

Making a World of Difference

RECENT USGS
CONTRIBUTIONS TO
THE NATION



1998

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

The People Who Make a Difference

Public service is about making a difference. As the Federal government's principal natural science and information agency, the USGS is committed to providing excellence in public service and to making a difference to the world we live in.



Our motto conveys an enduring message: *science for a changing world*. The changing nature of the natural and physical world is the primary driving force and motivation behind all of the work USGS does in



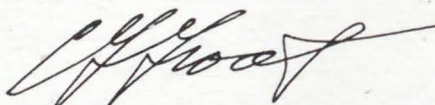
biology, geology, mapping, and water. We live our motto each day in fulfilling our mission to provide reliable, impartial information to the citizens of this country and to the global community.



In the following pages or through our website [<http://www.usgs.gov>], we invite you to explore some of the recent ways in which USGS is making a world of difference.



Charles G. Groat



Director



Making a World *of* Difference

RECENT USGS
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THE NATION

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Making A Difference on Land



*U.S. Geological Survey
researchers make a difference
on land by studying the
changing Earth and helping
decision makers deal with
problems these changes bring:
earthquakes, landslides, coastal
wetland loss, land subsidence,
and melting glaciers.*

Research Raises Earthquake Awareness in Pacific Northwest

THE PUGET SOUND REGION LIES IN A complicated and potentially dangerous tectonic setting. Not only can moderate earthquakes of about magnitude 7 occur in the shallow part of the Earth's crust under Puget Sound, but also evidence has been discovered in the last few years that large earthquakes of magnitude 8 or greater can strike the region.

These large earthquakes occur at greater depths in regions called subduction zones, where the oceanic crust is forced beneath the continental crust. Evidence for these large earthquakes has been collected over the past 10 years from studies of large tracts of submerged land near the coast. Field evidence for a large, subduction zone earthquake circa A.D. 1700 has recently been augmented by tree-ring studies and by historical tsunami records from Japan.

The impact of this research has been substantial. The Uniform Building Code contains nationwide standards for structure design. Before 1994 the code placed the Puget Sound area in a zone having the second highest hazard level defined in the code, and most of Oregon and Washington was placed in a zone having the next lower hazard level. A later addition to the Uniform Building Code extends the higher level hazard zone to include western parts of Washington and Oregon that are near the potential sources of these great earthquakes. This extension of the higher hazard level is based on USGS research.

USGS work in this region has brought attention to the earthquake hazard problems of

the area. From 1988 to 1995, the public and private sectors invested more than \$130 million to strengthen bridges, dams, lifelines (electrical, gas, and water lines), and buildings against earthquakes in the Pacific Northwest. These improvements in resistance to earthquake shaking reduce the region's vulnerability to loss of life and property from future earthquakes.

Private and public institutions have formed the Cascadia Region Earthquake Working Group (CREW) to address the earthquake hazards issues. Participants in CREW include representatives from the aircraft, computer software, and transportation industries and representatives from the banking and insurance sectors. The USGS provides CREW with scientific information and advice on the nature and severity of earthquakes.

FOR MORE INFORMATION

Website:

<http://www.usgs.gov/>

The USGS homepage provides lists of current earthquake information; current seismic activity; maps; earthquake parameters on global, national, and regional scales; general information on earthquakes and earthquake research; and seismic data in near real-time from national and world-wide stations.

Alerting Nation to Landslides

LANDSLIDES ARE A NATIONWIDE HAZARD with direct and indirect costs estimated at \$2 billion a year. Landslides threaten many metropolitan areas and communities, as well as transportation and communication lifelines. As development intrudes upon unstable terrain, the potential for landslide losses increases, and planners and engineers often lack information about the stability of terrain and the threat of landslides.

The USGS Landslide Hazards Program, in conjunction with many partners, is developing and communicating technical knowledge about landslides associated with unstable geologic formations, heavy precipitation, earthquake shaking, and volcanic activity. Geologic and engineering consultants and planners and decision makers use this knowledge to protect lives and safeguard property.



USED WITH PERMISSION KEVIN LAMB

Aerial view of a landslide near Madison, Virginia.

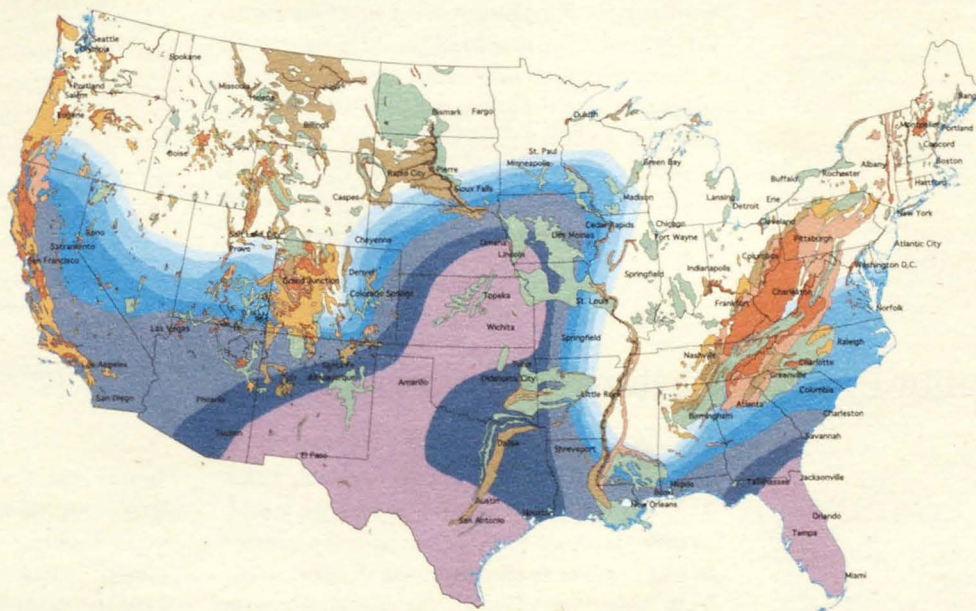
National Landslide Hazard Outlook Map

December 1997-February 1998

How To Interpret Precipitation Outlook:

These precipitation outlook maps show contours of the probability that a given area will experience above-, near-, or below-normal precipitation. These contours are based on measured precipitation from historical El Niño events and several models used by NOAA to characterize climate and weather. These maps do not show areas of below-normal precipitation because this condition does not generally increase landslide activity.

For example, the dark pink contours show areas for which there is a 63 to 67 percent chance for above-normal precipitation; a 33 percent chance for near-normal precipitation; and a 0 to 3 percent chance for below-normal precipitation. In a two-category system, there is approximately an 80 percent chance for above-normal precipitation and approximately a 20 percent chance for below-normal precipitation.



How To Interpret Landslide Incidence/Susceptibility:

The landslide incidence/susceptibility map was prepared by (1) classifying geographic areas as having high, medium, or low landslide incidence and (2) evaluating geologic formations or groups of formations in these areas as being of high, medium, or low susceptibility to landsliding.

Landslide incidence is defined by the number of landslides that have occurred in a given geographic area. Susceptibility to landsliding is defined as the probable degree of response of geologic formations to natural or artificial cutting, loading of slopes, or to unusually high precipitation. Generally, it is assumed that unusually high precipitation or changes in existing conditions can initiate landslide movement in areas where rocks and soils have experienced numerous landslides in the past.

The map units are split into three incidence categories according to the percentage of the area that has been involved in landslide processes. High incidence means greater than 15 percent of a given area has been involved in landsliding; medium incidence means that 1.5 to 15 percent of an area has been involved; and low incidence means that less than 1.5 percent of an area has

PRECIPITATION OUTLOOK

Probability of Occurrence (in percent)

Above	Near Normal	Below
33-38	33	28-33
38-43	33	23-28
43-48	33	18-23
48-53	33	13-18
53-58	33	8-13
58-63	33	3-8
63-67	33	0-3

Modified from NOAA, 1997

LANDSLIDE INCIDENCE

- Low (less than 1.5% of area involved)
- Moderate (1.5-15% of area involved)
- High (greater than 15% of area involved)

LANDSLIDE SUSCEPTIBILITY/INCIDENCE

- Moderate susceptibility/low incidence
- High susceptibility/low incidence
- High susceptibility/moderate incidence

been involved. High, medium, and low susceptibility are delimited by the same percentages used for classifying the incidence of landsliding. Susceptibility is not indicated where it is the same as or lower than incidence.

Long-range meteorological forecasts of heavy precipitation from the 1997-98 El Niño raised concern about possible increased landsliding in parts of the Nation. Characterized by warming of equatorial waters in the Pacific Ocean, El Niño influenced weather patterns in the United States and elsewhere. The El Niño of the winter of 1982-83 was marked by widespread landsliding in various parts of the Western Hemisphere.

To alert the Nation to where landslide problems might be most abundant in 1997-98, in mid-November the USGS prepared National Landslide Hazard Outlook Maps for the ensuing winter and spring quarters. These maps superimpose precipitation forecasts by the National Oceanic and Atmospheric Administration on the USGS National Landslide Overview Map for the conterminous United States.

The maps, posted on the Internet, indicated broad regions of the United States where the potential for landsliding may be increased during this El Niño episode. Such information alerts government and private planners and decision makers to review and make ready contingency plans for responding to increased landslide activity. As the El Niño months progressed, the outlook maps were revised to incorporate records of actual precipitation.

Beyond the national hazard outlook, the USGS is cooperating with the National Weather Service and the California Office of Emergency Services and Division of Mines and Geology to inventory and understand El Niño-related landslide activity, including debris flows, in southern and central California and to enhance rapid communication of hazardous conditions. These efforts include the preparation of large-scale (1:24,000) demonstration hazard maps that can be used to guide development.

FOR MORE INFORMATION

Websites:

<http://geohazards.cr.usgs.gov>

<http://www.usgs.gov/themes/landslid.html>

Publications:

Godt, J.W., 1997, Digital representation of Landslide Overview Map of the conterminous United States: USGS Open-File Report 97-289.

U.S. Geological Survey, 1997, El Niño and the national landslide hazard outlook for 1997-1998: USGS Fact Sheet 180-97.

Helping Protect, Restore Louisiana's Coast

MOST U.S. COASTAL AREAS, LIKE other coastal regions around the world, are under increasing stress from natural processes such as erosion, storms, sediment deficits, subsidence, rising sea level, and the effects of human population growth and development.

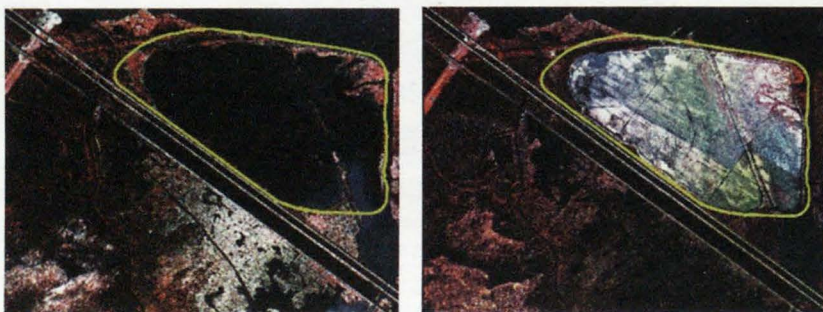
Coastal regions now contain more than 50 percent of the U.S. population and are greatly used for recreation, transportation, and oil and gas extraction. Coastal wetlands, estuaries, and barrier islands not only buffer the inland from

storms and flooding, but also provide critical habitat for fish and wildlife.

Unfortunately, 80 percent of the Nation's coastal regions are undergoing long-term erosion. Louisiana leads the Nation, and likely the world, in area lost to coastal erosion and wetland deterioration.

Louisiana contains 40 percent of the coastal wetlands in the lower 48 States. These wetlands support a harvest of renewable natural resources like seafood with an annual value exceeding \$1 billion. At the same time, Louisiana also has the highest rates of coastal wetlands loss: 80 percent of the Nation's total loss of coastal wetlands.

According to mapping studies and measurements by the U.S. Army Corps of Engineers and the USGS, approximately 1,000 - 1,500 square miles of coastal wetlands in Louisiana have been eroded or converted to open water in the past half century, and, if current rates of wetland loss continue, an equal amount may be lost over the next 50 years. This land loss is due to a complex combination of natural factors and human activities such as flood control, navigation channels, and energy development, severely affecting the State's economy and directly



Before (left) and after (right) restoration of the LaBranche wetland site just west of New Orleans, Louisiana, and adjacent to the Mississippi River. This is an example of a successful restoration being monitored by the USGS.



Shrimp boats harvest a valuable resource that depends on coastal wetlands for part of the shrimp life cycle.

increasing storm and flooding threats to New Orleans and surrounding urban areas.

The USGS Coastal and Marine Geology Program and National Wetlands Research Center, with other Federal agencies and local universities, are scientifically assessing Louisiana's rapid coastal erosion, wetlands loss, and environmental changes, as well as quantifying and providing a better understanding of the natural and human processes responsible.

