Leading Article

Dedicated to Dr. Otto Hutzinger, professor emeritus, University of Bayreuth, Germany

Integrating Information for Better Environmental Decisions

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Abstract. As more is learned about the complex nature and extent of environmental impacts from progressive human disturbance, scientists, policy analysts, decision makers, educators, and communicators are increasingly joining forces to develop strategies for preserving and protecting the environment. The Eco-Informa Foundation is an educational scientific organization dedicated to promoting the collaborative development and sharing of scientific information. The Foundation participated in a recent international conference on environmental informatics through a special symposium on integrating information for better environmental decisions. Presentations focused on four general themes: (1) remote sensing and data interpretation, including through new knowledge management tools; (2) risk assessment and communication, including for radioactively contaminated facilities, introduced biological hazards, and food safety; (3) community involvement in cleanup projects; and (4) environmental education. The general context for related issues, methods and applications, and results and recommendations from those discussions are highlighted here.

Abbreviations: BSE: bovine spongiform encephalopathy; DOE: U.S. Department of Energy; EMPA: Swiss Federal Laboratories for Materials Testing and Research; EPA: U.S. Environmental Protection Agency; FMD: foot-and-mouth disease; GIS: geographical information system; GPS: global positioning system; ISEP: International Society for Environmental Protection; m: meter(s); SARA: Superfund Amendments and Reauthorization Act; SPOT: Satellite Pour l'Observation de la Terre; TCU: Texas Christian University

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Introduction: Shared Environmental Concerns

Ours is an increasingly global environment in which we share not only pollution and resource problems but also the responsibility and capability to solve them. Sustainable solutions will be anchored by two key elements. The first is integrated science and technology that improves our understanding of key physical, chemical, and biological interconnections, so we can better predict and mitigate adverse changes to environmental resources. The second is multi-organizational partnerships for education, communication, and constructive action to protect and preserve the environment.

Three decades ago, environmental programs tended to deal with problems at the regional to national scale, for example from leaking landfills to clean water supplies. By the beginning of the 21st century, scientific studies had increased our understanding of the environment and demonstrated the global scale of these issues. Across the planet, the quality and availability of basic resources – from air, water, and soil to food and energy – are at the heart of shared environmental concerns. For example, researchers have identified a 'grasshopper effect' for transboundary transport of persistent organic pollutants from one continent to another, using fingerprint techniques to trace atmospheric contaminants to their origin. Other scientists have proposed a link between levels of carbon dioxide in the atmosphere (resulting from more fossil fuel combustion associated with industrialization) and changes in Gulf Stream salinity, with possible serious implications for future climate change. And in daily news announcements we see the effects of limited reserves of drinking water and fossil fuel on political stability and resource development plans.

An enhanced appreciation of global interconnections has led to broader initiatives designed to better understand the causes of various environmental conditions and develop strategies for sustainability. Scientists, policy analysts, decision makers, and educators from a range of disciplines are increasingly joining forces to share emerging data and approaches for environmental preservation at a variety of topical conferences and summits, with a clear trend toward international partnerships over the past decade. From its inception, the **Eco-Informa Foundation** has been a catalyst for this type of international collaboration on environmental programs. A brief history of the Foundation, which is headed by the editor-in-chief of this journal, is provided below.

1 History of Eco-Informa

A lifelong dedication to environmental education and shared scientific research led three professors to develop the Eco-Informa Foundation more than a decade ago. Created by Dr. Otto Hutzinger of Germany with Dr. Leo Newland and Dr. Ken Morgan of the United States, its roots were the common vision and complementary research that began many years earlier during Dr. Newland's sabbatical year in Germany. Following extensive international careers in environmental chemistry, Dr. Hutzinger is professor emeritus at the University of Bayreuth, and Dr. Newland is professor and Director of the Environmental Sciences Program at Texas Christian University (TCU). Dr. Morgan is professor of geology, Director of the Center for Remote Sensing, and Associate Dean of the College of Science and Engineering at TCU. After several years of scientific collaboration and educational outreach, these three scientists formally established the foundation as a non-profit educational organization in 1996.

Dr. HUTZINGER'S pioneering work with polychlorinated biphenyls and dioxin established him as an early leader in the field of environmental risk analysis. He was among the first to integrate the separate disciplines of ecological chemistry, exposure assessment, toxicology, risk characterization, and communication to better understand possible health risks from man's pollutants in order to guide protective environmental policies. Dr. Hutzinger's TCU colleagues have been similarly committed to understanding environmental conditions and preserving natural resources. Together, these scientists established the Eco-Informa Foundation to support the organization and hosting of educational and scientific conferences, workshops, and seminars that focus on the use of science and technology to develop and share environmental information around the world. The 'fathers' of the Eco-Informa Foundation are shown in **Fig. 1**.

