near Raymondville, TX produced Mo values near 100% during a prolonged wet period in November, 2003. Mineral maps produced using drought period ASTER imagery (March, 2001) and x-ray diffraction results from Beaumont soil samples suggest that the wetter, impermeable areas may have relatively higher smectite contents than the surrounding sandier, moderately permeable areas. Satellite-derived soil moisture data could be useful for targeted mosquito control measures in the future.

Epidemic Malaria Early Warning System for Africa

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At least 110 million Africans are estimated to live in regions prone to malaria epidemics. Compared to endemic regions, populations in epidemic-prone regions have higher risk of death in all age groups because of their low levels of immunity. Improved early warning and detection of malaria epidemics in Africa remain among the key technical elements of the World Health Organization’s (WHO) Roll Back Malaria (RBM) Program. In December, 2001, the Third Meeting of the RBM Technical Support Network on Epidemic Prevention and Control identified an immediate operational need to identify areas with anomalously high rainfall as an early warning indicator of malaria risk.

In response, the USGS Center for Earth Resources Observation and Science developed simple maps of the difference between current rainfall and the long-term average. These products were staged through the Famine Early Warning System’s Africa Data Dissemination Service website and have been used operationally since 2002. The maps were developed in consultation with WHO field staff to ensure they would be compatible with WHO’s Health Mapper GIS software. A review of the maps’ usefulness in desert fringe settings in southern Africa has shown a high correlation between rainfall anomalies and both confirmed (Botswana) and unconfirmed (Namibia, Swaziland, and Zimbabwe) malaria incidence anomalies, with a lead time of at least two months. The rainfall anomaly maps also proved valuable for forecasting, warning, and detection of malaria epidemics in Kenya and Uganda.

We are now developing a mechanistic vectorial capacity model that incorporates rainfall anomalies and air temperature. Malaria early warning products may be improved in highland settings by including temperature information, given the importance of temperature as a limiting or enabling factor in malaria transmission. Based on feedback from WHO field staff, we have also modified our epidemic risk mask to better reflect current conditions.

Over the next three years, we plan to evaluate our simplistic difference product and our mechanistic vectorial capacity models with field observations of malaria in southern Africa, east Africa, and the Sahel.

Avian Influenza Viruses in Water and Sediments of the Atlantic Migratory Flyway

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A pilot study, between the U.S. Geological Survey (USGS) Georgia Water Science Center in Atlanta, Georgia and the USGS National Wildlife Health Center (NWHC) in Madison, Wisconsin, was completed to monitor the presence and persistence of avian influenza viruses (AIV) in aquatic habitats of migratory water fowl along the Atlantic Migratory Flyway. Understanding the persistence of AIV in these waters may help identify a method of transmission of AIV between birds and from infected birds to other species including humans. This information could aid in identification of areas of potential AIV exposure.

Surface-water and sediment samples were collected from selected locations at National Wildlife Refuges (NWR) in Georgia, South Carolina, North Carolina, Virginia, and Maryland in late February and late May 2006 after the birds had migrated from these areas. The AIV subtype H3N1 was detected in one sediment sample collected at the Savannah NWR in late February 2006. AIV was not detected in the remaining surface-water and sediment samples collected during February and May 2006. Water and sediment samples were collected again during January 2007 at the same sites while large populations of migratory waterfowl were in residence. Results are not yet available for the January 2007 samples. Each sample was analyzed at the NWHC for the presence of AIV by viral isolation using hemagglutination assay (HA). HA and positive samples were subtyped at the U.S. Department of Agriculture (USDA) National Veterinary Services Laboratory at Ames, Iowa. Water-quality parameters were measured at each sample location.

The detection of AIV in late February 2006 but not in May suggests that; (1) AIV was shed from waterfowl during over-wintering at the Savannah NWR, and (2) that the viruses remained infective a period of days after the birds had departed. The lack of detection of AIV in samples collected in late May 2006 indicates that AIV may be sensitive to changes in water conditions such as warmer water temperatures in late May as compared to the colder water temperatures observed in late February. Further study is necessary to understand the aquatic conditions that may enhance the persistence of AIV in natural waters.

