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Land Data Assimilation Systems

BY PAUL HOUSER

Accurate assessment of the spatial and temporal variation of surface hydrology is essential for addressing a wide variety of highly socially-relevant science, education, application, and management issues. Rainfall-runoff prediction, meteorologic processes studies, climate system and ecosystem modeling, and soil system science all greatly benefit from improved knowledge of land surface conditions. Improved land surface water and energy storage estimates also find direct application in agriculture, forest ecology, civil engineering, water resources management, and crop system modeling. As people increasingly modify the land surface, concern grows about the ensuing consequences for weather, climate, water supplies, crop production, biochemical cycles, and ecological balances of the biosphere at various time scales (Wetzel and Woodward, 1987).

Accurate initialization of land surface moisture and energy stores in weather and climate system models is critical for extended atmospheric and hydrologic prediction because of their regulation of surface water and energy fluxes between the surface and atmosphere over a variety of time scales (Shukla and Mintz, 1982). Soil moisture, temperature, and snow exhibit persistence on seasonal-to-interannual time scales; together with external forcing and internal land surface dynamics, this persistence has important implications for the extended prediction of climatic and hydrologic extremes (Koster and Suarez, 1995). Because soil moisture, temperature, and snow are integrated states, errors in land surface forcing and parameterization accumulate in these stores, which leads to incorrect surface water and energy partitioning.

However, new high-resolution land surface observations are becoming available that will provide the additional information necessary to constrain land surface predictions at mul-

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NEW REPORT

Inland Navigation System Planning: The Upper Mississippi River-Illinois Waterway

BY JEFFREY JACOBS

The Upper Mississippi River-Illinois Waterway (UMR-IWW) system is an important component of the nation's inland navigation systems. The 29 locks and dams on the Upper Mississippi River were constructed and are operated by the U.S. Army Corps of Engineers. In addition to commercial navigation, sport fishing, recreational boating, and tourism are popular activities on the Upper Mississippi River and generate billions of dollars per year for the regional economy.

Waterway traffic congestion presents a problem to towboat operators. Although congestion on the waterway's locks is spotty, towboat operators occasionally must wait several hours before passing through some locks, especially those on the lower portion of the Upper Mississippi.

In the late 1980s, the Corps began a feasibility study to gauge the economic viability of extending several locks on the UMR-IWW. Most of the waterway's locks, constructed in the 1930s and 1940s, are 600 feet long. But tows on the waterway today are frequently 1,200 feet long, which requires that they be split in order for them to pass through the locks. The additional time required for these multiple lockages increases shipping costs. The U.S. com-

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tiple scales. These constraints can be imposed in two ways (Figure 1). Firstly, by forcing the land surface primarily by observations (such as precipitation and radiation), the often severe atmospheric numerical weather prediction land surface forcing biases can be avoided. Secondly, by employing innovative land surface data assimilation techniques, observations of land surface storages such as soil temperature and moisture can be used to constrain unrealistic simulated storages. These land data assimilation systems also have the ability to maximize the utility of limited land surface observations by propagating their information throughout the land system to unmeasured times and locations. Data assimilation is a scientific tool that can not only lead to better predictions, but also helps to diagnose model weaknesses and suggests where better parameterization is needed. The fusion of modeling and observations via data assimilation requires access to large volumes of surface atmospheric and hydrologic variables, usually in near-real time.

Significant progress has been made in land-surface observation and modeling at a wide range of scales. Projects such as the International Satellite Land Surface Climatology Project (ISLSCP), the Global Soil Wetness Project (GSWP), and the GEWEX Continental-Scale International Project (GCIP), among others have paved the way for the development of operational Land Data Assimilation Systems (LDAS). The development of LDAS serves as an integrating linkage between a variety of Earth science disciplines and geographical locations. But most importantly, LDAS integrates state-of-the-art modeling and observation on a operational basis to provide consistent high quality land states in a timely enough manner to be used in real-time applications.

Remote Sensing of the Land Surface: The observational emphasis of LDAS is to assimilate spatially-distributed observations (i.e., remotely sensed observations) of the land surface that will provide memory to land-atmosphere interaction. Remote observations of interest include temperature, soil moisture (surface moisture content, surface saturation, total water storage), other surface water bodies (lakes, wetlands, large rivers) and snow (areal extent, snow water equivalent).