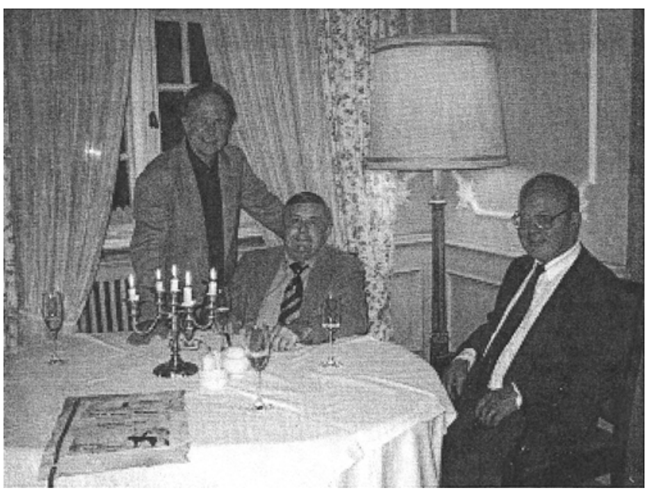

Fig. 1: Founders of the Eco-Informa Foundation at a conference planning meeting in Bayreuth, Germany (March 2002). From right to left: Otto Hutzinger, Leo Newland, Ken Morgan

The Foundation is anchored by three main goals. The first is to develop environmental information conferences that address current and future scientific, technical, and environmental topics. The second is to provide a forum for interaction among scientists, educators, and other professionals about information exchange technology and encourage the sharing of data and use of remote databases. The third is to stimulate the global exchange of scientific ideas through the use of computers and the Internet, promote communication (through wireless, satellite, and other means), and utilize special tools (such as satellite tracking and video conferencing) to enhance data collection and information sharing.

In keeping with these goals, the Foundation organized the *World Conference on Remote Sensing* in Germany's historic Bayreuth opera house in 1984. Speakers included Harrison SCHMIDT, then U.S. Senator from New Mexico and the last person to walk on the moon. This meeting was a precursor to the first formal Eco-Informa conference, which was held in Bayreuth in 1989. Subsequent Eco-Informa conferences were held in Bayreuth in 1992; Vienna, Austria, in 1994; Lake Buena Vista, Florida, USA, in 1996; and Munich, Germany, in 1997. The sixth conference in this international series was held in May 2001, hosted by Argonne National Laboratory and the U.S. Department of Energy (DOE) Center for Risk Excellence (under the directorship of Dr. Alvin Young), in Argonne, Illinois, USA.

Participants in these Eco-Informa meetings included environmental scientists and engineers, planners and policy makers, information managers and communicators, and educators from government agencies and private organizations, academia, and industry. The Argonne conference in 2001 brought together over 230 scientists from more than 25 countries to share their knowledge within the theme of *Environmental Risks and the Global Community: Strategies for Meeting the Challenges*. Topics ranged from sustainability and environmental information to engineering and biotechnology, public policy, and community involvement. Innovative approaches to better predict and manage environmental impacts of urbanization included combining remote sensing tools with geographical information systems and information technology. Topical issues extended from environmental pollution and the energy crisis to food safety, including organic foods and mad cow disease. The transboundary transport of persistent organic pollutants was discussed by Dr. Lars-Otto REIERSEN, Executive Secretary of the Arctic Monitoring and Assessment Program (Norway), global atmospheric changes were described by Nobel Laureate Dr. Sherwood ROWLAND (USA), and environmental risks of Cold War legacy sites were discussed by Paata SHEVARDNADZE of the United Nations Educational, Scientific, and Cultural Organization (France, Republic of Georgia). The 2001 meeting continued the Eco-Informa Foundation tradition of creating and enhancing environmental partnerships in a variety of technical areas.

2 Role of Collaborative Scientific Meetings

As an illustration of how scientific meetings can initiate new environmental collaborations, Professor Dr. Lorenz HILTY of the Swiss Federal Laboratories for Materials Testing and Research (EMPA, St. Gallen, Switzerland) and Professor Dr. Werner PILLMANN of the International Society for Environmental Protection (ISEP, Graz, Austria) were key plenary participants in the 2001 Eco-Informa meeting. As program chairs of the 2001 and 2002 international conferences on environmental informatics (the 15th and 16th of the annual conference series, held in Zurich and Vienna, respectively), these two scientists invited Eco-Informa members to join in the discussions of new approaches for obtaining and sharing knowledge while preserving environmental sustainability.

The 2001 environmental informatics symposium focused on information and communication technologies for sustainable development, with an emphasis on promoting the development of applications that contribute to sustainability by dematerializing production and consumption processes [1]. The 2002 conference focused on environmental communication in the information society, highlighting such areas as environmental and geographic information systems, web portals, environmental management, and sustainability [2]. The Eco-Informa Foundation organized a cross-cutting symposium within the 2002 conference that emphasized integrating information for better environmental decisions.

Both environmental informatics conferences were very successful, each providing hundreds of participants from a wide range of organizations and over 40 countries the opportunity to share constructive approaches for collecting, analyzing, synthesizing, disseminating, and retaining environmental information across multiple areas, sources, technical disciplines, formats, and projects. Such meetings are essential to shared progress in the environmental arena, as each participant serves as a further conduit for extending cutting-edge approaches to a larger community.

Presentations within the Eco-Informa session of the 2002 environmental informatics conference emphasized the crucial roles of obtaining relevant environmental data, effectively communicating scientific information, and establishing partnerships among scientists, regulators, and communities to deal with pressing environmental issues. In many instances the nature and magnitude of environmental problems have been distorted by misinformation, which can lead to misperceptions that result in poor decisions. Recent examples were provided to illustrate this point, ranging from cases of immediate high-risk concerns such as anthrax outbreaks and food safety to those of sustained but less urgent concern such as contaminated sites and global warming.

The aim of these discussions was to identify opportunities offered by new science and technology to improve our collective response to major issues that affect humans and the environment around the world. Highlights of the presentations and technical papers [3–10] are captured in the following sections; further detail is available from the full papers in the conference proceedings [2].