Image-based Environmental Health Initiatives at USGS EROS

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Scientists at the U. S. Geological Survey (USGS) Center for Earth Resources Observation and Science (EROS) are developing activities in support of the human health agenda put forth by the USGS Science Strategy Team and the Early Warning and Environmental Monitoring Programs at EROS. These activities fall into three areas: vector-borne disease monitoring, land cover classification as input for air- and water-borne bioaccumulation-based modeling, and participatory monitoring of toxic substances with an emphasis on Tribal Lands. The studies rely heavily on the use of remotely sensed imagery from EROS holdings.

Early projects included the NOAA-funded project “Rift Valley Fever: The Interplay of Climate, Landscape Ecology and Epidemiology”, which explored the relationship between extreme El Nino-southern Oscillation events and outbreaks of vector borne Rift Valley Fever in Africa. Parallel research involved improved detection and early warning of malaria epidemics in Africa through the identification of areas with anomalously high rainfall. More recently, the NASA-funded project, “Enhancing USAID Famine and Malaria Early Warning with NASA Earth Science Results”, is developing a mechanistic vectorial capacity model that incorporates rainfall anomalies and air temperature.

As an extension of earlier work done by EROS scientists, the recently initiated project on "Utilization of the Landsat Archive for Agricultural Chemical Exposure Assessment" applies object-based tools to more accurately classify crops on satellite images, for use as a preliminary input to regional cancer models. The results from this work will also demonstrate how current and historical Landsat data, as well as data to be collected by the Landsat Data Continuity Mission, can be used to derive and apply information that is directly beneficial to society.

The EPA-funded "Montana Indian Country CARE Project" maps toxic substances in order to better educate Tribal communities about the risk of exposure. Rocky Mountain College leads this work through a collaboration of four of Montana's tribal colleges, existing EPA Programs, EROS, and other partners. Source data for the project includes the EPA's toxic release inventory, tribal EPA and locally collected data, the analysis of imagery from the EROS archives of Landsat imagery and aerial photography, and data from other USGS sources.

Summary of Topical Breakout Sessions

Breakout sessions on each of the six topical areas were conducted to promote discussion among scientists of different disciplines and expertise and to gather lessons learned on improving coordination and integration among the earth and health sciences. A summary of cross-cutting issues and a record of discussions for each topical area is provided below and presented in terms of needs and actions for improved communication and coordination and science opportunities.

Cross-cutting Coordination and Integration

Broad strategic thinking will be needed to achieve desired health outcomes in the future. The need for increased communication with the public was pointed out consistently across the topical areas. There is a need to increase public awareness of the relation of our environment, wildlife, and domestic animals to public health, and how societal and economic factors influence this relation. An informed public is not only better equipped to participate in solutions, but is less apt to react inappropriately as a result of lack of knowledge or fear.

There is a need to increase communication across environmental and health sciences and agencies. Communication, information sharing, and integration of the sciences will improve understanding of the agents that cause disease, the factors that influence spread of disease, and the comparable economic and societal benefits of management alternatives, including disease prevention and mitigation. It is acknowledged that agencies have specific missions, and that "mission creep" and duplication of effort are not desired. Interagency and interdisciplinary collaborations are essential to maximizing use of all available relevant information and realizing efficiencies from complementary agency missions.

The scientific collaborations discussed herein convey the broadest interpretation of environmental health, including all factors related to the quality of our natural environment and the interactions with the ecosystems and organisms within those environments. Increasing the number of scientists with cross-disciplinary expertise will be achieved most effectively through the design of university curricula that develop scientists with the fullest appreciation for the spectrum of relevant disciplines and the integration of earth and health sciences. Furthermore, environmental and health databases should be integrated where possible and, at a minimum, be designed for cross-disciplinary applications. The utility of these databases should be demonstrated and made accessible for a broad range of public health uses.

Current law restricts release of medical data without authorization. This constrains public health authorities from providing data on human infection patterns from environmental disease agents that could be combined with environmental quality and wildlife disease information to elucidate patterns of disease spread and transmission. Access to such information is needed in a way that preserves privacy but enables spatial analysis of relations between disease occurrence and the factors that affect disease etiology and epidemiology.