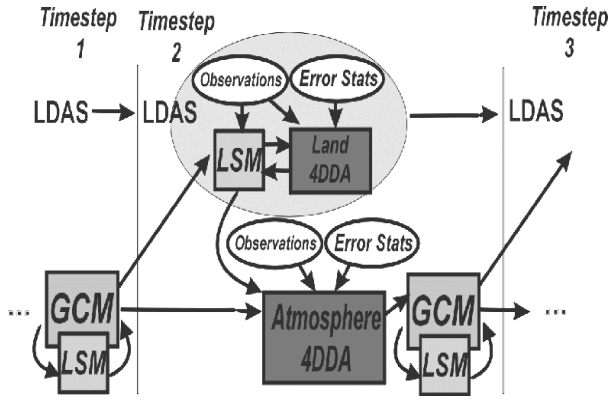

Figure 1: Interaction of the *Land Data Assimilation Scheme* (LDAS) with an operational *Numerical Weather Prediction* (NWP) system. The atmospheric *General Circulation Model* (GCM) is coupled with the *Land Surface Model* (LSM), and both use a *4-Dimensional Data Assimilation* (4DDA) process to integrate past forecasts with observations to improve performance.

Remote sensing of surface temperature is a relatively mature technology. The land surface emits thermal infrared radiation at an intensity directly related to its emissivity and temperature. The absorption of this radiation by atmospheric constituents is smallest in the 3 to 5 and 8 to 14 μm wavelength ranges, making them the best windows for sensing land surface temperature. Some errors due to atmospheric absorption and improperly specified surface emissivity are possible, and the presence of clouds can obscure the signal. Generally, surface temperature remote sensing can be considered an operational technology, with many spaceborne sensors making regular observations (i.e., Landsat TM, AVHRR, MODIS, and ASTER) (Lillesand and Kiefer, 1994). The evolution of land surface temperature is linked to all other land surface processes through physical relationships, which makes its assimilation possible.

Remote-sensing of soil moisture content is a developing technology, although the theory and methods are well established (Eley, 1992). Long-wave passive microwave remote-sensing is ideal for soil moisture observation, but there are technical challenges in correcting for the effects of vegetation and roughness. Soil moisture remote sensing has previously been limited to aircraft campaigns (e.g. Jackson, 1997a), or analysis of the Defense Meteorological Satellite Program (DMSP) Special Sensor Microwave Imager (SSM/I) (Jackson, 1997b). SSM/I has also been successfully employed to monitor surface saturation/inundation (Basist and Grody, 1997). The EOS-Advanced Microwave Sounding Unit (AMSR) instrument will provide additional C-band microwave observations that may be useful for soil moisture determination . The Tropical Rainfall Measuring Mission (TRMM) Microwave Imager (TMI), which is very similar to AMSR, is much better suited to soil moisture measurement (because of its 10 Mhz channels) than SSM/I, and is also currently available. All of these sensors have adequate spatial resolution for land surface applications, but have a very limited quantitative measurement capacity, especially over dense vegetation. However, Sipple *et al.* (1994) demonstrated that it is possible to determine saturated areas through dense vegetation using SMMR, which can greatly aid land surface predictions. Because of the large error in remotely-sensed microwave observations of soil moisture, there is a real need to maximize its information by us-

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mercial navigation industry maintains that several UMR-IWW locks must be extended from 600 feet to 1,200 feet in order to reduce congestion, reduce shipping costs, and to help midwestern U.S. grain (corn and soybeans) producers stay competitive in a global grain market.

In early 2000, the Department of Defense (DOD) requested that the National Academies appoint a committee to review the Corps' final feasibility study. A joint committee of the Water Science and Technology Board (WSTB) and the Transportation Research Board (TRB) was appointed, held three meetings in 2000, and issued its report in early 2001. Due to political and analytical complications, the Corps was unable to complete its feasibility study during the committee's work; the committee's report is, thus, based on a draft of the feasibility study. The committee was requested to review the draft feasibility study and provide recommendations for its improvement. The committee focused its review on the draft's economic assumptions, methods, and forecasts, but also provided advice on larger water resources planning issues as the committee saw appropriate. The report's conclusions and recommendations are in four areas: economics, integrated systems planning, environment, and engineering.