3 Key Themes for Better Environmental Decisions

The Eco-Informa presentations revolved around four main themes: remote sensing and data interpretation, risk assessment and communication, community involvement in cleanup projects, and environmental education (**Table 1**). The following highlights are organized according to: introductory context for the issues (this section); methods and applications; and results and recommendations.

3.1 Remote sensing and data interpretation

Decision makers around the world need many types of information to develop integrated plans for effectively managing resources, both natural and human. Sustainability initiatives depend on a better understanding of environmental conditions, including how and why things change over time. Remote sensing technology represents a major source of extensive data that can be provided in a variety of formats to satisfy multiple research and planning needs.

In use for decades, the satellite imagery business was booming by the 1990s as systems such as Landsat and the Satellite Pour l'Observation de la Terre (SPOT) demonstrated the value of remote sensing for geological and environmental mapping. Benefits were so significant that private corporations had become interested in developing sensor platforms for civilian uses. This trend was especially impacted by the development and widespread use of software for geographical information systems (GIS) to integrate environmental and/

Table 1: Eco-Informa session presentations

Presenter	Organization/Nation	Theme	Topic
Ken Morgan	Texas Christian University, USA	Remote sensing and data interpretation	Advances in remote sensing for smart environmental mapping
Klaus Tochtermann	KNOW-Center, Austria	Remote sensing and data interpretation	Two new knowledge management approaches to support search and retrieval of information objects
Walter Armbruster	Farm Foundation, USA	Risk assessment and communication	Partnerships for risk communications: environmental, agricultural, and food issues
D. Rick Bowlus	U.S. Army Center for Health Promotion and Preventive Medicine, USA	Risk assessment and communication	Fear of anthrax exposure: a communication challenge case study at a Pentagon health clinic
Margaret MacDonell	Argonne National Laboratory, USA	Risk assessment and communication	Integrating environmental and health data to assess cumulative risks
F. Ward Whicker	Colorado State University, USA	Risk assessment and communication	Radioactively contaminated sites: getting scientific information into cleanup decisions
Peter Waggitt	Department of Environment and Heritage, Australia	Community involvement in cleanup	Communicating with traditional landowners on uranium mine rehabilitation
Suzanne Wells	U.S. Environmental Protection Agency, USA	Community involvement in cleanup	Superfund's community involvement program: building a sustainable program
Gabriele Voigt	International Atomic Energy Association, Austria	Community involvement in cleanup	Working with affected communities on contaminated sites
Anthony Burgess	Biosphere 2 Center/Columbia University, USA	Environmental education	Biosphere 2 as a case study in global change: educational lessons learned
Leo Newland	Texas Christian University, USA	All four themes combined (panel)	Environmental information and communication: where do we go from here?

or exploration information into large data bases. In many instances, remote sensing imagery has become integral to the GIS planning process. The expanding market for digital data led to the design and launch of several new privately owned satellite systems that have come on-line in recent years, offering even higher resolution and more spectral bands for customers.

Keeping step with continuing advancements in data acquisition through remote sensing are new approaches for interpreting information from large data sets. The ability to rapidly and effectively search and retrieve environmental information is essential to efficient investigations. Environmental information exists in many different forms, such as satellite imagery, cartographic maps, empirical observations, data tables, and reports with a variety of data-storage formats. Current environmental information systems can provide a metadata structure to facilitate the location of specific topics from within large data systems. The problem is that querying large data sets usually yields overwhelmingly long lists of results, which require further steps to complete the search for the desired information. Knowledge-based search approaches and visualization techniques are being developed that provide enhanced user guidance related to existing metadata.

3.2 Risk assessment and communication

Acquiring and integrating environmental data is the first essential step in evaluating whether environmental conditions may be harmful. The next step is to apply risk assessment tools to determine whether people and the environment are safe, and to help guide actions that may be needed to assure protection. For example, certain contaminants in soil, air, water, or food could cause health problems if people are exposed to high enough levels over a long enough time. General methods are available to estimate risks by combining environmental measurements or predictions with an estimate of the amount of exposure an individual or group could incur, and then applying a toxicity value for the given hazard to estimate a cancer risk or non-cancer health effect. (This toxicity value is typically extrapolated from animal studies.) Because the public is increasingly interested in the combined or cumulative effect of multiple environmental exposures, enhanced methods are being developed to also consider the potential risks of mixtures.

It is not enough to simply estimate risks from human exposures to contaminants, whether they be routine (e.g., dietary exposures over a lifetime) or special (e.g., acute exposure to an introduced toxic or infectious agent). For the results of a risk assessment to be useful, they must also directly address the major concerns of the affected community and be communicated in an understandable way to those who will make decisions on the appropriate course of action.

While some risks are only of interest in a localized area, such as a specific contaminated site, others can gain national attention, as evidenced by recent U.S. scares relating to anthrax and the West Nile virus. Clear communication of scientific information is especially important when risks are perceived to be high and confidence in those responsible for managing the situation is low. These cases can range from large sites contaminated with mixed radiological and chemical hazards to buildings contaminated with biological hazards such as anthrax spores, or food contaminated with biological agents that can cause bovine spongiform encephalopathy (BSE, a prion disease commonly called mad cow disease) or foot-and-mouth disease (FMD, a viral disease).