Finally, productive partnerships among agencies will require both grass-roots collaborations among scientists working together to address a specific public health issue, and agency leaders acknowledging the need for resource investments to develop the potential synergies available among agencies. For example:

- Liaison assignments, placing representatives of one agency in residence at other agencies, will help expand the range of potential collaborations and areas of information and knowledge exchange.
- Partnerships on priority issues and formal coordination entities (such as interagency working groups) will contribute to an efficient approach to interagency coordination and guide the way to broader integration of the earth and health sciences.
- Technical meetings sponsored jointly by environmental and health science agencies will allow pioneering teams of interdisciplinary scientists to demonstrate approaches, opportunities, and advantages.

Ideas for minimizing roadblocks to the ability to share funding among agencies should be sought. Agencies should coordinate Internet web sites beyond simply posting links to each other's sites. Explicit discussion of the role their agency and their relationship to other agencies would significantly improve the understanding of the coordinated efforts of Federal agencies, as well as improve public understanding of the roles and interactions among agencies.

Exposure to Toxic Contaminants in Air, Dust, and Soil

Moderators: Geoffrey S. Plumlee, USGS, Denver, Colorado Kathleen M. Johnson, USGS, Reston, Virginia

Improving Communication and Coordination

- The Federal Interagency Working Group on Asbestos, which is supported by the Committee on the Environment and Natural Resources, Toxics and Risk Subcommittee, is an example of a highly productive interagency collaboration that brings all pertinent knowledge to policy and decision makers. This working group can serve as a model for working groups on other environmental health issues.
- The recent National Research Council and Institute of Medicine report titled *Earth Material and Health: Research Priorities for Earth Science and Public Health* indicated that the need for funding to support these activities needs to be acknowledged at the top levels of Federal agencies. Coordination of high-level agency representatives to identify and support areas of collaborative research is needed.
- More scientist-to-scientist collaborations are needed to develop additional success stories. These collaborations will be facilitated by steps (like this conference) to increase the awareness of colleagues in other disciplines who have valuable knowledge and expertise to offer. Information should be shared through Internet web sites, professional meetings, planning meetings, and working groups to facilitate development of these linkages.
- Increasingly, earth and environmental science information will need to be provided to health agencies in a time frame that enables prompt use and action. At the same time, the public sensitivity of such information will require care and review to assure that the information is communicated in an appropriate and understandable manner. Guidelines or protocols will be needed to assure that sensitive products are reviewed and transmitted to decision makers and the public in a timely manner and in an effective form.

Science Opportunities

- Dust and soil characterization is an important data need, particularly in the micron to sub-micron particle sizes. Technologies such as field emission scanning electron microscopy and transmission electron microscopy are particularly useful.
- Particle surface characteristics and details about the chemical composition (including elemental oxidation state) of particles and particle surfaces is an important information need.
- Dusts need to be examined from a complex, multi-component perspective, in order to examine synergistic or antagonistic effects of multiple constituents. For example, a mix of Chromium (III) and Manganese in dusts, when wet, can result in the oxidation of Chromium (III) to Chromium (VI), a more toxic form.

- Assessing potential health issues associated with "urban" soils, dusts, and particulates, including contaminants and pathogens, and understanding the relative impacts of anthropogenic urban particulate matter and natural and anthropogenic particulate matter from nearby rural areas are important research opportunities.
- Establishing environmental baseline conditions for inorganic and organic contaminants (pesticides, herbicides, metals) and pathogens (anthrax) in soils across the country provides an information base from which natural or human-induced (unintentional or deliberate) changes can be identified.
- Baseline levels of dust generation and deposition vary regionally with changing climate. Model analyses and use of historical dust information from the geologic record will enable scientists to factor major components of natural and long-term change into analyses.
- Examining the processes that affect exposure pathways from air, dust, and soil to humans will provide a knowledge base from which exposure risk can be better defined and remedial actions can be designed.
- The relevance of air, dust, and soil science will increase particularly in relation to occupational environmental health. Bringing traditional geochemical knowledge to the industrial hygiene community for use in assessing workplace health and exposures is an important opportunity.
- The spread of airborne organic particles including pollen, fungal spores, and bacteria, can influence spread of disease agents and pathogens on a global scale; and therefore is an area of increasing importance to the human health community.
- Advances in nanoparticle engineering have caused a significant increase in the awareness of potential health implications of environmental exposure to nanomaterial (materials on a scale of less than 100 nano meter). The highly varied nature of the types and characteristics of nanomaterial being developed and the potential for a dramatic increase in development and production makes this an important area of future research.