Economics. The Corps developed a theoretical spatial equilibrium model for the UMR-IWW feasibility study to help forecast future levels of barge traffic across the entire waterway system. This system model represents a major advance over previous economics models used by the Corps to forecast barge traffic. The report recommends that this spatial equilibrium model be used as a foundation for the feasibility study.

The Corps also developed the ESSENCE model, which calculates equilibrium values for barge traffic and waterway congestion; and changes in barge shipping costs that are consistent with waterway traffic forecasts and with past delay patterns at locks. The ESSENCE model does not, however, adequately use the most important concepts of the spatial equilibrium model that was advocated in the draft feasibility study.

Despite advances represented in the spatial equilibrium model and the ESSENCE model, many of the assumptions and data used as input to these models are flawed. The committee found that forecasts of future global grain demand did not adequately account for global or domestic supply and demand factors. In some instances, simple linear extrapolations were used in constructing demand forecasts, a practice unlikely to produce satisfactory results. The committee also found that assumptions regarding the sensitivity and variability of barge shipping rates were not empirically sound.

As a result of flawed assumptions and data, the report concluded that the current (September 2000) results of the spatial equilibrium model and ESSENCE model should not be used in the feasibility study. The key problem in this modeling effort was not in the theoretical motivation behind these models, but rather in their implementation and data used as input.

The locks and dams on the UMR-IWW system are presently not being used efficiently. Shippers and tow operators needlessly bear high costs because there is no traffic management system for the waterway. Rather than waiting for a decade for relief from the congestion by extending the locks, shippers and towboat operators could enjoy immediate improvements through better traffic management.

Only a narrow range of alternatives for addressing waterway congestion on the UMR-IWW system was assessed in the feasibility study. Several relatively inexpensive, nonstructural options exist for reducing traffic congestion on the waterway, including better scheduling, tradable lockage permits, and congestion fees. It is not clear how the benefits of lock extensions can be adequately evaluated without first managing waterway traffic more efficiently on the existing system.

The report recommends that the benefits and costs of lock extensions not be calculated until nonstructural measures for waterway traffic management have first been carefully assessed. The report recommends that a comprehensive review and assessment of the

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benefits and costs of nonstructural options for improving traffic management be conducted. It is also recommended that Congress instruct the Corps to fully explore nonstructural options for improving traffic management.

Integrated Systems Planning. The report concluded that the draft feasibility study lacked a comprehensive assessment of how changes in navigation might affect economic, environmental, and social systems. For example, the study did not describe the relations between the river's environmental resources and the substantial economies (tourism and recreation) that depend on those resources.

A thorough analysis that supports informed decisions must address environmental impacts with the same comprehensiveness that is expected for the evaluation of the National Economic Development alternative. The report recommends that the Corps aim toward a more comprehensive and integrated assessment of the navigation system's effects on the environment in the UMR-IWW.

The Corps conducted many environmental investigations as part of the draft study. However, it was not clear how the environmental studies affect the decision regarding lock extensions on the waterway. The report thus recommends that the Corps clarify the nature of the relations between environmental studies and the decisionmaking process regarding proposed lock extensions.

Environment. The report found that despite numerous environmental assessments conducted as part of the feasibility study, characterization of the current environmental system is insufficient, as it is in the early stages of scientific validation. The combination of construction (dams, wing dams, and other river training structures) and operations and maintenance continue to affect the river's environmental systems. Gaps in scientific understanding make it nearly impossible to accurately understand how additional changes will affect the river. Environmental studies on systemwide, cumulative effects, and site-specific effects are needed. The report thus recommends that systemwide research be conducted on the following topics in the UMR-IWW: (1) cumulative effects of the navigation system on river ecology, (2) environmental effects of recent navigation system improvements, (3) cumulative effects of increased towboat passage, and (4) site-specific effects of future construction activities on the UMR-IWW.