The cost of not effectively assessing and communicating risks of widespread concern can be substantial. To illustrate, globalization has increased public worries about the invasion of non-native species (most of which are relocated by human interference), the possible transmission of animal diseases to humans, human resistance to antibiotics used in animal production, and the possible use of bio-terrorism to cause disease outbreaks. In the United Kingdom, the cost of the BSE problem over a four-year period was estimated to exceed $5 billion. The BSE-related food scare was exacerbated by the subsequent FMD outbreak, even though this disease is not transmissible to humans, and further major economic damage resulted. The cost of a U.S. outbreak, including production losses and export restrictions, is also estimated in the billions of dollars. Thus, risk challenges with significant economic and social implications warrant targeted communication strategies and organizational partnerships to limit adverse effects that extend well beyond health risks.

3.3 Community involvement in cleanup projects

Recognizing that environmental solutions can be very expensive, that complicated scientific analyses underlie risk assessments, and that communication of risk-related information can be difficult, many programs have formalized the involvement of affected communities in the decision process to broaden support and improve progress. This is well illustrated by public participation in several environmental cleanup programs. At a combined cost of billions of dollars a year, thousands of contaminated sites around the world are being evaluated to determine what control or cleanup actions may be warranted. These range from U.S. facilities managed by federal agencies (such as DOE) to industrial sites in Eastern Europe and lands contaminated by mining activities in Australia. Common to each of these sites is the concern of affected communities. Without the support of local groups, making cleanup decisions can be difficult at best, and in some cases actions have been delayed for years when not effectively coordinated with community members. Involving the public and other interested parties in the evaluation process has been identified as a critical element of successful projects.

The U.S. Environmental Protection Agency (EPA) is overseeing the cleanup of more than 1,000 inactive sites under the Superfund program, which was established by the Superfund Amendments and Reauthorization Act of 1986 (SARA) and its predecessor legislation of 1980. In the initial regulations, community involvement requirements were designed to make information about each site accessible and to solicit public input on the work being proposed. This was to be achieved by (1) preparing a community relations plan, (2) establishing accessible information repositories nearby for all site-related public materials, (3) providing opportunities for public comment on proposed remedies, and (4) ensuring that all significant comments on the proposed remedy were addressed in responsiveness summaries. Six years later, the role of communities had expanded. Pursuant to SARA, funds were made available to local communities through technical assistance grants that enabled them to hire independent advisors who could assist with understanding site data and technical issues. The public also gained an opportunity to participate in community advisory groups for individual sites.

Halfway around the world in the Northern Territory of Australia, a similar process was developed over several years to involve the affected community in reclamation decisions for a valley previously used to mine uranium. This valley was incorporated into the World Heritage-listed Kakadu National Park 15 years ago and granted to the Gunlom Land Trust in 1996 under a 20-year-old land rights act. The land was then leased back to the National Park with the condition that the mine sites and associated lands be rehabilitated by 2015. These agreements were developed in consultation with the Northern Land Council, an organization set up under the land rights legislation to provide technical and legal assistance to the traditional owners, i.e., the Aboriginal people. The valley is not accessible during the wet months, and people do not live there. With nobody being exposed to contaminants, health risks were not a critical issue but cultural values related to sacred lands were. A program is underway to develop rehabilitation plans for the mine sites in close coordination with the traditional owners.

Community involvement activities are also under way at sites in Eastern Europe being evaluated by scientists from the International Atomic Energy Agency. These sites differ from the Australian example and many U.S. Superfund sites where no human exposures are occurring. At several locations in Eastern Europe, contaminants from past releases have entered the food chain and relatively high levels of exposure are occurring. For example, garden vegetables grown on contaminated soil and fish caught from contaminated rivers are major staples of the diet for many local communities. Thus, involving the public in the evaluation process for these contaminated areas – including understanding their behavior patterns relative to the type and amount of food taken from various locations – is critical to sound decisions for cleanup or risk management actions, such as recommended exposure limits.

In each of these cases, active community involvement is an important element of the cleanup project. Members of the public can serve as an important source of site-specific information needed for realistic risk evaluations. They can also serve as a sounding board for cleanup plans as they are developed, to ensure that key issues and expectations are factored into the ultimate decisions.

3.4 Environmental education

Activities such as communicating information about risks of invasive species and implementing community involvement programs for cleanup projects represent forms of environmental education that build capacity in the general population to participate in environmental studies and decisions. The heart of building human capacity for environmental knowledge beats in thousands of schools and other educational facilities around the world. One such facility is the Biosphere 2 Center in the United States, a 1.3-ha (3.1-acre) laboratory housed in a metal-and-glass shell in the Sonoran desert of southwestern Arizona (**Fig. 2**). It was initially constructed and operated with the intent of replicating natural ecosystems in a closed, artificial setting in which one atmosphere was shared by a variety of biomes ranging from desert to rainforest, mangrove swamp, and coral reef. A primary criterion for project success was the sustained recycling of material, and the dynamics of atmospheric carbon dioxide concentration was of key interest.

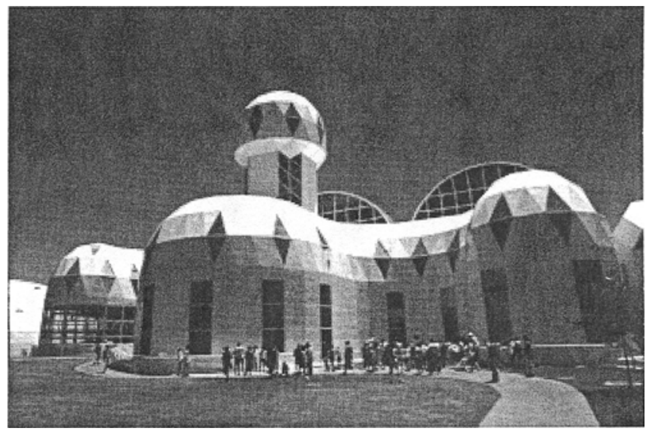

Fig. 2: The Biosphere 2 Center in Arizona (USA)