Chemical and Pathogen Exposure through Drinking Water

Moderators: Ward W. Staubitz, USGS, Reston, Virginia Michael J. Focazio, USGS, Reston, Virginia

Improving Communication and Coordination

- Communication related to drinking water can be facilitated by working through existing organizations such as the Source Water Collaborative, American Water Works Association, National Water Quality Monitoring Council, Association of State Drinking Water Administrators, and others.
- A workshop to address drinking water issues in the broadest sense needs to be organized and targeted to attract midlevel managers, policy implementers, and scientists from environmental and human health agencies.
- Low-level environmental occurrence data often is confusing and subject to misrepresentation. Research that focuses on improving understanding of the health implications of long-term exposure to low-levels of environmental contaminants and communicating that information to regulators, industry, and the public will help resolve this confusion.
- Health agencies currently place high emphasis on issues associated with outbreak of waterborne disease. Improved interagency contacts between environmental and health agencies with respect to chemical and pathogenic contaminant issues will serve the health community well.
- Interagency collaborations on drinking water are increasing. These case studies could be used as leverage to promote the advantages in collaborations between environment and health agencies. Examples include collaborations on the occurrence and effects of arsenic contamination, linkages between environmental and cancer databases, collaborations to relate chemical occurrence data and human biomonitoring data, and collaborations to identify causal factors at potential cancer clusters.

- No agency captures comprehensive information on hazardous waste sites nationally. Such a database would provide a valuable resource for assessing the potential human health impact of hazardous waste sites at a national scale.
- The Agency for Toxic Substances and Disease Registry (ATSDR), in partnership with other agencies including the U.S. Environmental Protection Agency (USEPA) and USGS, has investigated human exposure to toxic chemicals through drinking water near several hazardous waste sites. These case studies provide a valuable means for demonstrating potential advantages of collaboration, lessons learned, and data gaps.
- Growth in interdisciplinary scientific approaches to drinking water issues will be spurred by educational programs in our universities. Providing seminars at universities, increasing interdisciplinary curricula, and identifying the niche for this science in grant programs and the workplace will increase the future pool of skilled interdisciplinary scientists.

Science Opportunities

- Human exposure data continue to be the single major information need associated with linking drinking water quality with adverse human health outcomes. There is a substantial gap in understanding how exposure through drinking water compares to other exposure pathways and the relative contributions of various types of human exposure. Studies need to be designed acknowledging that drinking water is just one of a number of possible exposure pathways for a variety of environmental contaminants.
- Additional data on new, unregulated chemical and pathogenic contaminants in source and finished (point-of-use) water sources need to be collected to supplement data currently collected for compliance and treatment-efficacy purposes. Future data-collection efforts need to consider emphasizing collection of point-of-use water quality data, including information from both public and private water sources.
- Additional information is needed to assist investigations linking drinking water quality and human health implications. Continuing needs include access to human health-related data such as aggregated epidemiological data and biomonitoring data, improved locational data for drinking water intakes, information on the population served by individual facilities, information on the drinking water systems that enables characterization of the water quality at the point of use, and information that relates source-water quality data to the intake and distribution system. This information however, needs to be obtained within the context of national security and privacy requirements. Therefore, the emphasis is not necessarily on the raw environmental or health data but rather on the ability to relate exposure and health outcomes in a general sense.
- Information on the performance of alternative drinking-water treatment technologies continues to be extremely valuable to local purveyors who are deciding how to make capital investments to ensure the best and safest operations over the long term. Investigations to provide this information would benefit most from collaborations with drinking-water treatment experts and industry representatives to ensure effective study designs and relevant results. Better understanding of contaminant-specific natural attenuation in watersheds and aquifers will contribute to development and selection of alternative treatment technologies and the potential for source-water protection.
- Agencies need to think broadly when identifying chemicals and pathogens of potential human health concern. New methods are needed to analyze environmental samples, and environmental data are needed to make preliminary assessments of the potential drinking-water concerns of the future.
- Seeking innovative ways to identify the source (point of origin) of contamination at drinking water intakes remains a priority. Environmental tracers, ground-water age dating, microbial source tracking, modeling, and so on are all part of the toolbox currently being developed and used to address this need. More work is needed not only in developing new tools but in demonstrating effective use of these tools in the field.