Results from these studies are providing base-line information in the Federal-State wetlands restoration underway, funded through the Coastal Wetlands Planning, Protection and Restoration Act of 1992. This \$40 million a year effort consists of small-scale restoration across the entire Mississippi River Deltaic Plain; there are plans for multi-billion dollar major diversions of the Mississippi River and for sand nourishment of the barrier islands.

In addition to providing scientific information useful in implementing the restoration projects, the USGS has helped develop monitoring plans and is monitoring water and sediment fluxes for use in measuring the success of restoration projects.

Wetlands restoration in Louisiana is an example of Federal-State collaboration to enhance a degraded ecosystem and a demonstration of the value of linking scientific studies with coastal management. Louisiana is a model for similar efforts across the Nation.

FOR MORE INFORMATION

Websites:

USGS, Coastal and Marine Geology Program
<http://marine.usgs.gov>

USGS, National Wetlands Research Center
<http://www.nwrc.usgs.gov>

Publications:

Williams, S.J., and Stewart, R., 1996,
Understanding coastal wetland processes:
Geotimes, v.41, no.7, p. 18-22.

Williams, S.J., Stone, G.W., and Burruss, A.E.,
1997, A perspective on the Louisiana
wetland loss and coastal erosion problem:
Journal of Coastal Research, v. 13, no. 3, p.
593-597.

Satellite Watch: New Ways To Detect Changes on Earth's Surface

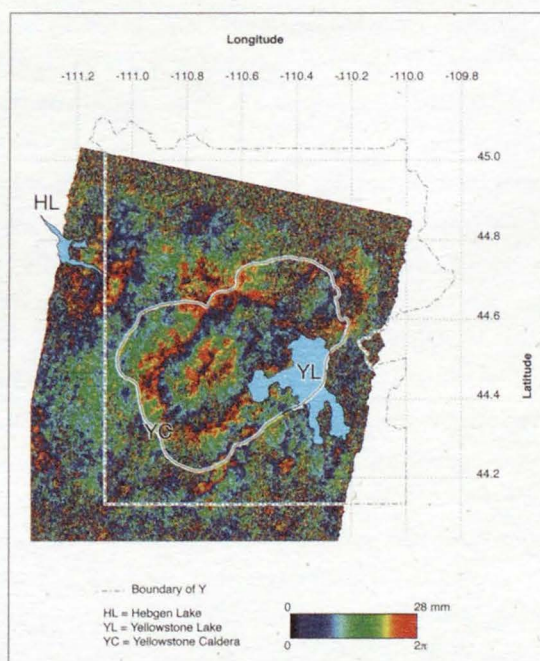
DATA FROM SATELLITES CONTINUALLY orbiting the Earth are giving scientists more effective and far less costly and time-consuming methods for detecting quite small changes in the elevation of the Earth's surface. These measurements can show how much land has subsided from the pumping of ground water, or how the land surface has been deformed, or raised, by the movement of magma deep within the Earth. Images created from these satellite data—interferometric synthetic aperture radar, or INSAR for short—provide a higher level of accuracy over a larger area than ever before.

INSAR color maps and models of the land surface, combined with other more traditional sources of information, give research scientists and resource planners and managers an unprecedented ability to determine the effects and risks of natural and human activities.

The level of detail and accuracy of INSAR technology allows researchers not only to have accu-

rate current data, but also to compare changes and conditions against predictive models. USGS researchers, for example, are able to obtain more information, more frequently over

INSAR data enable scientists to measure minute changes such as the increased subsidence (warmer colors) from 1993 to 1995 in the Yellowstone caldera. This satellite technology allows researchers for the first time to monitor the entire caldera and discern whether the deformation is a response to pressurization and depressurization of a hyperthermal system or a response to magma movement.



larger areas and at lower costs than has been possible using only traditional surveying methods. INSAR imaging provides an additional and valuable tool in the scientists' arsenal that complements and enhances other assessment techniques.

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Interferometric Synthetic Aperture Radar—How Does It Work?

INSAR images are created from data collected at different times from a satellite in the same orbital position. Satellite data that USGS uses are collected by the European Space Agency. The satellites orbit at altitudes of about 300 miles and transmit radar data that are recorded at ground stations. These data are then digitally analyzed on computer workstations to obtain refined radar images of the Earth.

The spatial resolution is quite detailed, with an individual picture element, or pixel, of data representing an area of 1,025 square feet on the Earth's surface. INSAR images are essentially a measurement of the differences when radar scans are compared. The pairs of radar images are compared to detect ground movements of four-tenths of an inch or less that occurred during the time interval between acquisition of the two images.

INSAR relies on changes in the Earth's reflective properties over time. This means that heavily vegetated lands, such as forests, cultivated fields, and other areas that have changing land cover, are not well suited to INSAR technology because they absorb, rather than reflect, infrared signals. Suitable areas include deserts and areas with minimal vegetation, urban areas, and other areas with extensive paved surfaces. Agricultural areas with fixed surface areas of more than 33 feet across, and such features as freeways, paved runways, urban clusters and factories, therefore, could be monitored for regional changes in surface elevation by using these sites as "markers."

A future generation of radar satellites scheduled for launch around the year 2000 is expected to improve data quality and the capability to combine radar images for analysis.

INSAR and Water Management in Antelope Valley, California—A Model for the Thirsty West

The thirst for water in the Antelope Valley of California follows the pattern of many arid regions of the West: initial development of ground water for agriculture, followed by urbanization and importing of surface water. Natural ground water and seasonal supplies of surface water may not be adequate to meet future demands.

Future water supplies may depend on managing surface water stored in aquifers during low-demand periods, and then pumping and "recovering" the water when needed. Such managed storage requires a detailed understanding of aquifer characteristics and behavior. INSAR is being explored to help provide that information.

In the Antelope Valley—home of Edwards Air Force Base and the Space Shuttle—long-term, ground-water pumping has caused irreversible compaction of the clay and silt layers in the aquifer from which ground water is pumped. The resulting land subsidence has caused substantial damage to runways, roads, wells, pipelines, and other structures. Surface fissures or cracks in the land surface 1,300 feet long, 6 feet wide, and 13 feet deep have been reported.

The additional accuracy and timeliness of data that INSAR can



provide in measuring the amount, rate, and distribution of subsidence, along with computer models of ground-water recharge, flow, and pumpage, will help managers evaluate how aquifers might be used as potential storage to expand future water supplies and limit the impacts of subsidence.

The USGS is exploring the use of INSAR data in other California watersheds, such as the Santa Clara Valley and Coachella Valley and in Las Vegas and Houston.

Melting Glaciers Signal Change in National Parks

NATIONAL PARKS ARE BEING ALTERED by global climate change. Though the impact is not always easy to detect, evidence for these changes is seen in the shrinking glaciers of Glacier National Park, Montana. As part of a comprehensive assessment of the park's ecosystem, USGS scientists are studying the glaciers' response to more than a century of warming.

invasions and redistribution, and other environmental variables. This tool provides explicit scenarios to help park managers, policy makers, and the public understand and make decisions about the future of national parks.

The results of this study paint a vivid picture, not only of the magnitude of a future problem, but of changes already apparent in national

"A computer model predicts that all glaciers in the park will be gone by 2030 if global temperatures continue to rise as forecast. Even with no additional rise in temperature, the park's glaciers will be largely gone by 2100."



Boulder Glacier, Glacier National Park, Montana, July 1932 (left) and July 1988 (right), 56 years later, from the same point.

The ice cave and glacier have completely disappeared.

Since 1850, larger glaciers in the park have been reduced to a third of their previous size and continue to shrink. Some have receded more than a mile into the shadows of steep cliffs. Many smaller glaciers have entirely disappeared. A computer model predicts that all glaciers in the park will be gone by 2030 if global temperatures continue to rise as forecast. Even with no additional rise in temperature, the park's glaciers will be largely gone by 2100.

Because glaciers respond to changes in temperature and precipitation, a long period of glacier shrinkage represents a shift in climate. Thus, glacial change provides an early indicator of fundamental climatic change, change that will ultimately affect other parts of the ecosystem as well. The absence of glaciers will directly affect environmental variables such as stream flow and temperature in mountain watersheds, especially late in summer. But perhaps of greatest significance is that melting glaciers indicate broader changes to which plants and animals must adapt.

The USGS's 7-year modeling and monitoring effort provides a computer-based system to simulate how plants and animals might respond to not only climate change but also to resulting changes in fire intensity and frequency, plant

parks. By better understanding the response of glaciers and other ecosystem functions to global warming, the Nation can better prepare and manage for its consequences.

FOR MORE INFORMATION

Website:

<http://www.mesc.usgs.gov/glacier>

Publications:

Fagre, D.B., 1998, Understanding climate change impacts on Glacier National Park's natural resources, in Mac, M.J., Opler, P.A., Puckett-Haecker, C.E., and Doran, P.D., eds., Status and trends of the Nation's biological resources: Washington, D.C., U.S. Department of the Interior, In press.

Key, C.H., Fagre, D.B., and Menicke, R.K., Glacier recession in Glacier National Park, Montana, in Williams, R.S., and Ferrigno, J.G., eds., Satellite image atlas of glaciers of the world, U.S. Geological Survey Professional Paper 1386-J, In press.

Making A Difference to Water



*U.S. Geological Survey
scientists make a difference to
understanding the Nation's
rivers, lakes, reservoirs, bays,
and ground water.*

*The USGS is not only concerned
with contaminants and pollutants in the water—some coming from the
air—but also with developing technology that can remedy
contamination.*

Weighing One Environmental Concern Against Another: The MTBE Story

IN ADDRESSING ONE ENVIRONMENTAL concern and its potential health implications, others may arise. Such is the case with MTBE (methyl tert-butyl ether), the most commonly used fuel oxygenate.

Under the 1990 Clean Air Act Amendments, oxygenated fuel is required in areas—usually urban—where there are high levels of carbon monoxide or ozone. About 40 percent of the American population lives in these areas, and this percentage is expected to increase to 70 percent by 2000.

The upside to the story is that air quality has been significantly improved—and carbon monoxide and ozone levels reduced—where oxygenates have been added to gasoline. In areas where carbon monoxide or ozone concentrations have been reduced, however, MTBE has been found in the air, stormwater runoff, streams, lakes and reservoirs, and ground water. This unanticipated downside to the benefit of adding MTBE to fuels causes concern that water quality may degrade as air quality improves.

Volatile organic chemicals, such as MTBE, easily change into gaseous form (are volatilized) and therefore are available to the air and water. MTBE does not biodegrade easily. It is not very soluble and moves with water in the hydrologic cycle. Urban non-point sources, like precipitation and urban land-surface runoff, are thought to be important sources of the MTBE concentrations detected (mostly at low levels) in shallow ground water.

The USGS National Water Quality Assessment Program (NAWQA) has been studying the point (specific) and non-point (general) sources and distribution of MTBE and other synthetic volatile organic compounds (VOCs) in surface and ground water across the country. Analyses of more than 1,700 samples nationwide show that MTBE is detectable in surface- and ground-water resources in many areas. How frequently MTBE is detected in water and at what concentration directly relate to urban land use. Because MTBE use and its patterns and presence in atmospheric and hydrologic systems track so closely, the currently available data suggest that policies to control the effects of MTBE will ben-

MTBE Detected in New England Ground Water

The USGS National Water Quality Assessment Program recently reported results of a ground-water resources study in an area of high MTBE use in central and southern New England in 133 wells sampled in the Housatonic, Connecticut, and Thames River basins.

MTBE was the most commonly detected VOC. It was found in 25 percent of the wells. Because of the strong correlation with land use, none of the samples from wells in forested areas had MTBE, but 40 percent of wells in urban areas had MTBE at detectable levels.

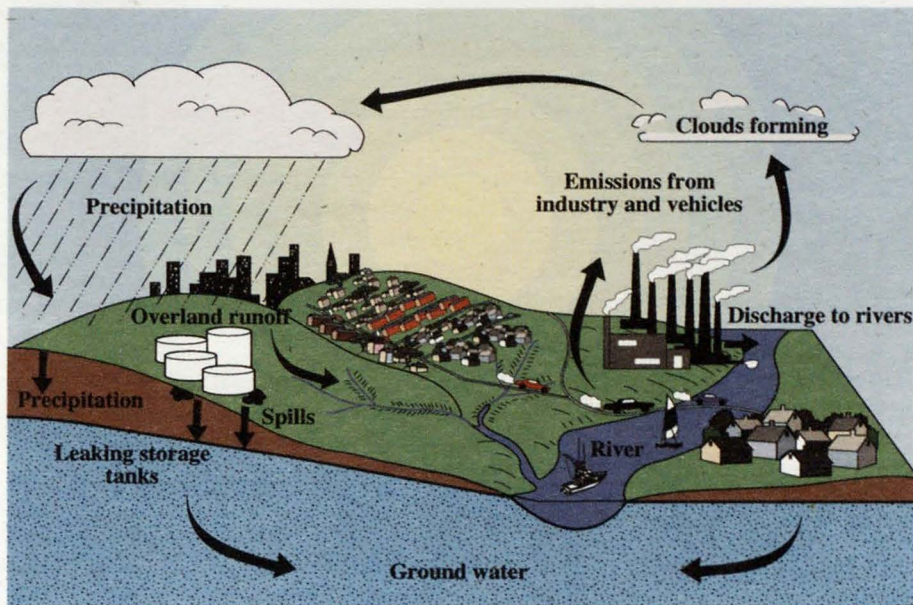
Other NAWQA studies have indicated that MTBE moves with infiltrating water that recharges the surficial aquifer through unsaturated soils and bedrock fractures. These New England detections may result from surface waters, with MTBE entering the wells through leaky well seals or shallow fractures rather than being an indication of contamination deep within the aquifer.

efit from a thorough understanding of how MTBE moves through the environment.