The report recommends that research within the federal Environmental Management Program be enhanced to improve assessment of the navigation system's cumulative effects on the environment, and broadened to include studies of the impacts of barge traffic on river ecology. It was also recommended that the Corps seek the authority and necessary funding from Congress to conduct the feasibility study based on the principles of adaptive management that have been articulated in the natural resources management literature.

Engineering. If the UMR-IWW locks are extended, the costs of rehabilitating the existing, aging locks, would be greatly reduced. The Corps estimates that the savings through these reduced rehabilitation costs would be considerable. The committee reviewed the basis for these savings and their magnitude, and found that the Corps' modeling to be sensible and therefore recommends no changes.

During the feasibility study, the Corps revised the contingency estimates for the costs of extending the locks. The Corps proposes a novel method for lock extension. Although the Corps has not used the method, it has been used extensively. As the Corps gains experience with this method in modifying the first few locks, they should be able to estimate future costs more accurately and to find means to lower costs. However, many factors have escalated lock and dam costs in the past and it seems prudent to expect that construction costs might increase significantly due to a variety of factors. The report thus concludes that a 25% cost contingency is likely to be too low, particularly since recent experience with Lock 26 suggests that major escalation of costs can occur.

Jeffrey W. Jacobs is a Senior Staff Officer with the Water Science and Technology Board.

NEW REPORT

Aquifer Storage and Recovery in the Comprehensive Everglades Restoration Plan: *A Critique of the Pilot Projects and Related Plans for ASR in the Lake Okeechobee and Western Hillsboro Areas*

BY WILLIAM LOGAN

Aquifer storage and recovery (ASR) is a major water storage component in the Comprehensive Everglades Restoration Plan (CERP), developed jointly by the U.S. Army Corps of Engineers (USACE) and the South Florida Water Management District (SFWMD). The plan would use the Upper Floridan aquifer (UFA) to store as much as 1.7 billion gallons per day (gpd) (6.3 million m^3/day) of excess surface water and shallow groundwater during wet periods for recovery during seasonal or longer-term dry periods, using over 300 wells.

ASR has advantages over surface storage: it may limit evaporation losses, keep land in productive use, and permit the recovery of large volumes of water during severe, multi-year droughts. However, there are many uncertainties about the ASR projects. The proposed scale is unprecedented. Little subsurface information has been compiled in areas where ASR wells will be located. Impacts of the combined regional hydraulic head increases on existing aquifer uses are unknown. Also unknown are the suitability of the source waters for recharge without extensive pretreatment, and environmental and/or human health impacts due to water quality changes during subsurface storage. Finally, there are questions about rock fracturing due to high

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NEW REPORT

Investigating Groundwater Systems on Regional and National Scales

BY WILLIAM LOGAN

While groundwater knows no political boundaries, studies of groundwater do. Most regional-scale groundwater studies conducted by the USGS are done under the Federal–State Cooperative Water (Coop) Program. Coop studies, because they must be funded at least 50% by a local partner, only occasionally cross county lines, much less state lines.

The Regional Aquifer-System Analysis (RASA) Program (1978-1995), in which the USGS mapped, modeled, and evaluated 25 of the nation's most important groundwater systems, was a welcome exception. However, since RASA's termination, sustainable groundwater resources management has become even more complex. Groundwater, surface water, and aquatic ecosystems are now seen to be closely interrelated, and management is complicated by overextraction, salt-water intrusion, subsidence, and ecological damage from lowered baseflow in streams.

As an outgrowth of RASA, the USGS created the Ground-Water Resources Program (GWRP); this program, however, represents less than 2% of the total USGS Water Resources Division effort (Figure 1). The NRC was asked by the USGS WRD to assess the need for the GWRP, and options for its future.

The report, authored by the standing Committee on USGS Water Resources Research of the WSTB, recommends that regional groundwater studies follow a complementary approach of (a) assessment and (b) science. Groundwater *assessment* should involve the quantitative evaluation of groundwater quantity and quality, recharge, discharge, and extraction rates, and related topics. Groundwater *science* should focus on critical processes of regional significance, systematically approached. The two approaches are linked; management and policy questions that drive regional assessments identify needs for fundamental process-oriented groundwater science, and the results of this science, in turn, support improved regional-scale management and policy-making.