Construction began in 1984, with two-year 'sustainable inhabitation' missions slated for the new facility. The first mission involved eight people and began in 1991, but during the two years atmospheric carbon dioxide levels increased and oxygen dropped to nearly 14%. The second mission began in 1994 and involved seven people, but it was canceled after seven months. Sensors provided streams of data but there was little time for continual analysis. The limited resources available were devoted to critical maintenance activities, as the crew inside struggled to keep the facility going. Thus, the system indeed represented a microcosm of problems created by civilization's influence on the biosphere Although both missions were considered failures, they provided scientists with an extraordinary amount of information about environmental interrelationships. Unfortunately, effective data archiving was not sustained.

Privately owned by an environmental philanthropist, the Biosphere facility was originally managed by a business corporation that expected to profit from the sale of expertise and technology. In 1996, Columbia University took over the management reins to operate the facility for scientific education, research, and outreach. A major goal is for Biosphere 2 to serve as a focal point for educational innovation for the sustainable inhabitation of Earth. Students at the Center are receiving a unique educational experience that combines classroom instruction with laboratory and field exercises emphasizing dynamic relationships as they exist in the real world.

4 Methods and Applications

4.1 Remote sensing and data interpretation

Remote sensing is an increasingly popular method for collecting data on environmental characteristics to support integrated analyses. For example, since its 1999 launch, the IKONOS satellite has taken more than 500,000 images from an altitude of 677 kilometers. Passing over a given location about twice daily, image data are collected at a resolution as refined as 1 meter (m), and spectral data are collected in blue, green, red, and near infrared wavelengths. Recent advances in remote sensing technology have resulted in several satellites now being available from which investigators can select characterization data. The decision on which data to use often comes down to which satellite provides the spatial and spectral resolution needed for a given project at an affordable price. For example, data ranging from 1-m resolution with 3 bands or 20-m resolution with 100 bands are now available, in black and white (**Fig. 3**), color, and multispectral display and increasingly in GIS-ready formats.

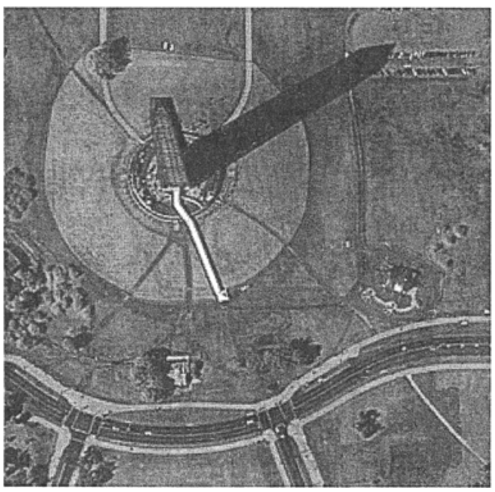

Fig. 3: Image of the Washington Monument in Washington, D.C. (USA) from the IKONOS satellite (1-meter resolution) (Source: Space Imaging, Thornton, Colorado USA)

Using high-resolution imagery tools now available, scientists and planners are exploring new ways to apply remote sensing technology. Innovative projects made possible by high-resolution satellite data include evaluations of possible retail sites, assessments of nutrient deficiencies, and surveys of tornado damage. Most new applications involve using GIS to fully integrate other data sources and enhance the overall utility of the imagery. When synthesized with field observations and site files, satellite data are being used to develop topographic maps; grids of street and highway information; census tracts; and maps of soils, biotic resources, and land use.

Making sense of increasingly large and complex data represents a significant challenge. In the field of environmental informatics, each object – such as a lake, forest or stream – is given a geo-referenced attribute that describes its geographical location. Also attached to this object are other attributes that often require multiple queries to gather all the information needed to support an investigation. An 'intelligent map' approach can be used to search the data if one knows how many environmental objects exist. This approach supports multi-referenced queries in one interface, always yields a hit, and displays results on a map according to their geo-reference.

A second approach involves developing information landscapes using visualization islands to search, retrieve, and display environmental information. With this technique, query results are represented by small islands where results for items with commonalities are placed closer together to form clusters. The information landscape technique is similar to traditional browsing where users have a vague idea of what they are looking for and use key words to locate information, which is presented in clusters of closely related objects rather than the traditional long list of items.

4.2 Risk assessment and communication

General frameworks exist for integrating environmental characterization data with other information to assess risks and evaluate management options, as illustrated by studies of pollutants in soil, water, air, and food. Two questions can be used to focus these assessments. The first: *What is the magnitude of risks from current or possible future contamination?* This involves understanding what resources, receptors, and locations could be affected over what time frame. The second: *What are the dominant contributors to risks?* Understanding the risk drivers allows response measures to be targeted in a way that maximizes the effectiveness of controls. An early step in the general approach for assessing risks at contaminated sites is to develop a conceptual model that identifies (1) hazards and sources, including affected resources; (2) release and transport mechanisms; (3) exposures that could occur; and (4) receptors or resources that could be affected. Typically applied for health and ecological risks, this process has also been extended to the evaluation of socio-cultural and economic impacts.

Under the traditional assessment framework, health risks are calculated for one chemical at a time. However, there is increasing interest in risks from exposures to environmental contaminants as they actually occur, i.e., as mixtures. Approaches are being developed to evaluate the combined risks from multiple stressors, whereby opportunities for interaction are considered beginning with environmental co-location and extending to internal distribution, target organs and effects, and mechanisms of toxic action.