Urban stormwater samples collected in 16 cities and metropolitan areas showed that although MTBE was detected, all detections were less than the lower limit of the U.S. Environmental Protection Agency's (EPA) draft lifetime health advisory for drinking water.

The use of recreational boats on lakes and reservoirs is another source of MTBE in the water environment. Such use has been found to produce concentrations of MTBE up to 10 parts per billion. Where much larger concentrations of MTBE are found in water, they result from point-source releases, such as leaking underground storage tanks, large spills, and wastewater discharges. In rare instances, MTBE concentrations can be very high, but such high concentrations are easily traced to large spills or leaking storage tanks.

MTBE in water samples is generally detected most frequently and at the highest concentrations in urban areas. Even in shallow urban ground



Pathways by which methyl tert-butyl ether moves through the environment.

water, however, concentrations are usually low in comparison to the EPA Drinking Water Advisory of 20 to 40 parts per billion. The advisory levels

EPA and USGS Study Drinking Water in 12 Northeastern States

The EPA and USGS are studying MTBE and other VOC contaminants in the drinking water supplies of 12 Northeastern States from Virginia north through New England. The 65 million people who live in this region use large amounts of oxygenated gasoline, which contains MTBE. The cooperative study will use data collected since 1995 by 2,100 of the 10,500 community water systems. Data from other Federal and State programs will also be used.

EPA will gain important information on potential human exposure from drinking water to MTBE and other unregulated and regulated VOCs. The USGS will gain an increased understanding of the factors that affect the distribution of MTBE and other VOCs in a large, highly urbanized part of the Nation. Study results will be used by water resource managers in areas with similar land use, and geologic and hydrologic characteristics.

MTBE Frequently Detected in New Jersey

New Jersey is densely populated and highly urbanized, which makes it not too surprising that MTBE and other VOCs are found in surface- and ground-water resources throughout the State. USGS studies in New Jersey are investigating the occurrence and distribution of MTBE and other VOCs in relation to land-use patterns, geohydrology, soils, and other natural and human factors. More specifically, they are conducting a broad assessment of ground-water quality conditions in aquifers used for public supply.

Sampling of surface waters over the past few years has shown that MTBE is one of the most frequently detected VOCs. Frequency

and concentrations are correlated with urbanization and population density, as is the case elsewhere in the country.

In the rapidly growing Glassboro area, the surficial Kirkwood-Cohansey aquifer system is becoming an important source of public water supply. This underground water supply is recharged directly from surface water that infiltrates the aquifer through overlying unconsolidated sands and gravels, and is, therefore, vulnerable to contamination from that surface-water influence. The USGS has established a network of 72 wells to monitor recently recharged ground water. In the initial sampling, MTBE was detected in 44 percent of the wells.

primarily reflect taste and odor considerations. Although MTBE has been tentatively classified as a possible human carcinogen, EPA believes that, based on current knowledge, the advisory level provides a wide margin of public health safety. Studies continue to further define the health risks.

USGS studies of MTBE and other VOCs will give policy makers, resource managers, and environmental health officials the scientific information they need to weigh the trade offs between

air-quality improvements and potential adverse water-quality impacts.

FOR MORE INFORMATION

Website:

<http://www.sd.cr.usgs.gov/nawqa/vocns/>

Stopping Contamination in Its Tracks

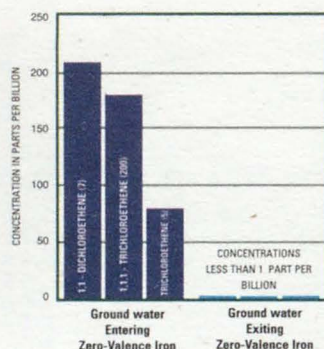
BECAUSE OF THE APPLICATION OF A new remediation technology by USGS researchers in Colorado, the movement of chlorinated solvents off the Denver Federal Center has literally been stopped in its tracks. Chlorinated solvents are one of the most common contaminants of ground water in the United States.

The remediation technology—permeable reactive barriers—destroys the solvents in the ground water. With such a barrier, water passes through, but is chemically altered in the process. The barrier uses zero-valence iron to completely destroy the chlorinated solvents as ground water moves through the iron.

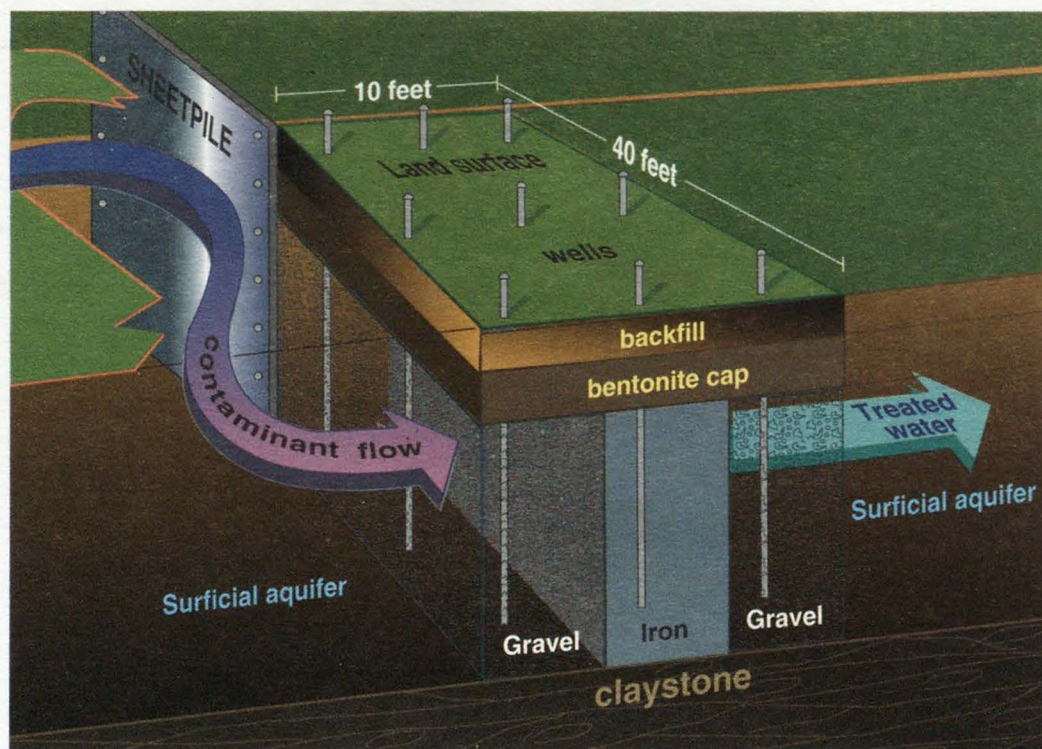


Zero-valence iron being placed in aquifer to form a permeable reactive barrier that will destroy contaminants in water.

The reactive barrier technique has a lot going for it. The technology is maintenance free



Concentrations of selected chlorinated solvents in ground water entering and exiting zero-valence iron at the Denver Federal Center. Numbers in parentheses are the drinking water standards for the indicated compounds.



Contaminant concentrations entering and leaving zero-valence iron.

What Are Chlorinated Solvents?

Chlorinated solvents, such as carbon tetrachloride, chloroform, and ethylene dichloride, were developed after World War II as safe non-flammable cleaning agents. They are used in various industrial processes and replace volatile hydrocarbon-based solvents. By sub-

stituting chlorine for hydrogen, industry had a still-efficient solvent that was less volatile. As with many chemical compounds used by industry and agriculture, it was not known at the time of development what their impacts would be to human health or the environment.

and less expensive than other remediation technologies. The Federal Highway Administration and the General Services Administration are using the technology at the Denver Federal Center because it is an essentially natural remediation method that is cost effective. The USGS served as an advisor to the U.S. Army Corps of Engineers during design and installation of the barrier. Continued evaluation of the hydraulic and geochemical performance of the reactive barrier by the USGS will provide valuable information for future applications of this technology.

The reactive barrier method is a technology that can be applied across the country in dealing with chlorinated solvents.

FOR MORE INFORMATION

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Getting the Lead Out—Positive Effects of the Clean Air Act

LEAD CONCENTRATIONS HAVE declined significantly in several urban lakes and reservoirs across the country, an encouraging sign that the switch to unleaded gasoline and the Clean Air Act of 1990 have produced positive effects on the Nation's water resources.

Lead concentrations declined despite significant increases in both population and the number of motor vehicles during the same period. Lead concentrations in water sediments declined as much as 70 percent since the 1970's and 1980's. While this is good news, lead concentrations still remain almost twice as high as the baseline levels of the 1950's and 1960's. Clearly, large amounts of lead still exist in soils and in lake sediments. It will take many years to reduce these concentrations to the levels experienced before the rise of leaded gasoline, even if there are no new sources of lead introduced into the environment.

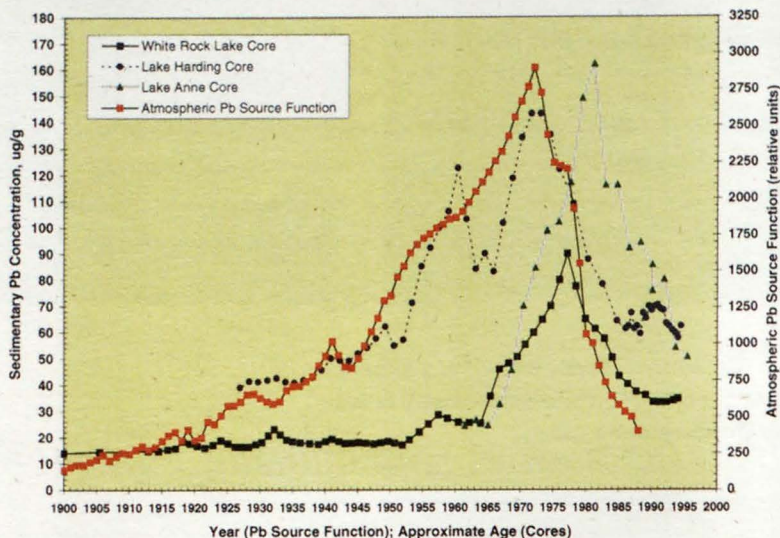
USGS hydrologists collected core samples of lake-bottom sediment from lakes and reservoirs in four areas of the country, representing urban and suburban lakes and reservoirs that drain agricultural watersheds. They used gravity-type coring devices and grab baskets to collect samples of the lake-bottom sediments. In the

same way that tree rings can provide insight to historical climatic conditions, the chemistry of slices of the sediment contained in these cores can provide historical water-quality information.

Because lakes and reservoirs efficiently trap sediments and heavy-metal concentrations, such as lead, from rivers and streams, the accumulated sediments can provide a valuable historical record of lead in the lake's drainage basin. Accumulated lead in sediments can become a source of future water pollution if the sediments are disturbed, reintroduced into the water column, and transported elsewhere in the watershed.

Scientists can look at the lead concentrations recorded in the core and determine whether or not there has been a decrease. The decrease can be seen in the more recent sediment deposits in the upper part of the core compared to the baseline concentrations in the oldest sediments in the bottom of the core. Radiochemical dating is used to determine the time represented by specific points along the length of the core. The "dated" historical record of the sediment cores contains a distinct "signature" of the water quality in the lake and its drainage basin over time. Analysis of this signature can determine the time frame when leaded

"Lead concentrations in water sediments declined as much as 70 percent since the 1970's and 1980's."



Lead (Pb) distributions in urban and suburban sediments and peak levels of lead accumulation in selected reservoir sediments. Note recent declines due to switch to unleaded gas.

gasoline was being used in the basin. By tracing the history of the lead concentrations in the core, USGS hydrologists can tell if there has been a change in the percentage of lead present in sediments deposited in more recent times, as compared to the earlier sediments.

The lake study is part of the USGS National Water Quality Assessment Program, which is the first comprehensive, ongoing study of trends in the quality of the Nation's surface- and ground-water resources. Looking at trends can improve understanding of the influence of human activities on water-quality conditions. Trends can also indicate the effectiveness of environmental regulations, like the Clean Air Act. Another important function of information on water-quality trends is to signal a warning of additional degradation of water quality in the future, for which additional study or action might be taken.