The committee's report suggests that groundwater "regions" be defined flexibly. These would include, of course, geographically contiguous areas such as the High Plains aquifer region (an original RASA study area). However, "regions" should also include discontinuous but widespread aquifer types characterized by a common set of processes, such as karstic aquifers in temperate climates. The USGS can build on the earlier RASA work and ongoing process studies by extrapolating the understanding of processes at key sites to larger regions.

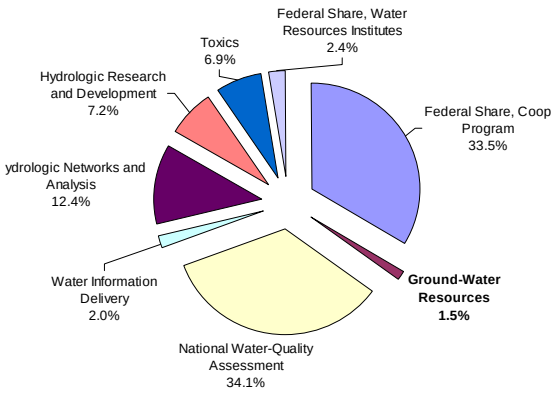

Figure 1: GWRP budget as a percentage of total USGS water resources programs for FY 1999. Data source: USGS.

The report especially recommends work in seven general research areas. These are (1) aquifer management, making use of optimization techniques, (2) aquifer storage and recovery projects, (3) quantifying rates, distribution, and mechanisms of recharge, (4) surficial aquifers, (5) interaction of groundwater with surface water, (6) characterization of heterogeneous aquifers, and (7) flow and transport in karst and fractured aquifers.

In order to prioritize such studies, the report suggests that the USGS consider implementing a steering process for GWRP project selection similar to that of the Mapping Advisory Council, which aids decisionmaking for the Mapping Division. It should also leverage the resources of the National Water Quality Assessment (NAWQA), Coop, Toxic Substances Hydrology, and National Research Programs of the USGS. Coordination might include the identification of common data collection, QA/QC, sampling, and archiving protocols to maximize each issue-driven study's contribution to the regional and national groundwater information base. The NAWQA program has already dealt with many of these issues, and this experience should be tapped by the GWRP.

Regional projects are complex and multidisciplinary. This argues for collaboration among the Biological Resources, Geologic, and National Mapping Divisions of the USGS, as well as with other federal agencies, state and local governments, universities, and industry. For example, geologic information (geologic maps, facies analyses, and hydrostratigraphic models) may assist in scaling up the results of a local groundwater study into areas where "hard" hydrogeologic data are sparse or nonexistent.

Finally, the report encourages the USGS to continue posting primary and interpretive data on the Internet, perhaps in association with the thematically organized, GIS-based *National Atlas of the United States*.

William Logan is a Staff Officer with the Water Science and Technology Board.

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Land Data Assimilation

ing algorithms (such as data assimilation) that can account for its error and that extend its information in time and space.

There is a potential to monitor variations in total water storage (ground water, soil water, surface waters (lakes, wetlands, rivers), water stored in vegetation, snow and ice) using satellite observations of the time variable gravity field. The Gravity Recovery and Climate Experiment (GRACE), an Earth System Science Pathfinder mission, will provide highly accurate estimates of changes in terrestrial water storage in large watersheds when it is launched this year. Wahr *et al*. (1998) note that GRACE will provide estimates of variations in water storage to within 5 mm on a monthly basis. Rodell and Famiglietti (1998) have demonstrated the potential utility of these data for hydrologic applications, including their application in large (>150,000 km^2) watersheds; and they further discuss the potential power of GRACE for constraining modeled water storage in land surface models when combined with surface soil moisture and altimetery observations. Birkett (1998) demonstrated the potential of satellite radar altimeters to monitor height variations over inland waters, including climatically-sensitive lakes and large rivers and wetlands. Such altimeters are currently operational on the ERS-2 and TOPEX/POSEIDON satellites, and are planned for the ENVISAT and JASON-1 satellites.