Defining acceptable levels of residual contamination is a key element of the process for determining what risk management controls may be necessary. These acceptable levels are estimated on the basis of risks that can be calculated for a variety of receptors. As an example, for large radioactively contaminated sites being controlled by DOE to prevent harmful exposures or health risks, three types of receptors are typically evaluated to guide the cleanup decision. These are: workers who would conduct the cleanup, environmental resources, and a hypothetical member of the public who might be exposed if they came in contact with site contaminants in the future. The latter is unlikely to ever exist as postulated for purposes of the traditional risk assessment. In contrast, the worker called upon to implement the cleanup decision will certainly incur exposures and more importantly be at risk for construction-related accidents that could be (and have been) fatal. Similarly, lands that previously sustained richly diverse and productive ecosystems, which naturally established in the wide buffer zones of large DOE sites during decades of minimal human disturbance, have been decimated in many cases by aggressive earthmoving and other engineering measures conducted in the name of protective cleanup.

Despite clear adverse effects to workers and the environment, cleanup decisions for many federal sites have been driven by risks estimated for that highly improbable receptor: the hypothetical future public. This outcome results in part from ineffective communication of the full set of risks, complicated by long-held public fears about radiation and a general distrust of large cleanup projects. To address this imbalance, additional site-specific data have been collected to replace default values and produce more realistic risk estimates that provide a more credible basis for site decisions. Sharing data-collection plans with local communities and oversight agencies and better communicating results of the risk assessments as they are developed can also play major roles in improved decisions.

In contrast to the protracted risk assessment and communication process for large radioactive sites, the recent anthrax scare in the United States posed an urgent risk assessment and communication challenge. Among the factors feeding public fear was that the source of the risk was unfamiliar. Although the number of people affected was very small, the nation fell into a collective panic over the possibility of widespread exposures. Communication of basic facts about anthrax and the locations where it had been detected were crucial to gaining public confidence that the situation was under control. In addressing this considerable risk-communication challenge, personnel at the Pentagon health care clinic developed clear, consistent language to explain scientific concepts to the public and also took the time to listen to the concerns of those who came for testing. This approach helped increased the public's general sense of protection and security.

Similarly, recent concerns about food safety and infectious diseases that could be transmitted through the agricultural system have highlighted the need for balanced risk assessments and intensive communication programs. Various intervention strategies have been implemented by many organizations working together to limit the introduction and spread of non-native species. These include border protection, surveillance and early detection (sometimes with remote-sensing technologies), rapid diagnostics, vaccination, and educational outreach programs. Communication challenges include (1) explaining risk tradeoffs that range from health effects (sometimes death) to local and national economic risks; (2) providing sound, consistent scientific information that includes a background context (to help offset the problem caused by some journalists distributing information to the public from studies that have been neither scientifically reviewed nor replicated); and (3) presenting bottom-line information in clear language understandable to the general public. Through ongoing international partnerships, policies and standards are being established, enforcement mechanisms are being created, and scientific research studies and findings are being shared. Communication partnerships for dealing with risks to the environment, agriculture, and food systems are also being enhanced at international scientific seminars.

4.3 Community involvement in cleanup projects

Ways to effectively involve stakeholders in the assessment and decision processes for contaminated sites continue to be developed. In the United States, the EPA Superfund Community Involvement Program has sought additional ways of involving citizens in local cleanups beyond what is required by the regulations. Two important objectives were identified for this effort: build capacity in EPA staff so they can more effectively work with communities, and build capacity in communities to enable them to be more knowledgeable about local sites and to provide them with constructive ways to discuss and resolve site issues. Because of the considerable time and money involved, it is important that the success of this program be assessed to determine whether adjustments were needed.

To evaluate program success, EPA initially counted indicators such as how many technical assistance grants were awarded or community advisory groups were formed. While characterizing the number of these involvement activities is helpful, more important is the actual impact on the community and the cleanup project. Thus, EPA modified its program evaluation to consider several outcome measures. These are: percent of sites at which activities go beyond what the statute requires; level of citizen satisfaction with the information EPA provides about the site; level of citizen understanding of associated environmental and human health risks; and level of citizen satisfaction with opportunities EPA provides for their input, as well as with EPA's response to that input. Applying community involvement methods combined with new self-evaluation approaches, the Agency has further enhanced its national Superfund program.

The stakeholder involvement process being implemented for the Australian mine reclamation project has been strongly influenced by the unique characteristics of the setting and Aboriginal community. The community created a Consultative Committee with the majority being traditional owners. It was agreed that meetings would be held every 6 to 8 weeks, open to any interested Aboriginal person, and preferably conducted outside (although shelter has been taken during some wet-season meetings). When possible, meetings are held in the valley to promote more informal discussions in camp after the work day is done. Project presentations are dominated by the use of small models (e.g., of earth-moving equipment) and pictures rather than text and data summaries. Meeting records are maintained as photographs of the flip charts on which the day's discussions and agreements are recorded.

One issue frequently raised by the Consultative Committee in project meetings has been the safety of food and water obtained from the valley. The issue has been addressed through sample collection and discussion of results (all negative to date) at subsequent meetings. This same issue has also been important for contaminated sites in Eastern Europe. There too, community input regarding the nature of local exposures such as subsistence fishing and associated risk concerns has directly influenced the sampling program implemented by project teams. For example, contaminant levels in fish have been measured to determine whether it's safe to eat as a main staple of the local diet. In each of these cases, the community involvement process has helped increased support for and confidence in the project.