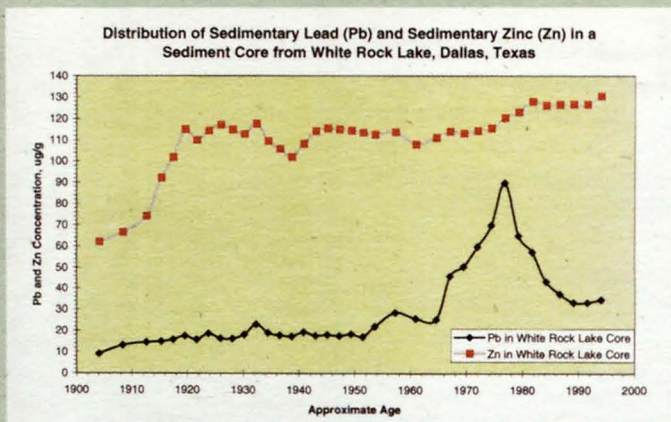
Where the Rubber Meets the Road—A Source for Zinc in the Environment?

Zinc is a heavy metal that can be toxic. An intriguing finding that came out of the USGS reservoir coring study was the perplexing pattern of the zinc curve. While lead showed a reassuring and rather dramatic drop in its presence in the environment, strongly correlated to the removal of lead from gasoline, the picture for zinc is quite different.

Take, for example, White Rock Lake, a 2-square-mile reservoir in Dallas, Texas, with a drainage area of 100 square miles. The watershed was mostly agricultural before 1950 or so. Since then, it has undergone urban development, which now dominates land use. Sediment is washed off the land surface into streams during rain storms. Much of it is deposited in White Rock Lake. Over time, sediments have accumulated to form a thick layer on the bottom of the lake more than 8 feet thick in the deepest part of the lake.

Cores from these sediments and other similar reservoir bodies show that, in general, lead and zinc respond similarly to environmental disturbances. Data from White Rock Lake and other suburban-urban reservoir sediments, however, show that while lead declines in modern sediments, zinc either increases or stays elevated in concentration to the present time. The zinc anomaly suggests a continued, as yet unknown, contaminant source of zinc to the environment.

What might be the source for the zinc? One hypothesis that USGS will test is whether rubber tires are the source. The simple fact is that automobile use has outstripped population growth by more



Distribution of sedimentary lead (Pb) and sedimentary zinc (Zn) in a sediment core from White Rock Lake, Dallas, Texas.

than four times. Manufactured rubber contains zinc, which means that each time the tire runs over the road, it leaves a residue of zinc that can run off into streams and enter ground-water systems.

FOR MORE INFORMATION

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Simple Environmental Equation: Less Nitrogen = Healthier Chesapeake Bay

FISH AND CRABS IN CHESAPEAKE BAY have a chance to live in a healthier environment as a result of efforts to reduce the amount of nutrients entering the bay from its tributary rivers.

Pollution in the form of nutrients, such as nitrogen and phosphorus, enters the bay's estuary from its rivers and threatens the bay's health and productivity. Algal blooms, nourished by large amounts of nitrogen and phosphorus, block sunlight needed by grasses and other submerged aquatic vegetation, which are prime habitat for commercially valuable fish and crabs. The blooms also deplete oxygen from the water, depriving fish and crabs of much needed oxygen, resulting in fish kills.

Additionally, high nutrients are believed to be linked to the outbreaks of *Pfiesteria* in the bay. A one-celled microorganism, *Pfiesteria piscicida*, was identified as a culprit in the 1997 Chesapeake Bay area fish kills, prompting Maryland officials to issue health warnings and to temporarily close rivers to commercial fishing and recreational activities. The fish kills in Maryland rivers seem to be associated with a combination of high nutrient concentrations, warm water temperatures, high salinity, and storm events.

In the early 1980's, Federal, State, and local governments began reducing the amount of nutrients in the rivers that flow into Chesapeake Bay. Bans on phosphorus detergent, upgrades of sewage-treatment facilities, control of runoff from city streets and farmland, and preservation of forest and wetlands were all designed to reduce the impact of nutrients on the bay.

USGS hydrologists and colleagues at several State agencies began the River Input Program in the mid 1980's to quantify the improvements in water quality resulting from those nutrient-reduction efforts. Partners in the River Input Program are Maryland, Virginia, and the Metropolitan Washington Council of Governments, under the auspices of the U.S. Environmental Protection Agency's Chesapeake Bay Restoration Program.

After more than a decade of monitoring the amount of nutrients entering the bay, there is mixed news to report.

The good news is that Federal, State, and local nutrient-reduction programs are reducing the concentrations of nutrients in the rivers that flow into Chesapeake Bay. Where once researchers saw increasing trends in the concentrations of nutrients entering the bay from tributary rivers, they now see a leveling off or significant decreases. Phosphorus

concentrations are declining in all but two monitored rivers. The decrease in phosphorus can be particularly attributed to effective environmental policy action by the States. The phosphate detergent bans enacted in Maryland, Virginia, Pennsylvania, and the District of Columbia during the mid 1980's lowered phosphorus inputs. Nitrogen, which is more difficult to control because of its many sources, is declining in all but four monitored rivers.

The bad news is that even though concentrations of nutrients have decreased, large floods in the last 5 years have increased loadings of nutrients into the bay. Researchers are just beginning to realize the impacts of those increased loads on the bay's living resources.

The return on the investment of scientific cooperation and proactive environmental policy is significant: the Chesapeake Bay is showing hopeful signs of restored health and habitat. Continuous monitoring has proven to be worthwhile in determining reductions in nutrient concentrations that



Crabs from Chesapeake Bay.



High flows of tributary rivers carry large amounts of nutrients and suspended sediment to Chesapeake Bay. USGS samples conditions like these at Conowingo Dam on the Susquehanna River.

have occurred as a result of human impacts. Further measures are needed, however, to deal with the forces of nature and to understand the effects of those forces on Chesapeake Bay.

FOR MORE INFORMATION

Websites:

River Input Program

<http://www-va.usgs.gov/chesbay/RIMP>

Ecosystem Program

<http://chesapeake.usgs.gov/chesbay>

Making A Difference for Plants and Animals



U.S. Geological Survey biologists are making a difference to the living resources of the Earth. Their work can affect policy and legislation, as it has in the Conservation Reserve Program, which benefits both farmers and wildlife when grasses are

introduced into highly erodible cropland. Biological research is also responsible for restoring lake trout to the Great Lakes, safeguarding the health of native salmon and trout, and establishing new nesting sites for the world's most endangered sea turtle.

Conservation Reserve Program Benefits Wildlife and Farmers

FOR MORE THAN 10 YEARS, MANY wildlife species including white-tailed deer, cottontail rabbits, songbirds, and waterfowl have found winter cover and nesting sites on farm lands set aside under the U.S. Department of Agriculture's Conservation Reserve Program (CRP).



Scientist identifies grass species in a Conservation Reserve Program field.

cooperation with USDA and the International Association of Fish and Wildlife Agencies. Findings from the multi-state, 10-year study and a 1996 environmental risk assessment have helped USDA refine conservation policies in recent legislation. As a result, farmers have benefitted from increased economic opportunities and wildlife habitat has increased.

As of January 1998, 28.7 million acres of land were enrolled in the CRP. As part of the program, farmers are paid to keep highly erodible cropland from production and reclaim it with introduced and native grasses. Nearly \$2 billion have been paid to farmers nationwide each year as part of the CRP.

USGS found that grassland productivity peaks early in a typical 10-year CRP contract, and the amount of vegetative cover in most fields declines during later years if it is not disturbed. This finding has led to further studies to determine if periodic disturbances, such as grazing, will enhance vegetative growth on CRP lands. Scientists are investigating relationships between "emergency" grazing (e.g., grazing during drought years) and long-term trends in habitat quality on CRP lands in 13 Midwestern and Southern Plains States.

Other USGS studies have documented CRP benefits to waterfowl and songbirds. In addition, a study by USGS, USDA, and the Minnesota Department of Natural Resources is using a geographic information system and 30

USGS scientists at the Midcontinent Ecological Science Center in Fort Collins, Colorado, and Northern Prairie Wildlife Research Center, Jamestown, North Dakota, began evaluating wildlife habitat on CRP lands in 1987, in



Approximate locations of Conservation Reserve Program fields monitored periodically since 1987.

years of population data to investigate CRP effects on long-term trends in wildlife populations associated with agricultural land use.

FOR MORE INFORMATION

Publications:

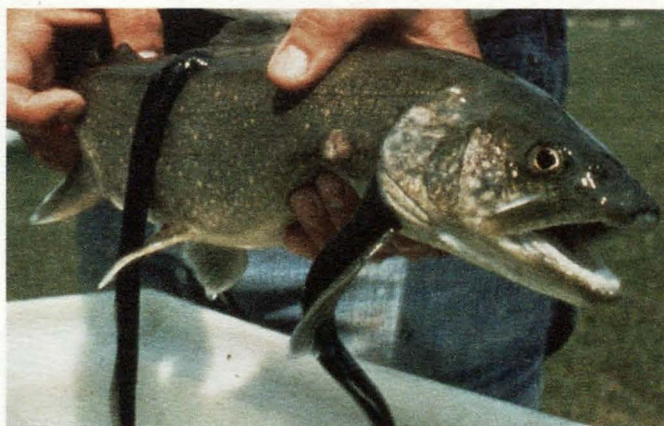
Allen, A.W. 1995. Agricultural ecosystems, in LaRoe, E.T., Farris, G.S., Puckett, C.E., Doran, P.D., and Mac, M.J., eds., *Our living resources: a report to the Nation on the distribution, abundance, and health of U.S. plants, animals, and ecosystems*. Washington, D.C., U.S. Department of the Interior, National Biological Service, p. 423-426.

Johnson, D.H., and Igl, L.D., 1995. Contributions of the Conservation Reserve Program to populations of breeding birds in North Dakota: *Wilson Bulletin*, v. 107, no. 4, p. 709-718.

Lake Trout Restored in Lake Superior after Lamprey Invasion

HIGHLY PRIZED LAKE TROUT HAVE been successfully restored in Lake Superior through research of USGS scientists working closely with management agencies. This combined science and management approach is now being adapted to other lakes and species in a basin-wide effort to restore native fish species.

Lake trout historically were the top predator in Lake Superior and supported valuable commercial, subsistence, and sport fisheries. Starting in the 1920's, sea lampreys began to invade the upper Great Lakes, and their predation, combined with fishery exploitation, caused the collapse of



Sea lampreys dangling from an adult lake trout.



USGS researcher holds a 25-year-old wild lake trout from Stannard Rock, central Lake Superior.

most lake trout populations throughout the basin.

Given the scale of this ecological disaster, the Great Lakes Fishery Commission was established in 1955 to control sea lamprey and restore lake trout populations. Priority was given to Lake Superior, since lake trout populations had not been completely eliminated there. During the late 1950's and 1960's, the USGS Great Lakes Science Center in Ann Arbor, Michigan, worked closely with the Great Lakes Fishery Commission to identify a selective chemical to control sea lamprey larvae in streams.

After scientists tested more than 6,000 chemicals, they determined 3-trifluoromethyl-4-nitrophenol (TFM) the most suitable and developed it for field use. Shortly after TFM application to larval populations, sea lamprey numbers began to decline in Lake Superior, allowing for the reintroduction of lake trout through plantings of hatchery-reared fish and protection of remnant stocks.

Scientists measured performance of hatchery-reared lake trout as well as recovery of wild

populations through long-term assessment programs developed by USGS scientists. These field programs were later assumed by State and tribal management agencies and used as a model to develop assessments in other jurisdictions.

Ongoing analysis of these important field data by USGS scientists, working with State, tribal, provincial, and other U.S. Department of the Interior agencies, led to the decision in 1996 to discontinue stocking federally produced hatchery



Progress of lake trout restoration in the Great Lakes, 1970's to present.

Saga of the Sea Lamprey

Although more than 140 non-native species have entered the Great Lakes, the sea lamprey is considered the most harmful. During part of their life cycle, sea lampreys are parasitic, feeding only on the blood of fish.

They likely entered Lake Ontario from the Atlantic Ocean through the New York State barge canal system in the 1800's, and entered the upper Great Lakes after the Welland Canal was completed in 1829, allowing passage past Niagara Falls. By the 1950's, predation by sea lampreys and overfishing combined to exterminate lake trout in Lakes Ontario, Erie, Huron, and Michigan, and depleted stocks in Lake Superior. These declines caused economic devasta-

tion and a severe imbalance of predator and prey species.