Animals as Sentinels of Human Health

Moderators: Rick F. Kearney, USGS, Reston, Virginia Caldwell Hahn, USGS, Laurel, Maryland

Improving Communication and Coordination

- Information on current knowledge of human health risks gained from fish and animal studies needs to be shared with the public. Examples include studies of endocrine disruption in fish, surveys of the spread of West Nile Virus in birds and other animals, and Highly Pathogenic Avian Influenza (HPAI) surveillance.
- The activities related to HPAI and the associated surveillance activities can be used as a model for coordination and communication both nationally and internationally. This is an important model given the global nature of disease emergence and spread in modern society.
- The disease mapping activities posted on the Internet through collaboration between USGS and Centers for Disease Control and Prevention (CDC) are an excellent example of making information available and usable by the public and the broader scientific community.
- The considerable research on animals and fish conducted on ecosystem-, population- and organism-level effects of environmental contaminants needs to be integrated and made accessible for use in assessing human health concerns. There are numerous emerging environmental health concerns, including chemical contaminants and pathogens. The availability of early information from fish and animal studies will improve our ability to assess and prioritize emerging human health concerns.
- There is a need to increase our ability to share data among scientists in other disciplines and with stakeholders. This will require organized efforts among agencies with varying health and environmental and wildlife science missions.
- A "knowledge map" that defines current research and the associated investigators needs to be developed and used to improve interagency linkages and initiate specific interagency pilot activities. Agency Internet web sites could be modified to include a listing of subject matter experts to encourage grass-roots collaborations.
- Information on wildlife morbidity/mortality events need to be shared more widely and rapidly. Criteria for notifications need to be defined collaboratively.
- The creation of a reporting infrastructure among wildlife veterinarians will enable early warning and tracking of disease outbreaks. Veterinarian groups/organizations can be of assistance in this area.

Science Opportunities

- Studies of contaminant occurrence in biological samples have provided significant insight into contaminants of potential human health concern. These studies need to be expanded with respect to the scope of contaminants tested, and designed with the intention of application to concerns for human health as well as ecological health.
- Expansion of methods development activities I needed to support field surveys of bioavailability and uptake in fish and wildlife. Development of field techniques is needed, including new genomic and proteomic methods that promise improved biomonitoring approaches and passive sampling devices that simulate uptake in lipids of living organisms.
- Other opportunities for sentinel monitoring include research on use of lichens as a monitoring device for air quality and air exposure pathways, and research on coral diseases as indicators of changing environmental conditions.
- The use of animals as sentinels of health risks has significant potential to support increasing efforts to ensure safety from terrorist threats.
- Research I needed that focuses on defining linkages between healthy landscapes and human health, as well as linkages between potentially harmful environments and adverse human health effects.

- Model avian species with species-specific traits that make them either particularly susceptible or resistant to zoonoses like West Nile Virus need to be identified and studied more extensively.
- Geospatial capabilities will provide increasing opportunities to relate fish and wildlife health and exposure data to assessments of human health.
- Research needs to provide more diagnostic services for wildlife diseases and identify new infectious diseases through various wildlife surveillance programs.
- Research is needed that explores linkages between marine and terrestrial animal disease events.
- Research needs to identify options for vector control, including coordination with efficient surveillance and management programs.
- Research needs to investigate the increased potential for applying remote sensing techniques to disease emergence and surveillance.

Human Consumption of Bioaccumulative and Other Chemical and Pathogenic Contaminants

Moderators: William H. Orem, USGS, Reston, Virginia Sarah Gerould, USGS, Reston, Virginia

Improving Communication and Coordination

- There are a significant number of separate databases on the occurrence of chemicals in fish tissue, soil and sediment, sediment core chronologies, source characterization (such as land use and coal quality), and wildlife exposure. These databases require linkages to improve the ability to conduct relational studies across the spectrum of contaminants sources, exposure pathways, and modes of action.
- There is a need to communicate information on emerging issues rapidly across discipline boundaries. Emerging issues often are detected through environmental occurrence or ecological effects studies. This information is valuable for prioritizing future human health concerns and for defining initial research needs.
- There is reluctance in some cases to cross discipline boundaries because of unfamiliarity and other factors. This reluctance can only be overcome by persistent efforts to attend professional meetings of other disciplines and communicate directly with scientists who may have knowledge and expertise to offer.
- Prioritization of contaminants of concern, exposure pathways, diseases of greatest potential health risk, and other factors will require coordinated discussion and consideration of scientific knowledge from the broadest range of scientific disciplines. Such coordinated activities will serve the public health interest and promote important interdisciplinary studies.
- Quantifying sources of bioaccumulative contaminants increasingly requires national and often global inventories and a high level of international cooperation. This coordination can be supported by organizations like the World Health Organization and facilitated by the Department of State.