4.4 Environmental education

Educators combine methods for characterization, assessment, and community involvement in teaching students about environmental systems. For example, students at the Biosphere 2 Center are immersed in an intensive multidisciplinary program that includes team projects and field experiences with extensive faculty and staff involvement. The educational methods are designed to engage students in critical thinking, especially about the role of humans on Earth. The emphasis is on species and their interactions, with direct observations, in contrast to the typical ecosystem paradigm that focuses on compartments and flows taught from textbooks in a classroom. The aim of this innovative educational program is to instill an appreciation of ecological complexity that leads to broader insights.

To illustrate, in an initial assignment students are asked to consider how the Biosphere 2 Center should be used to create or disseminate knowledge in the context of four research paradigms: biome, community, and ecosystem (with their traditional hierarchical theories), and the noosphere, which focuses on the role of humans in the environment and considers economics, aesthetics, and values. In addition to scientific concepts, students who may never have operated as a team before are taught concepts of learning cycles, learning style, rapport, conflict resolution, and dialogue with an emphasis on integration and the importance of diversity.

Peer instruction and role models are used to enhance group learning in the field. For example, in a course on deserts, students are asked to record both scientific and personal observations in a field notebook. This information can range from images or personal emotions to descriptions of how people live in an oasis town. It also includes more traditional observations such as measurements of the depths of different soil horizons, information on vegetation types, and relationships among topography, soil, and plants in the desert. These field observations are captured on laptop computers and ultimately synthesized into a group composition. Extensive outdoor experiences are complemented by classroom training that includes explanation of scientific concepts, as well as non-traditional instruction such as painting to develop color perception.

5 Results and Recommendations

5.1 Remote sensing and data interpretation

Combining satellite data and other information into a GIS system allows scientists to track, monitor, and predict environmental changes. This is especially true when the imagery is in digital format, of high resolution, and based on repetitive data capture. Emerging GIS software development provides robust techniques for processing images, merging data, querying databases, and integrating global positioning system (GPS) information to produce accurate and detailed maps for interpretation and management. Increasingly precise, accurate, and rapid characterization data from satellites, combined with the power of the Internet, are providing broad access to extensive scientific information. Remote sensing images for virtually any site can be accessed quickly on-line, processed, and utilized for ongoing projects. For example, 1-m images from IKONOS were used to show the area of the U.S. World Trade Center Towers and the Pentagon immediately after the events of September 11, 2001 (made available through the Internet at http://www.space.com/news/ikonos_wtc_010912.html), and IKONOS data at 1- and 5-m spatial resolution are also available through Space Imaging (http://www.spaceimaging.com).

The future for space-acquired, high-resolution digital data is bright. Collaboration across disciplines and nations can greatly enhance current plans for even higher resolution imagery on a more repetitive basis using more than 100 bands of digital data. By improving GIS and image-processing software and considering developing markets for new applications, an even greater incentive will be developed for designing and launching better sensors for integrated and smarter environmental characterization from the local to the global scale. These advances will continue to increase our understanding of environmental change so that we can develop better approaches for mitigating adverse effects that will enable us to sustain the environment.

Parallel advancements in information technology and knowledge management will further improve our ability to harness data for environmental programs. Intelligent maps and information landscapes represent two new approaches for searching and retrieving information from extensive data sets. While both techniques are broadly applicable to environmental data sets, the latter is preferred when the user has a clear idea of the target and applies conceptual navigation in the data search. The success of either approach obviously depends on the quality of the metadata, but results using the landscape technique are especially affected by poor data. Thus, intelligent maps are more appropriate when data quality is limited. Recommendations for next-generation modifications include developing new algorithms for better retrieval and data profiling, integrating metadata more tightly by weighting known fields, and arranging clusters identified by information landscape techniques into a hierachy to represent whole-document space rather than only the selected search space.

5.2 Risk assessment and communication

The objective of programs that address environmental contamination should be to do more net good than harm, by focusing on hazards that truly pose threats and evaluating combined risks or detriments as well as overall benefits. Ongoing communication with affected groups during the development of risk assessments is important to ensure that the ultimate decisions address key concerns.

To illustrate, the risk assessments for contaminated DOE sites have often led to decisions that called for extensive excavation and disposal. The general aim has been to achieve low residual contaminant levels that would support unrestricted land use such as residential housing, even though on-site residential exposures are not occurring now nor are they expected to occur in the future. Perhaps the bias toward such engineering solutions simply reflects an illusion of progress generated when the public can see something happening, such as bulldozers and dump trucks moving piles of dirt across a site. It is unlikely that people realize how their well-intentioned support of this type of cleanup often results in much greater risks being created than any being reduced, notably to workers and the environment. In a few recent cases, better science has allowed decision makers to move away from environmentally damaging engineering measures and focus more on the restorative role of natural processes.

Better communication of the full set of risks estimated for a given situation, and a clearer presentation of the scientific bases of those estimates, can help improve the sensibility of risk-based decisions. Several key recommendations can be synthesized from the risk assessment and communication cases discussed in the Eco-Informa symposium. These are:

Collect setting-specific data to address key uncertainties in predictive models. Actual field data can fill critical knowledge gaps and greatly strengthen the outputs of environmental models on which decisions are based. For example, better characterization of contaminant transport and fate at a contaminated site will allow default assumptions to be replaced by representative values that produce more meaningful risk estimates. Similarly, better characterization of actual exposure levels for high-concern hazards such as airborne anthrax spores or food-borne pathogens can result in more realistic risk estimates and more sensible management decisions.