Efforts to reestablish predators failed without sea lamprey control. Although application of a chemical lampricide, TFM, continues to be successful in most areas of the Great Lakes, the Great Lakes Fishery Commission has adopted an integrated pest management plan with the goal of using alternative methods for sea lamprey control. The USGS Upper Mississippi Science Center and Great Lakes Science Center are conducting research to reduce lampricide use and develop alternative methods of sea lamprey control. This USGS research is vital for restoring U.S. and Canadian commercial, recreational, and tribal fisheries in the Great Lakes.

lake trout in most areas of the lake. Results indicated that lake trout restoration is well on its way in most areas of Lake Superior and that protection of self-reproducing wild lake trout populations from over-exploitation and sea-lamprey predation is the primary strategy to foster further restoration. Results from additional USGS research on the recruitment and survival dynamics of wild, remnant lake trout stocks also provide a benchmark to measure the performance of hatchery-reared fish in the other Great Lakes.

FOR MORE INFORMATION

Website:
www.glsc.usgs.gov

Publication:
Proceedings of the 1994 International
Conference on Restoration of Lake
Trout in the Laurentian Great Lakes:
Journal of Great Lakes Research, v. 21,
supplement 1, 1995.

Genetic Tool Differentiates Strains of Deadly Fish Virus, Saves Fish

MILLIONS OF HATCHERY-RAISED salmon and trout have been saved from possible destruction because DNA probes developed by USGS biologists can now be used to distinguish between European and North American strains of a highly feared fish disease agent, viral hemorrhagic septicemia virus (VHSV).

To safeguard the health of salmon and trout in North America, Federal and State fish disease control policies require immediate quarantine, killing of fish, and disinfection of hatcheries upon discovery of certain exotic fish pathogens. In 1988 and 1989, more than 5 million fish and eggs in western Washington were destroyed after scientists discovered VHSV in North America during routine examinations of adult salmon returning to hatcheries from the Pacific Ocean. Until then, scientists

believed that VHSV was confined to Europe, where it has caused high mortality and losses of over \$40 million a year at rainbow trout farms.

Scientists at the USGS Western Fisheries Research Center in Seattle, Washington, began research that has completely changed the understanding of the geographic distribution and epidemiology of VHSV. Their partners in this work are the Washington Department of Fisheries and Wildlife, Northwest Indian Fisheries Commission, Alaska Department of Fish and Game, Department of Fisheries and Oceans Canada, and U.S. Fish and Wildlife Service.

Using laboratory facilities at Seattle and Marrowstone Island, Washington, USGS scientists found that the North American strain of VHSV was much less virulent for salmon and

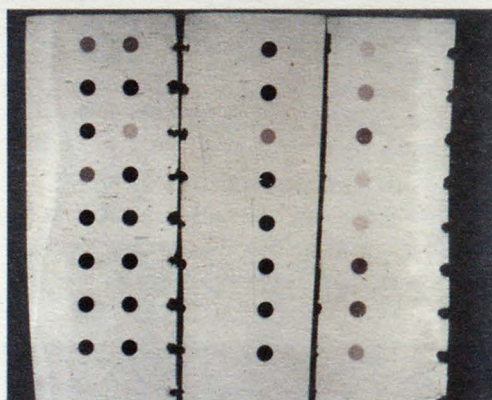


USGS scientist loading a "dot-blot" device for identification of viral hemorrhagic septicemia virus and differentiation of European and less virulent North American strains.



Destruction of several million fish at the Makah National Fish Hatchery following initial discovery of viral hemorrhagic septicemia virus at the facility.

trout than the European variety. Additional findings of VHSV in Pacific cod and Pacific herring led to the realization that this strain of VHSV is



Results of the test using strains of the viral hemorrhagic septicemia virus from North America (left column) and Europe (right column). The strip on the left has been reacted with a non-radioactive probe that recognized all strains of the virus. The middle strip was reacted with a probe that reacted only with the North American strains while the right strip was reacted with a probe for the European strain. The test takes only a few hours rather than the traditional cell culture-based assay requiring two weeks.

endemic among marine fish species along the Pacific coast of North America.

USGS scientists applied techniques from molecular biology—genetic fingerprinting and sequence analysis of the genome—to show genetic differences between North American and European strains. They used this information to develop three DNA probes and sets of primers for

DNA amplification to rapidly identify the virus and distinguish the strain. This method has greatly increased the speed and precision of detecting VHSV. Within hours, instead of weeks, scientists can now determine the identity of the fish disease agents. These diagnostic tools have been transferred to the U.S. Fish and Wildlife Service, and tribal, State, and Canadian fish disease diagnostic laboratories, as well as the private sector's aquaculture industry.

Results from the USGS studies have been of critical importance to the State, Federal, and tribal fishery programs in the Western United States, where management policies have changed. Recent work by these scientists has shown that the North American strain of VHSV is quite lethal for Pacific herring. These findings may help to explain the decline in certain stocks of this valuable commercial species in Alaska; however, the costly destruction of all fish at salmon and trout hatcheries where the North American strain of VHSV is found is no longer required.

FOR MORE INFORMATION

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Kocan, R., Bradley, M., Elder, N., Meyers, T., Batts, W., and Winton, J., 1997, The North American strain of viral hemorrhagic septicemia virus is highly pathogenic for hatchery-reared Pacific herring (*Clupea pallasii*): *Journal of Aquatic Animal Health*, v. 9, p. 279-290.

Meyers, T.R., and Winton, J.R., 1995, Viral hemorrhagic septicemia virus in North America: *Annual Review of Fish Diseases*, v. 5, p. 3-24.

Kemp's Ridley Sea Turtles Return to Padre Island

THE WORLD'S MOST ENDANGERED sea turtle is making a comeback on the Texas coast where USGS scientists have helped the National Park Service (NPS) establish a new nesting site at Padre Island National Seashore.

Until recently, the only known nesting location for the Kemp's ridley sea turtle was on the Gulf Coast of Mexico, where they had reached the brink of extinction. In 1978, the United States and Mexico launched an international recovery effort to save the endangered sea turtle. Between 1978 and 1988, 22,507 Kemp's ridley turtle eggs were transplanted from Rancho Nuevo, Mexico, about 250 miles north, to Padre Island, where they were incubated and hatched. Turtles were imprinted on Padre Island's protect-

ed beaches and then reared in captivity for 11 months prior to release into the Gulf of Mexico.

In 1996, USGS scientists confirmed that two of their hatchlings had returned to the Texas coast to nest, the first indication that a secondary nesting colony was being established. By August 1998, three more turtles had returned. The number of Kemp's ridley nests discovered on the Texas coast has more than doubled from 6 in 1996 to 13 in 1998.

USGS and NPS staff and volunteers search local beaches to detect, document, and protect nesting Kemp's ridley turtles and their eggs.

Located eggs are transferred to the incubation facility for protected care. USGS scientists also gather biological data on the eggs and turtles that will be used in the conservation of this species. Of the 968 eggs incubated by USGS scientists during 1997, 92.6 percent hatched, and 893 hatchlings were released into the Gulf of Mexico. The recent nestings give researchers great hope that a secondary nesting colony in the United States will



A Kemp's ridley turtle hatched at Padre Island National Seashore in 1983 returned to nest in 1996. This was the first turtle from the experimental project confirmed to have nested at Padre Island National Seashore or any other location outside of captivity.



Two Kemp's ridley hatchlings released on the beach at Padre Island National Seashore.

Turtles Go High-Tech, Tracked by Satellite

In June 1997, USGS scientists attached satellite transmitters on the backs of two Kemp's ridley sea turtles that had nested in south Texas and began using satellite telemetry to monitor their movements. Both turtles immediately moved northward and spent most of their time in Gulf of Mexico waters off the coast of Louisiana. Scientists wanted to know where the turtles went after nesting and which areas they preferred. The satellite tracking indicated that neither turtle had nested elsewhere after the transmitters had been affixed.

Four more transmitters were deployed on Kemp's ridley turtles that nest in south Texas during 1998. Tracking information will be used to help find nesting sites and to help protect breeding turtles in the marine environment.



Kemp's ridley sea turtle outfitted with a satellite transmitter returns to the Gulf of Mexico, where its movements will be monitored by USGS scientists.

continue to be successful, adding substantially to the long-term survival of the Kemp's ridley turtle.

Protecting this species is a cooperative venture of the USGS, NPS, U.S. Fish and

Wildlife Service, National Marine Fisheries Service, National Park Foundation, Canon U.S.A., Mexico's Instituto Nacional de la Pesca, and many other organizations.



USGS and NPS personnel release Kemp's ridley hatchlings at Padre Island National Seashore.

Because the media and public are extremely interested in this project, they are invited to attend most hatchling releases.

FOR MORE INFORMATION

Publications:

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Shaver, D.J., 1990, Kemp's Ridley Project at Padre Island enters a new phase: *Park Science*, v. 10, no. 1, p. 12-13.

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Making a Difference for People



The U.S. Geological Survey is not only a scientific agency. The USGS is also an information agency, striving to make a real difference in people's lives by providing unbiased scientific

observations on conditions ranging from the ocean depths to planetary frontiers. People, industry, and governments need this information to alert them to hazards, to help them restore the environment and intelligently use natural resources, to help them make sound policy decisions, and to improve the Nation's economy.

USGS distributes its physical, chemical, and biological information in databases, maps, scientific and general interest publications, CD-ROMs, and over the Internet. The strength of USGS information, often representing partnerships with other agencies, lies in its breadth, consistency, long-term maintenance, and use of the latest technology to meet the American people's needs.

FOR MORE INFORMATION

Publication:
U.S. Geological Survey, 1997, Innovative
earth science databases: USGS Fact
Sheet, 190-97.

To order products, see page 32.



Students see map features like this one of the Lincoln Memorial on the USGS multi-media CD-ROM, *A Topographic Field Trip of Washington, D.C.*

A *Topographic Field Trip of Washington, D.C.* is a multimedia CD-ROM product developed by the USGS to teach map-reading skills by using topographic maps in a game-like tour of the U.S. capital. Running on either Macintosh or Windows platforms, it uses digital map data to teach middle-school students how to read and interpret spatial information. By providing stimulating and amusing methods to teach abstract concepts such as coordinate systems, scale, and terrain representation, this work addresses the 1994 National Geography Standards. The project was

Topographic Field Trip of Washington, D.C.

started under a Department of the Interior Human Resources Initiatives grant to develop "Excellence in Education" products.

This CD allows non-traditional USGS audiences to become familiar with topographic maps. It uses geographic information system technology, scanned photographs, recorded and commercially available sound bytes, and digital cartographic data. These multimedia sources relate the topographic maps to real-world features by employing sounds, graphics, text, animation, and interactivity.

Ten thousand of these CDs have already been distributed to educators who are now incorporating them into school geography and earth science lessons. The product continues to generate enthusiasm as more teachers and students discover its potential. As a 10-year-old student at USGS Science camp noted, "This makes geography fun!"

As Flood Waters Rise, You Need Information Fast

WHEN FLOODWATERS THREATEN A community and county officials are racing against a rising river to warn their citizens, real-time streamflow information truly can be a lifesaver.

Stream-Gaging Data: Very Versatile Information

The USGS stream-gaging program provides hydrologic information needed to help define, use, and manage the Nation's water resources. The program provides a continuous, documented, archived, unbiased, and broad-based source of reliable and consistent water data for scientists, engineers, industrial managers, and community planners. In fact, the program is broadly supported by user agencies—93 percent of the USGS gaging stations are funded, in whole or part, by USGS partners at the Federal, State, or local level. But because of the nationally consistent, prescribed standards by which the data are collected and processed, the data from individual stations are commonly used for purposes beyond that for which an individual station may have originally been funded. Those possible uses include the following:

Public Safety

- River-flood forecasting
- Emergency response and management to flooding
- Delineating and managing flood plains

Resource Management

- Operating and designing multipurpose reservoirs
- Designing highway bridges and culverts
- Developing or operating recreation facilities
- Scheduling power production
- Designing, operating, and maintaining navigation facilities
- Allocating water for municipal, industrial, and irrigation uses
- Administering compacts or resolving conflicts on interstate rivers
- Defining and apportioning the water resources at our international borders

Environmental Protection

- Characterizing current water-quality conditions
- Determining input rates of various pollutants into lakes, reservoirs, or estuaries
- Computing the loads of sediment and chemical constituents
- Setting permit requirements for discharge of treated wastewater
- Setting minimum flow requirements for sustaining aquatic life
- Monitoring compliance with environmental regulations

Science and Public Policy

- Understanding the biological effects of contamination
- Evaluating surface- and ground-water interaction
- Undertaking scientific studies of long-term changes in the hydrologic cycle

During severe flooding in Texas in June 1997, the USGS received the following about its real-time streamflow information on the World Wide Web: "Just a note of great appreciation for your site Your site has been the best source of river information we have ever been able to obtain to make rescue and evacuation decisions. We are currently using the Blanco River data to plan the search for two drowning victims on the Blanco River in Wimberly. Your work and site is much appreciated and invaluable to us!!! Thanks from the citizens in Hays County." The writer was Dan O'Leary, Fire Chief and Emergency Management Coordinator for the City of San Marcos, Texas. Saving lives and protecting property are the tangible human and economic benefits of having real-time streamflow information available.