Science Opportunities

- The phenomenon of global distillation is being recognized more and more as an important manifestation of the release of organic chemicals in the environment, as well as an important human health concern for inhabitants of arctic regions, particularly those who consume significant amounts of food from local sources.
- Studies of the biological uptake and processing of contaminants in fish and wildlife increasingly will be used to support studies of human disease and assist in defining human exposure pathways.
- Maps of distribution and concentration of naturally occurring elements and pathogens can aid in developing exposure scenarios. Interfacing these maps with epidemiological studies may be helpful in identifying the causative agents of

disease. A good starting place for obtaining this chemical information is soil surveys, geologic maps, geochemical databases, fish monitoring databases, or Internet sites such as the Environmental Mercury Mapping, Modeling, and Analysis (EMMMA) web site (*http://emmma.usgs.gov/*), which brings together available USGS information on mercury.

- Increased use of environmental tracers will provide significant improvement in the ability to identify specific sources and their relative contributions to environmental contamination and human exposure. Tracers include isotopes, rare earth elements, and selected organic compounds.
- Biogeochemical studies can provide improved understanding of contaminant mobilization, cycling, and transformation, and human exposure pathways. This information will provide improved insights into how to control contaminant exposure and effects. Examples include understanding the processes that promote mercury methylation, mobilize arsenic, or change chromium to a more toxic form.
- Although there has been significant progress in characterizing the processes that affect mercury methylation in freshwater environments, important questions remain regarding the processes that control mercury cycling and methylation in marine environments, the relation of marine cycling to terrestrial loadings, and the processes that control mercury bioaccumulation in marine fishes.
- Broad-scale regional assessments of the occurrence of bioaccumulative contaminants are needed to provide information suitable for assessing the scope, extent, and magnitude of contamination issues, as well as identifying geographic hot spots and the reasons for their vulnerability.

Chemical and Pathogen Exposure through Recreational Waters

Moderators: Donna S. Francy, USGS, Columbus, Ohio Dale W. Griffin, USGS, Tallahassee, Florida

Improving Communication and Coordination

- Information on new capabilities to support daily decisions regarding recreational risk need to be shared widely with the public. For example, new model-based estimates of daily bacterial concentrations at beaches enable beachgoers to decide whether and where to go to the beach. Knowledge of the availability of such models will increase public interest in having these capabilities to check local beach water quality.
- New methods to identify chemicals and pathogens in recreational waters are complex and require significant field testing. Increased communication among the methods development community is needed to improve efficiencies, share lessons learned, and avoid duplication of effort. Interagency roundtables on issues such as new molecular methods, new culture methods, and new chemical analytical methods can be valuable investments of time and resources.
- Partnerships among agencies need to include the education of the user community through seminars and fora that include the use of cutting-edge models, technologies, and analytical methods. USEPA Office of Water has used its contacts with state and local government agencies to improve communication on beach health issues and can provide an important role facilitating communication with the user community.
- Two list servers currently exist for recreational issues–*Beachnet* [*http://www.great-lakes.net/lists/beachnet/beachnet.info*] and *Beachinfo* [to become a member send an email to *beachinfo-subscribe@lists.epa.gov*]. These are valuable communication tools that can be used more broadly to disseminate information.
- The National Beaches Conference and the Great Lakes Beach Conference are two examples of meetings that are attended by many state agencies, and therefore, provide valuable venues for communication.

Science Opportunities

- Federal investment in methods and model development for beach health reporting currently is limited. Although beach health monitoring is largely the responsibility of local governments, there is a need for development of consistent and

reliable methods that are effective throughout the range of beach conditions across the Nation. Although local governments can apply for the grants to implement beach-monitoring activities, they have limited ability to implement such research.