Base decisions on comprehensive risk assessments with clearly identified benefits and costs. All risks associated with a condition or action should be considered if net protection is to be achieved. For example, risks estimated for hypothetical future receptors at contaminated sites should be placed in appropriate context with the harm that could befall real workers and ecosystems if engineering solutions are implemented. For anthrax, the risks of wide-scale prophylactic antibiotic therapy should be presented together with the risks of infection, especially where the likelihood of exposure is very low. For invasive species, the cost of integrated control programs such as surveillance and detection combined with educational outreach should be compared with the cost of species introduction to guide policies and decisions.

Maintain control of vulnerable areas. For example, large radioactively contaminated sites should be designated as federal environmental science and technology complexes to be used for research and educational outreach, not housing developments. Retaining this control would obviate the need to achieve very low residual contaminant levels to protect hypothetical future residents. Similarly, collaborative programs such as border controls and quarantines should be sustained to control or prevent the introduction of invasive species that could significantly impact the health and welfare of a region or nation. Recommendations recently developed by an agricultural partnership, the Council for Agricultural Science and Technology, to control non-native species can also be modified for application to other environmental control programs. These recommendations are: (1) implement aggressive public information programs that emphasize global movement controls; (2) adopt balanced, realistic approaches to protect resources; (3) concentrate on highest-risk pests (or hazards); (4) decrease biological uncertainties (such as pest distribution, transit survival, and establishment); (5) emphasize voluntary compliance over enforcement through an effective information and education campaign; (6) encourage private efforts, for protection is a shared responsibility; (7) establish science-based risk standards for proposed controls (of species introduction); (8) maintain and support emergency strike force capability; and (9) periodically evaluate risks and regulatory programs.

5.3 Community involvement in cleanup projects

Several key recommendations for community involvement in cleanup projects can be extracted from case studies across the United States, Australia, and Eastern Europe. These are:

Build relationships. From the outset, seek opportunities to meet with community members to answer questions and understand concerns, and spend time being visible and available. These efforts can help demonstrate the interest and sincerity of project staff and help break through suspicion or distrust associated with generic opposition often rooted in misunderstanding, which can otherwise delay progress.

Listen. When site managers shed their own preconceptions and genuinely listen, much can be learned from the community. New insights can extend from understanding the deep-seated risk concerns of the local public to new information about past disposal practices, or about sacred lands and limitations on actions that can be taken there. By actively listening, all parties can gain a greater appreciation and trust of each other that can lead to closer cooperation.

Communicate clearly and often. Early, frequent, honest, and open communication of information presented in an understandable way is crucial to successful community-based programs, whether the information is presented on posters at an information workshop or public availability session, or on sheets of paper tacked to the side of a trailer in the woods. Interacting in settings that promote further communication outside of working sessions can also enhance trust and cooperation.

Be proactive in collaboration. While it might take more time initially, providing the community with early thoughts and drafts of technical documents can save time in the long run. Regardless of the quality of a proposed plan, if the community has not been involved in its development, the action will likely not go forward. Conversely, where a community has been part of the evaluation process and shares ownership of the plan and its implementation, success is much more likely.

Be creative. The community involvement process should be tailored to the setting, extending beyond traditional approaches to respond to the different styles and activities of a given community. For example, meetings can be conducted in libraries, schools, or church basements, or they can be conducted in outdoor camps with flip charts to capture key discussion points and agreements.

The bottom line is that input from community members can greatly increase public confidence in a cleanup project, contribute important information for the risk analyses, and ultimately result in more effective and lasting decisions. Continuing to share practical lessons learned under various cleanup projects will enhance effective community involvement in environmental programs.

5.4 Environmental education

Environmental education encompasses a wide variety of issues, including interpretation of remote sensing data, risk assessments, and public participation. The outcome of a strong education in any area is a student who has learned to think 'outside the box,' which can happen when dedicated faculty extend the learning environment far beyond the typical classroom experience. For example, at the Biosphere 2 Center, students are taught different learning cycles and styles, and they hone dialogue skills during hours of outdoor work on team projects. These students synthesize their individual observations and interpretations into an integrated project composition that reflects the contributions of a full learning community. By this approach, the students gain not only a greater understanding of ecological complexity but also a new and often very different perspective of the role of humans on Earth. They learn the value of diversity and often come to realize that one person can indeed make a difference by thinking globally (understanding interconnections) and acting locally, one step at a time.

In surveys, Biosphere 2 students identified the three most valued aspects of the educational program as: the student community, field experiences, and easy access to faculty and teaching staff. Central to the innovative Biosphere approach is community learning through a dialogue process, whereby individuals learn to think together and develop a collective sensibility that results in thoughts and feelings and actions that belong to the group rather than a single person. Students can then carry forward into their adult life new skills for interacting with others to solve many types of problems.

Innovative educational programs can promote an understanding of environmental interconnections at multiple scales through critical thinking and community-building with hands-on experience. Creative programs such as the one being implemented at the Biosphere 2 Center can light the collective flames of individual interests far more effectively than what can be achieved in the standard classroom setting with rote memorization. In the words of the passionate educator Dr. Burgess, "It is not enough to simply inform, the learning process must also enchant" [10]. Through the creativity and dedication of such teachers, students will continue to learn long after they have left school. Education that inspires the search for meaning across environmental and human complexities and sustains a collective dialogue for adaptive solutions is essential to our long-term survival.

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