Throughout the country, USGS streamflow gaging stations, equipped with real-time telemetry, are integral components of reservoir operations and river-forecast and flood-warning systems. The USGS gaging station network has been the backbone of the flood warning and management system throughout the United States. The real-time streamflow data provided by the USGS are used by the National Weather Service, the U.S. Army Corps of Engineers, the Federal Emergency Management Agency, and by countless State and county emergency and planning officials to ensure that lives and property are protected during floods.

Customer use of real-time streamflow information on the Web (<http://water.usgs.gov/realtime.html>) has increased by leaps and bounds. During September 1997, for example, 3.1 million "pages" of water resources information were delivered to 118,000 Web users. When the worst flooding in more than a century struck North Dakota in April 1997, anxious USGS customers "hit" the USGS North Dakota home page more than 580,000 times, seeking the latest information on the unprecedented spring flooding.

The percentage of external customers for USGS water resources data—95 percent are outside USGS—is persuasive testimony to the usefulness of the information to a wide audience. While the flood-warning and emergency-response uses of the information are perhaps the most critical to the Nation as a whole, the information is also routinely used by recreationists to provide for a safe whitewater rafting experience or a prime day of fishing.

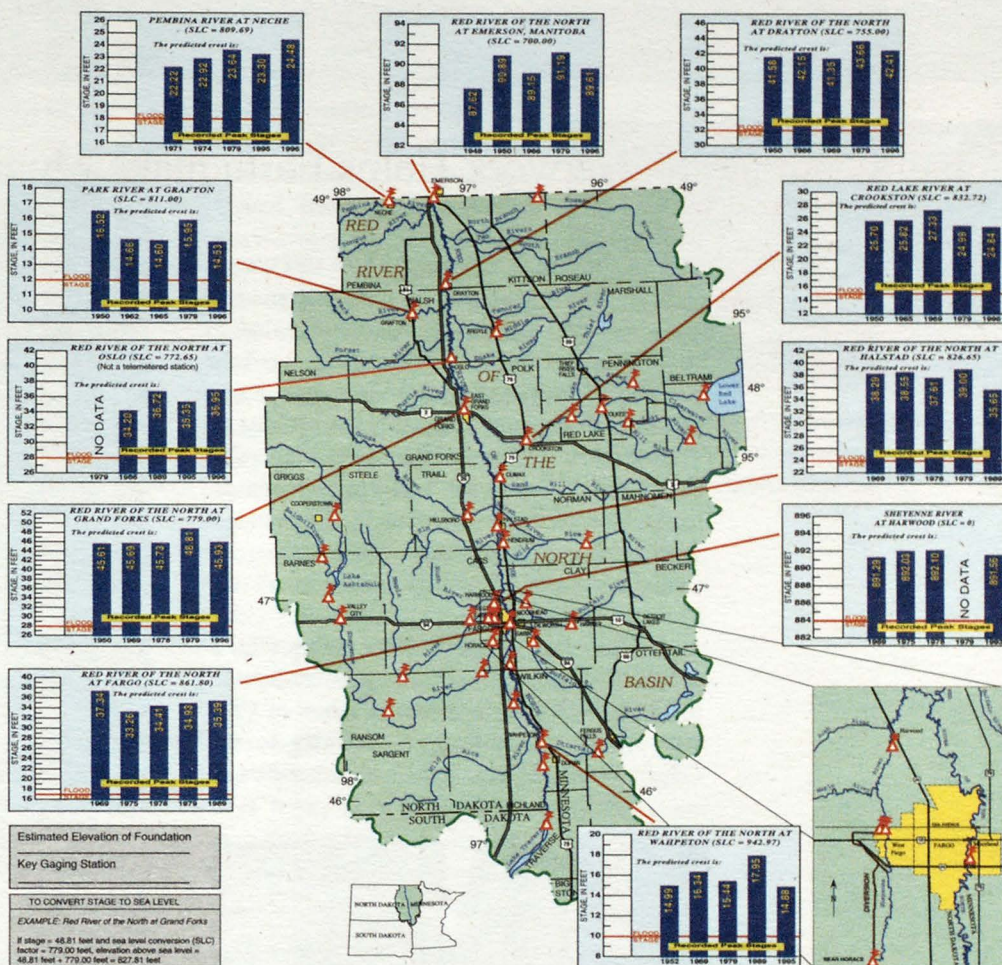
Tracking a Flood's Course

With a colorful flood tracking chart in hand and a computer modem on line, citizens and emergency response personnel can record the latest river stage and predicted flood-crest information and plan accordingly. By comparing the current stage (the level of the river) and predicted flood crest to the recorded peak stages of previous floods, residents and emergency personnel can make informed judgments about impending floods and actions needed to lessen threats to life and property.

The flood tracking chart, available for selected rivers in several States, shows a map of the basin, the location of major real-time streamflow-gaging stations in the basin, and the historical recorded peak stages of previous major floods. Each of the small insert graphs represents a station and has a scale on which to record recently reported river stage from the USGS. The predicted flood-crest information from the National Weather Service also can be recorded on each graph.

During a flood, citizens and emergency personnel can obtain the most current river-stage data on the Web from the USGS by accessing <http://water.usgs.gov> and then clicking on "real time."

1997 FLOOD TRACKING CHART FOR THE RED RIVER OF THE NORTH BASIN (Modified)



The "1997 Flood Tracking Chart for the Red River of the North Basin" can be used by local citizens and emergency response personnel to record the latest river stage and predicted flood-crest information. By comparing the current stage (water-surface elevation above sea datum) and predicted flood crest to the recorded peak stages of previous floods, emergency response personnel and residents can make informed decisions concerning the threat to life and property. The flood tracking chart shows a map of the basin, the location of major real-time streamflow-gaging stations in the basin, and the historical recorded peak stages at selected stations. Each graph represents a station and has a scale on which to record the most recently reported river stage from the U.S. Geological Survey (USGS). The predicted flood-crest information from the National Weather Service (NWS) also can be recorded on each graph.

During a flood, the USGS provides current river-stage information to the public through news releases and, more directly, through the USGS "Home Page" on the Internet. The North Dakota District of the USGS displays available real-time river-stage data on the World Wide Web at the following address: <http://srv1.dndmkr.cr.usgs.gov/public/>

The NWS has direct access to all information collected by the USGS for use in their forecasting models and routinely broadcasts the forecast information to the news media and on shortwave radio. The radio frequencies are 162.400 MHz (megahertz) in Petersburg, N. Dak., and Detroit Lakes, Minn.; 162.425 MHz in Webster, N. Dak., and Bemidji, Minn.; 162.450 MHz in Roseville, Minn.; 162.475 MHz in Grand Forks and Ardenia, N. Dak.; and 162.550 MHz in Thief River Falls, Minn.

To use the flood tracking chart for a particular property, determine the approximate elevation of the threatened property and record the elevation in the box at the lower left corner of the map along with the elevation of the "key gaging station." The "key gaging station" is the station that is closest to the threatened property. For example, most people in Grand Forks, N. Dak., probably will use the Red River of the North at Grand Forks station as their "key gaging station." Using the news media, Internet, or shortwave radio, routinely find out the latest river-stage information. Record the information for each station, especially the "key gaging station," and convert the stage to sea level (see the example in the lower left corner of the map). The sea level conversion (SLC) factor, if available for the station, is shown on the

corresponding graph for that station and can be added to the current river stage and also to the historical recorded peak stages to relate the information to sea level elevations. Compare the information to the elevation of the property to immediately know if the property has an impending threat of flooding. One must be cautioned by the fact that the surface of flowing water is not flat but has a slope. Therefore, the water-surface elevation near a threatened property might not be the same as the river stages at the gaging stations. For those stations where an SLC factor is not available, past historical peak gage heights can be compared to the latest river-stage information and used as a guide to determine the threat of flooding.

The network of river-gaging stations in the Red River of the North Basin is operated by the USGS in cooperation with the U.S. Army Corps of Engineers, the North Dakota State Water Commission, the Minnesota Department of Natural Resources, the Southeast Cass Water Resources District, the Cass County Joint Water Resource District, the Red River Joint Water Resource Board, and the Red River Watershed Management Board. For more information about USGS programs in North Dakota, contact the District Chief, U.S. Geological Survey, North Dakota District, at (701) 250-4601.



Prepared by Gregg J. Wiche, Cathy R. Martin, Luverne L. Albright, and Geraldine B. Wald of the U.S. Geological Survey in cooperation with the U.S. Army Corps of Engineers, the National Weather Service, the North Dakota State Water Commission, and the Southeast Cass Water Resources District

U.S. Geological Survey
Open-File Report 97-193



U.S. GEOLOGICAL SURVEY



U.S. ARMY CORPS OF ENGINEERS

Informing Tomorrow: Data from Today and 100 Years of Yesterdays

In addition to the real-time data for current streamflow and flood conditions, customers also have access to the entire historical file of surface-water records for rivers and streams throughout the country. This wealth of information includes data from 6,950 streamflow gaging

stations nationwide, 400,000 station years of data, and 160 million daily records of water data on what has been happening with the Nation's rivers over time. Check out <http://water.usgs.gov> and then click on "historical."

Global Seismograph Network Helps Earthquake Monitoring, Research

THE GLOBAL SEISMOGRAPH NETWORK (GSN) is a system of some 100 modern seismographic stations deployed worldwide to collect data for monitoring earthquakes and for research on earthquakes and the structure and processes of the Earth. The GSN is supported by a partnership of the USGS, the Incorporated Research Institutions for Seismology (a consortium of universities supported by the National Science Foundation), and the Institute for Geophysics and Planetary Physics at the University of California, San Diego.

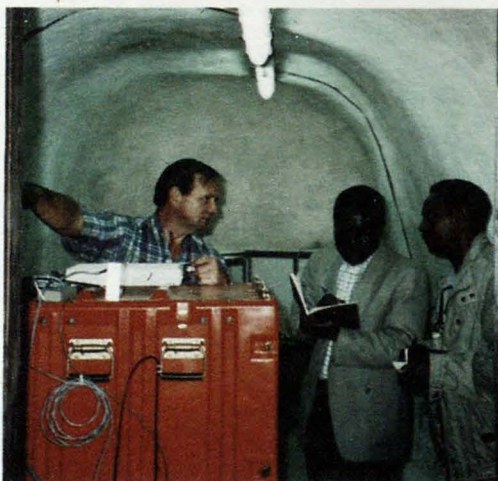
GSN data are used daily in the routine operations of the National Earthquake Information Center. Data from a subset of GSN stations are transmitted continuously to the Center, where they are used with other data to

caused an earthquake. This information can be used to quickly assess the damage potential of an earthquake and its potential for generating a tsunami.

GSN data are widely used in basic research on the internal structure of the Earth and the physics of earthquakes. Recently researchers at Columbia University used GSN data to determine that the inner, solid core of the Earth rotates at a slightly different rate than the rest of the planet. This difference in the rate of rotation was detectable only with the high quality, digital data available from the GSN. This discovery provides fundamental support and substance to the "dynamo theory" used to explain the existence of and changes in the Earth's magnetic field.

Several GSN stations have been formally affiliated with the International Monitoring System being established to monitor the Comprehensive Test Ban Treaty (CTBT). Additionally, the entire GSN can contribute to the independent capability of the United States to monitor this treaty.

For example, on August 16, 1997, a small seismic event occurred near a known Russian nuclear test site on Novaya Zemlya Island in the Barents Sea. According to public reports, U.S. government experts initially identified this event as a possible underground nuclear explosion. Various additional data were used to help target the location of the suspected explosion. The improved location moved away from the island test site, out into the ocean. More importantly, data from the USGS station at Kevo, Finland, were used to show that the seismic waves recorded from the event in question were similar to those generated by earthquakes and different from those previously recorded at Kevo from explosions on the Russian test site. Additionally, GSN data are used extensively in major research programs conducted by the Department of Defense and the Department of Energy to improve CTBT monitoring.



USGS scientist training personnel from the University of Nairobi, Kenya, in the operation of Global Seismograph Network instruments.

determine the locations, depths, magnitudes, and other measurements of earthquakes worldwide. A unique feature of the GSN data is that they can be used to estimate, within an hour, the geometric orientation and overall length of the fault that

Breeding Bird Survey Flies on Internet

IN THE 1960'S, WHEN RACHEL CARSON'S book, *Silent Spring*, focused public attention on widespread bird deaths caused by DDT and other pesticides, the full extent of declining bird populations was unknown. Today, after 30 years of managing the North American Breeding Bird Survey (BBS), scientists know a great deal more about North American bird populations and are



Declining populations of wood thrush and other neotropical migrants have led scientists to examine issues such as forest fragmentation and predation.

making the information available to a global audience through the Internet.

Wildlife biologists at the USGS Patuxent Wildlife Research Center designed the bird population monitoring program in 1966 and began documenting population trends. Jointly coordinated by the USGS and Canadian Wildlife Service, the BBS now covers over 3,000 routes scattered across the continental United States and Canada that are surveyed annually by more than 2,400 skilled birders.