- As more and more data on occurrence, distribution, and sources of pathogens at beaches are collected, there is an opportunity to disseminate these data through a real-time repository that is accessible to users. State regulators need more information to help explain and design regulations that are suitable for the range of conditions at local beaches. Researchers would benefit from integrated data sets over large regional and national scales.
- New methods for detecting a wide range of algal toxins and the chemicals that cause taste and odor issues are opening the door to expanded interagency research on harmful algal blooms and the specific health risks that they can pose through contact, inhalation, and consumption during recreational activities on estuaries, rivers, lakes, and beaches.
- Models to estimate current beach health have been developed and applied at only a few beach sites. There is significant opportunity to expand predictive modeling capabilities to a broader range of conditions and to implement models at many more beaches across the Nation. Integration of greater understanding of coastal processes into beach health assessments and models will improve understanding of sources and pathways of fecal contamination at beaches.
- Recreational water assessments need to be expanded beyond lake and coastal beaches to river environments and provide data for a wide range of activities, including total- and partial-body-contact recreational activities.
- Epidemiological studies of predictive models for beaches are needed. These studies would determine whether the rate swimmers are becoming ill is related to the variables that are used in predictive models. Epidemiological studies involving the use of predictive models need to be advocated for purposes of model validation and enhancement.
- Data, knowledge, and models on beaches that extend over regions that may have similar mechanisms influencing beach health need to be aggregated. As an example, efforts are being made to develop regional beach condition models in the Great Lakes, and information on pathogens and red tides near Florida beaches could be compiled and analyzed.

Zoonotic and Vector-Borne Diseases

Moderators: Leslie A. Dierauf, USGS, Madison, Wisconsin Eric Hofmeister, USGS, Madison, Wisconsin Caldwell Hahn, USGS, Laurel, Maryland

Improving Communication and Coordination

- Improved public communication will increase awareness of disease etiology and epidemiology, so that the potential for emerging disease is factored more prominently in day-to-day human activities, planning, and development. An example is designing new communities considering the factors that affect abundance of disease vectors.
- The public needs to be provided with additional information based on the most current scientific knowledge on emerging diseases, such as Highly Pathogenic Avian influenza (HPAI). An informed public will minimize misconceptions regarding human health concerns.
- The CDC National Center for Zoonotic, Vector-Borne and Enteric Diseases, organized in 2007, can provide leadership in coordination of Federal agencies and serve as a nidus for discussion, collaboration, and interdisciplinary scientific research.
- Interagency communication can be increased through interagency working groups, such as the U.S. Coral Reef Task Force, the National Invasive Species Council, and the Oceans and Human Health Initiative.
- The expertise and abilities of the Federal public health Epidemic Intelligence Service (EIS) officers can be used to bridge the disciplines. The personnel in these 2-year CDC training positions are available for short- or long-term assignments, both during and after training. Situating one or more jointly funded EIS officers at USGS or as liaisons at CDC would help link earth and public health science.

- USGS membership at CDC's Emergency Operations Center would promote increased interagency collaboration.
- Meetings on emerging infectious diseases, such as that held in Atlanta in spring 2008, will provide an opportunity for communication among agencies.
- The International Society for Environmental Epidemiology provides a means to communicate with the broader health community beyond the Federal agencies including academia and industry.
- Increase communication between wildlife biologists, who study the effects of disease on populations, and veterinarians, who study the effects of disease on organisms.

Science Opportunities

- A short-term science priority is to develop useable products, such as accessible morbidity and mortality databases for state and local governments.
- Research needs to increase the understanding of the connection between avian diseases and human health, including the involvement of aquatic animals.
- The linkages between climate change and the emergence and spread of zoonotic and vector-borne diseases are a high research priority.
- Research needs to examine how changes in biodiversity and other measures of ecological health affect disease emergence, and address the large-scale drivers of ecosystem change and how they influence public health.
- The usability of databases for epidemiological studies needs to be improved by extending their scope and utility across species.
- Research needs to increase the priority of investigating the evolutionary bases of susceptibility and resistance to disease.
- Vulnerable human sub-populations that stand to be most at risk to emerging zoonoses needs to be identified.
- Information on environment, wildlife, and human health needs to be integrated to provide a complete picture of potential cause-and-effect linkages, including use of four-dimensional relational databases (who what where when), the visual thesaurus concept, and the "Georef" literature database.

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