The BBS gives valuable information on the distribution and trends of more than 400 bird species breeding across the continent and serves as an early warning system. It is used by government agencies and private organizations to document bird populations in peril. For example, the BBS has shown marked declines of wood thrushes and other neotropical migrant birds in the Northeastern United States, leading natural resource managers to examine issues such as forest fragmentation and predation that may be contributing to these declines. More recently, when the BBS indicated significant declines in grassland birds, such as eastern meadowlarks and grasshopper sparrows, resource managers began looking at potential causes, like poor range management and habitat loss across the United States.



Declining grassland birds like grasshopper sparrows (above) and eastern meadowlarks are causing resource managers to examine range management and habitat loss.

Re-Tooled USGS Bird Banding Lab To Revolutionize Information Use

Each year, before hunting season, thousands of waterfowl are banded on breeding grounds across the country. The metal bands, provided by the USGS Bird Banding Laboratory (BBL), have unique identifying numbers and are attached to the birds' legs. Later, when a banded bird is observed or recaptured, the band number, date, and location are reported to the BBL. The information is recorded in a computer file that over time becomes a record of that bird's life history.

USGS provides this information to the U.S. Fish and Wildlife Service, which analyzes the banding reports, estimating population size and survival probabilities, factors used in managing waterfowl-hunting programs. Bird-banding also is a critical tool for scientific studies that require tracking of individual birds over time.

USGS has begun re-engineering its Bird Banding Laboratory, taking advantage of new technology to streamline and speed customer service, with special attention going to the information needs of the U.S. Fish and Wildlife Service. The BBL contains records of 58 million bandings and 3.1 million recoveries of banded birds (updated with 1.2 million and 75,000 recoveries annually) representing about 900 bird species and subspecies.

An important change underway is a complete reconfiguration of the BBL's computer network. Development of extensive Internet capabilities and streamlining of the band-reporting process will revolutionize operations and increase responsiveness. The use of a toll-free telephone number for reporting bird bands already has had a tremendous impact with a much higher percentage being reported.

The BBS is a leading example of how results of USGS biological science can be disseminated electronically to reach a wide audience of existing and potential users. Researchers have developed a homepage (<http://www.mbr-pwrc.usgs.gov/bbs/bbs.html>) that is part of the National Biological Information Infrastructure (NBII). A broad collaborative effort led by the USGS, the NBII (<http://www.nbii.gov>) uses the Internet as a connection to significant biological data and

information from government agencies, universities, museums, and other sources.

It is now much easier for traditional users of the Breeding Bird Survey data and analyses to retrieve what they need. And, the information is also available for potential users who may not have been previously aware of the BBS. Thus, environmental scientists, resource managers, educators, students, and the general public are now able to use the Internet to easily access and use the findings of the BBS for a wide variety of new applications.

World Wide Web Expedites Access to USGS Mapping Data

EXCEPT FOR PRINTED TOPOGRAPHIC maps, USGS geospatial (mapping) data have not been readily accessible to the general public in the past. Because of their size and complexity, these data traditionally were stored on and distributed on bulky tapes from hard-to-use mainframe computer systems. Customers were mainly limited to government and commercial organizations able to afford and operate the expensive geographic information system software needed to create maps from the data. All of that has changed.

The growing availability of powerful desktop computers, simple browsing software, and inexpensive links to the Internet World Wide Web has provided the perfect vehicle for USGS to share easily and at the lowest cost possible its vast collections of digital mapping data, aerial photography, and satellite-derived imagery.



Aerial photographs like this one of Boston Harbor (Logan Airport) are accessible through USGS websites.

TerraServer: Seeing Your Neighborhood from the Sky

Ever wonder what an aerial view of your neighborhood might look like?

Now, with a few mouse clicks scientists, planners, consumers, and school children can see USGS aerial images with resolutions as close as 3 feet—enough to distinguish buildings and cars, but not people—over the Internet using the new Microsoft TerraServer (<http://www.terraserver.microsoft.com>).

In 1997 USGS and the Microsoft Corporation entered into a cooperative research and development agreement to make vast amounts of geospatial data available to the general public through the Internet. Under the 36-month joint effort, Microsoft agreed to modify a massive volume of USGS geospatial data so that images can

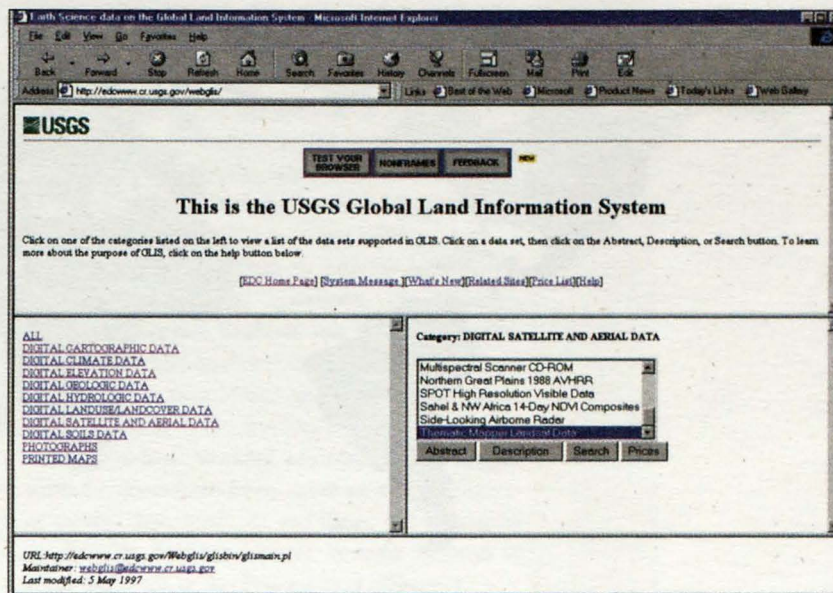
be quickly and easily displayed with unprecedented clarity over the Internet.

The Microsoft TerraServer website opened to the public in June 1998 serving more than one terabyte (1,000,000,000,000 bytes) of geospatial data from a user-friendly interface. The TerraServer enables users to view and download digital orthophoto quadrangle images—digital images of aerial photography that combine the image characteristics of a photograph with the geometric qualities of a map.

Initial response to the TerraServer has been spectacular. Early statistics show the average number of hits at 12 million per day with a peak of almost 29 million hits on July 1.

The primary USGS Web gateway to these invaluable national assets is the National Mapping Information Server [<http://mapping.usgs.gov/>]. Customers wishing to locate and obtain specific products can follow links from the Mapping Information homepage to a variety of general and technical information resources, including product descriptions, graphics depicting availability, examples, price, and ordering instructions. Professional customers are encouraged to enter the USGS National Mapping and Remotely Sensed Data Clearinghouse [<http://mapping.usgs.gov/nsdi/>] node of the Federal National Spatial Data Infrastructure [<http://nsdi.usgs.gov/nsdi/>], which provides technical product descriptions and collection-level metadata (data about data), as well as links to other Federal, State, and local geospatial data resources. In addition to the highly technical information available, the general public can obtain product information of a less technical nature through links to online fact sheets.

To obtain specific products, customers are directed to the Global Land Information System (GLIS) [<http://edcwww.cr.usgs.gov/webglis/>]. Using GLIS, customers can graphically query inventory holdings to determine data availability, view extensive online metadata and data set documentation to determine suitability, examine online digital browse images, and place online requests for products.



GLIS entry screen is useful for finding scientific products [<http://edcwww.cr.usgs.gov/webglis/>].

Many types of digital mapping data, especially digital images from aerial or satellite photographs, are too large to deliver over the Internet efficiently, and are usually distributed on CD-ROM or tape. Selected digital data sets are available for downloading at no cost from the U.S. GeoData online repository [<http://edcwww.cr.usgs.gov/doc/edchome/ndcdb/ndcdb.html>].

USGS, Partners Map Land Cover, Global Elevations

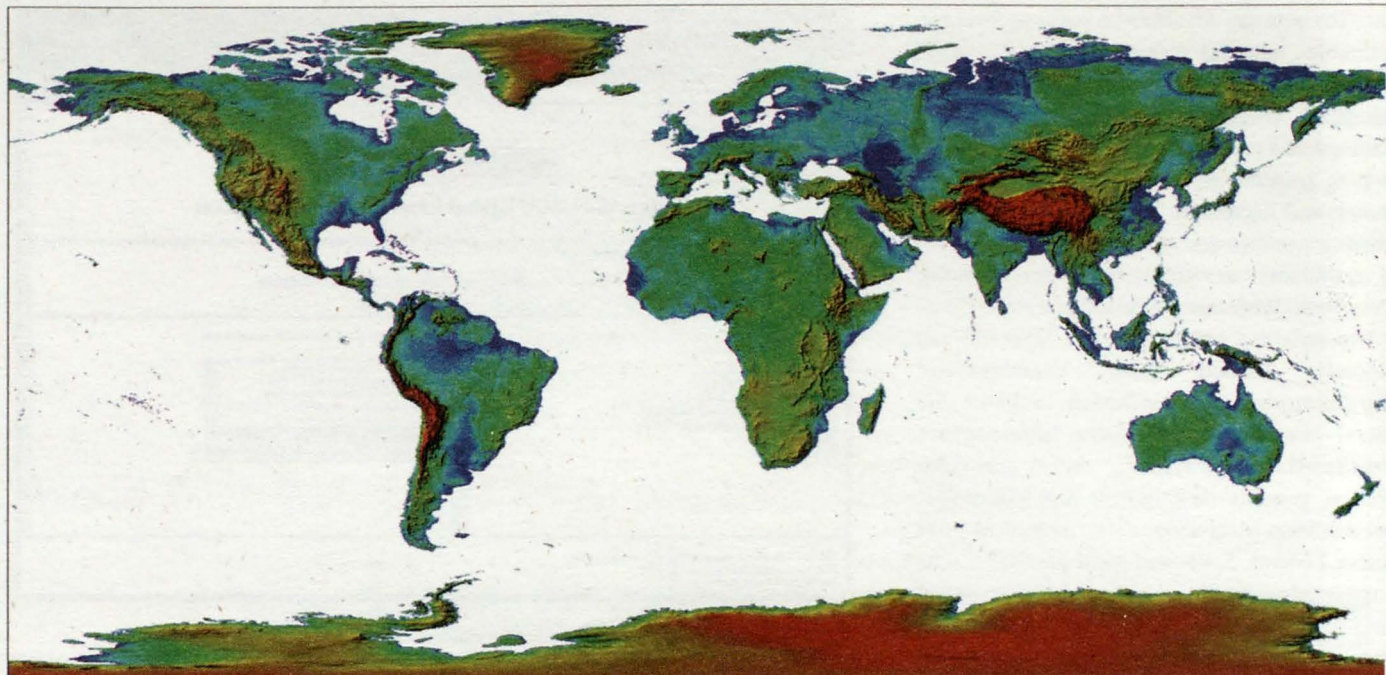
TWO NEW INFORMATION PRODUCTS developed by the USGS and its partners—the National Land Cover Dataset and the GTOPO30 digital elevation model—will make new levels of detailed spatial information available to the public.

At a resolution of 98 feet, the National Land Cover Dataset provides the most detailed data ever collected for a national land cover program. Employing satellite imagery and a variety of supporting data such as topography, census, agricultural statistics, and wetland maps, scientists determine and label the land cover type for each 98-foot pixel in Landsat Thematic Mapper images. The information has many uses, including managing land and watersheds, modeling transportation, and assessing fire risks.

In 1997, scientists at the USGS Earth Resources Observation Systems (EROS) Data Center in Sioux Falls, South Dakota, completed a

detailed land cover data set for the Middle Atlantic States as part of a 4-year effort to map the conterminous United States. The National Land Cover Dataset, a cooperative project of the Multi-Resolution Landscape Consortium (MRLC), is funded by the U.S. Environmental Protection Agency and USGS.

A new digital elevation model, GTOPO30, provides the first global coverage of moderate-resolution elevation data. The dataset was developed over 3 years through a collaborative effort led by USGS, and completed in 1996 at the EROS Data Center. This collaboration included the National Aeronautics and Space Administration (NASA), the United Nations Environment Programme Global Resource Information Database (UNEP/GRID), the U.S. Agency for International Development (USAID), the Instituto Nacional de Estadística Geografía e Informática (INEGI) of Mexico, the Geographical Survey Institute (GSI)



A new digital elevation model, GTOPO30 provides the first global coverage of moderate-resolution elevation data.

of Japan, Manaaki Whenua Landcare Research of New Zealand, and the Scientific Committee on Antarctic Research (SCAR). GTOPO30 was developed to meet data users' needs for regional- and continental-scale topographic data. A truly global data set, GTOPO30 covers from 90°S to 90°N and 180°W to 180°E.

A continental-scale digital elevation model such as GTOPO30 is required for climate and global change studies spanning several disciplines: atmospheric science, hydrology, biogeochemistry, wildlife biology, forestry, range science, and others. These data are suitable for many regional and continental uses, such as climate

modeling, continental-scale land cover mapping, and geometric and atmospheric correction of certain satellite image data. GTOPO30 provides a new level of detail in global topographic data.

FOR MORE INFORMATION

All GTOPO30 data are available free to the user and can be obtained from the Internet at

<http://edcwww.cr.usgs.gov/landdaac/gtopo30/gtopo30.html>

Montana Geoenvironmental Explorer: Communicating Science to Decision Makers

FEDERAL LAND MANAGERS FACED with increasingly complex decisions on management of land use, resource development, environmental problems, and ecosystem health are requesting more scientific information and analyses from the USGS as a basis for their decisions. The USGS is faced with an equally complex task of collecting, analyzing, synthesizing, and disseminating a wealth of data to answer specific questions posed by land managers and

to provide analytical capabilities in support of decision making.

The Montana Geoenvironmental Explorer offers a powerful data management tool for both CD-ROM and Internet application as a first step toward an integrated decision-support system that answers the needs of both Federal land managers and USGS scientists.

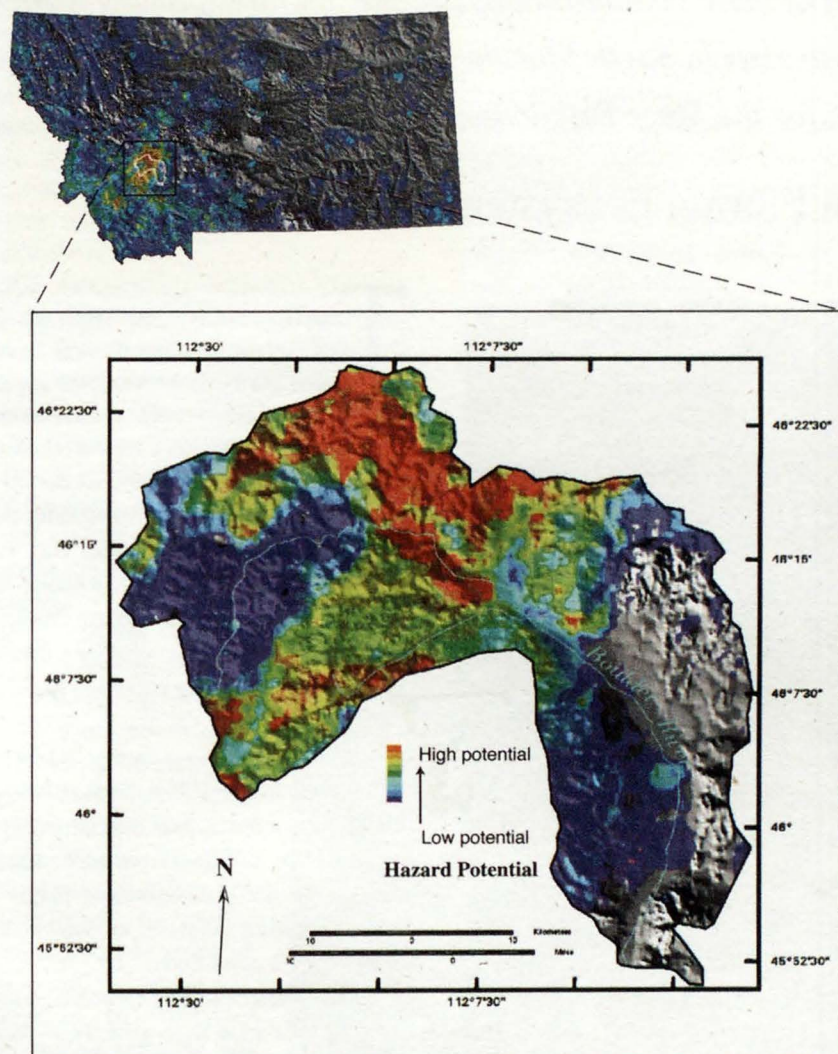
Developed jointly by the Mineral Resources Program (MRP) and the Environmental

Systems Research Institute (ESRI), the Explorer is a prototype for data management and display that provides platforms for analytical applications and modules that will allow users to download both data and science applications from either a CD-ROM or the Internet.

ESRI designed the Explorer to incorporate data from the Montana geoenvironmental map, which depicts the potential for acid generation within watersheds, and the Boulder Basin study, one of two pilot projects in the USGS Abandoned Mine Lands Initiative. The Explorer incorporates these data layers, models of the data, statistics, photographs, and other information in an easily accessible format on a CD-ROM or the Internet to allow Federal land managers and other MRP partners to display, download, and query data and analyses necessary for resolving environmental questions on abandoned mine lands and watershed health.

The scientific data and geochemical, geophysical, and geologic models embedded in the Explorer can be used to resolve environmental questions related to the habitats of indicator fish species that are sensitive to the presence of metal loadings in streams, the identification and cleanup of metal loadings, and the location of geologically suitable deposit sites for mine tailings.

Although designed to provide information on geoenvironmental questions, the Montana Geoenvironmental Explorer can be used in other applications and analyses such as resource assessments, mine permitting, and road construction. Intranet access to the Boulder Basin data will provide a real-time working environment for Project team members from many agencies to work together sharing data, analyses, and ideas, and partnering to develop decision-support systems tailored to meet the needs of the Federal land managers.



The Montana geoenvironmental map, which depicts the potential for acid generation within watersheds, is one layer of information on the Montana Geoenvironmental Explorer. The Explorer incorporates several layers of data for CD-ROM and Internet applications that allow natural resource managers to resolve environmental questions on abandoned mine lands and watershed health.

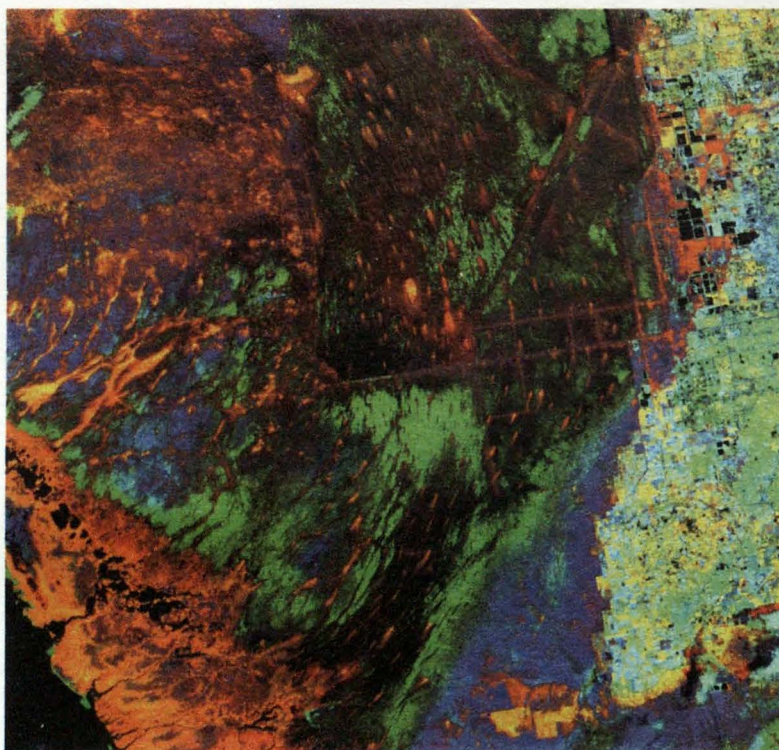
Making A Difference by Working with Others



No one person, no one agency can do it all—can provide all the answers to the many scientific issues we face as we stand on the brink of a new century and millennium, as we try to understand our own world and other worlds. USGS has

marshalled its scientists from many different disciplines to work together and has fostered partnerships with other government agencies to better serve the American people. Two of the best examples of these collaborations are the interdisciplinary work of USGS scientists in South Florida and USGS work with NASA scientists for the Mars Pathfinder.

Integration of Science in Florida Ecosystem Study



This remote sensing image displays the boundary areas between urban and agricultural lands as well as the natural landcover of the Everglades. The open water of the Gulf of Mexico is visible in the bottom left corner of the image. Such images present a timely, objective record of ecosystem conditions and have many productive applications in earth, biological, and social sciences.

THE FRAGILE AND HUMAN-ALTERED ecosystem of South Florida, including the Everglades, is a place where all the capabilities of the USGS are being brought to bear on one important issue—the area's environmental restoration.

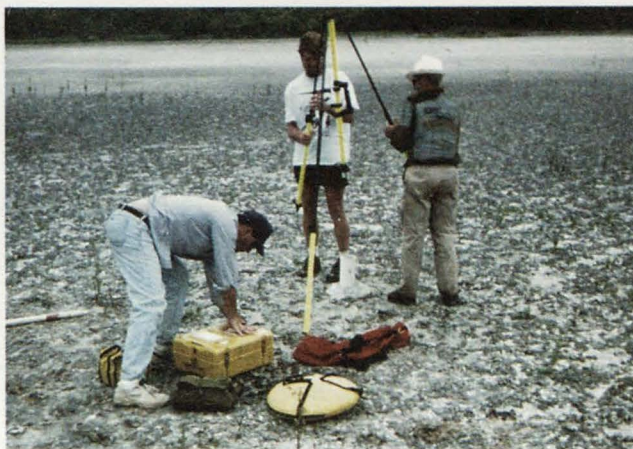
USGS geologists have collected cores of sediments to be used in establishing the natural ecosystem history of the area. This knowledge enables scientists to distinguish human influences on the environment from natural change.

USGS mappers are making detailed topographic maps showing elevation details to about two inches.

Such precision is crucial to USGS hydrologists who are modeling the almost imperceptible flow of water across the flat terrain.

USGS biologists are also mapping and monitoring the distribution of plants and animals, including invasive species, as indicators of ecosystem conditions.

The geographically based integration of scientific information from geology, hydrology, and biology is a characteristic USGS strength. The fusion of knowledge from many fields of natural and earth sciences is critical for evaluating the success of efforts to restore the South Florida ecosystem.



Multidisciplinary teams of scientists work together in the Everglades and other areas of South Florida to bring all the capabilities of USGS to help restore the area's environment.

Participating in Mars Pathfinder Mission

THE USGS HAS BEEN A PARTNER WITH the National Aeronautics and Space Administration (NASA) in space exploration for more than 30 years. Scientists in the USGS Flagstaff, Arizona, Field Center are involved in an extensive cooperative program for NASA's Mars Pathfinder Mission.

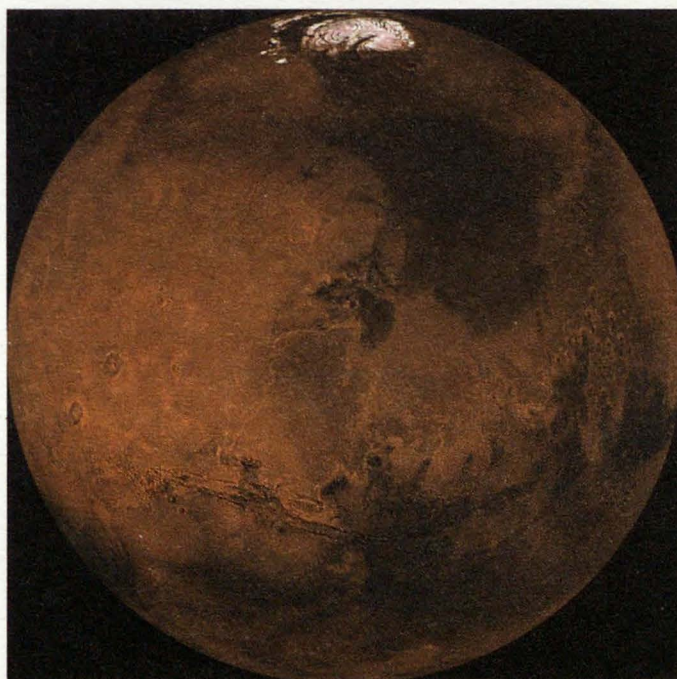
USGS Astrogeology Team scientists participate in the mission in two ways. They provide all cartographic products to be used by Pathfinder and other scientists around the world in their individual investigations. They also produce a variety of specially processed individual images, as well as panoramic and map-view renditions of the landing site that will be used by the global community to characterize the landing site.

Survey scientists also carry out their own topical scientific research. Their major goals are to describe the processes that are actively modifying the surface of Mars and to understand the geologic history of the Pathfinder landing site. In pursuing these goals, the team identifies and quantifies evidence for erosive and chemical processes acting on the rocks and soils of the planet.

Examples of individual processes include abrading and grooving of rock surfaces and dust sedimentation and dune formation controlled by strong winds. From studying the patterns

formed on surfaces of different ages and formed over different lengths of time, the team will be able to develop models of the nature and rates of surface modification over time scales ranging from a single season to millions of years.

As USGS continues to gain new knowledge about the history of Mars, this information will provide increasingly valuable insights into the workings of the solar system as a whole. Such knowledge is essential if our Nation is to understand fully the story of how our own world developed.



Mars, the latest frontier.

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