Key snow variables of interest to LDAS include areal coverage and snow water equivalent. While the estimation of snow water equivalent by satellite is currently in research mode, snow areal extent can be routinely monitored by many operational platforms, including AVHRR, GOES and SSM/I. Recent algorithm developments even permit the determination of the fraction of snow cover within Landsat-TM pixels (Rosenthal and Dozier, 1996). Cline *et al*. (1998), describe an approach to retrieve SWE from the joint use of remote sensing and energy balance modeling.

Modeling of the Land Surface: Recent advances in understanding soil-water dynamics, plant physiology, micrometeorology, and the hydrology that control biosphere-atmosphere interactions have spurred the development of Land Surface Models (LSMs), whose aim is to represent simply yet realistically the transfer of mass, energy, and momentum between a vegetated surface and the atmosphere (Dickinson *et al*., 1993; Sellers *et al*., 1986). LSM predictions are regular in time and space, but these predictions are influenced by model structure, errors in input variables and model parameters, and inadequate treatment of sub-grid scale spatial variability. Consequently, LSM predictions of land surface hydrology and land surface states will likely be much improved by the assimilation strategies.

There are many different approaches to land surface prediction, which has lead to great diversity in LSMs. Three recent LSMs that are currently used in LDAS are presented here. These are the Mosaic LSM of Koster and Suarez (1992) and Koster *et al*. (1998), the National Centers for Environmental Prediction (NCEP), Oregon State University (OSU), United States Air Force (USAF), and Office of Hydrology (OH) LSM, called NOAH, and the recently emerging Common Land Model (CLM).

The Mosaic LSM addresses the problem of subgrid heterogeneity by subdividing each GCM grid cell into a user-specified mosaic of tiles (after Avissar and Pielke, 1989), each tile having its own vegetation type and hence water and energy balance. Surface flux calculations for each tile are similar to those described by Sellers *et al*. (1986). Tiles do not directly interact with each other, but influence each other indirectly, by their collective influence on the overlying atmosphere. Like the plethora of LSMs that have been developed over the past decade (e.g. the PILPS participants, Henderson-Sellers *et al*. [1993]), Mosaic is well suited to modeling the vertical exchange of mass, energy and momentum with the overlying atmosphere, but includes a poor representation of lateral moisture movement, which significantly controls variations in soil water, surface energy fluxes and runoff. Recognizing this weakness, Koster *et al*. (1998) developed a new, catchment-based LSM that includes a more realistic representation of hydrological processes, including the lateral transport of soil water through the subsurface. The catchment-based model, which relies heavily on the concepts originally put forth by Famiglietti and Wood (1994) (i.e. the TOPLATS model), will represent a major advance in LSMs for the following two reasons. First, the TOPMODEL [Beven and Kirkby, 1979], topographically-based framework will result in improved runoff prediction, and consequently, more realistic catchment-scale water balance. Second, the downslope movement of moisture within the watershed will yield sub-catchment-scale variations of surface and unsaturated-zone moisture content, which will result in more realistic prediction of within-catchment variations in surface fluxes. Improved simulation of runoff will ultimately result in a more realistic flux of continental streamflow from the land to the oceans, and similarly, the within-catchment variations in surface fluxes result in more representative catchment-average exchanges with the atmosphere.

The NOAA-NOAH LSM simulates soil moisture (both liquid and frozen), soil temperature, skin temperature, snowpack water equivalent, snowpack density, canopy water content, and the traditional energy flux and water flux terms of the surface energy balance and surface water balance. This model has been used in a) the NCEP-OH submission to the PILPS-2d tests for the Valdai, Russia site, b) the emerging, realtime, U.S.-domain Land Data Assimilation System (LDAS), c) the coupled NCEP mesoscale Eta model [Chen *et al*, 1997] and the Eta model's companion 4-D Data Assimilation System (EDAS), as well as in d) the coupled NCEP global Medium-Range Forecast model (MRF) and its companion 4-D Global Data Assimilation System (GDAS).

The Common Land Model (CLM) is being developed by a *grassroots* collaboration of scientists who have an interest in making a general land model available for public use. By *grassroots*, we mean that the project is not being

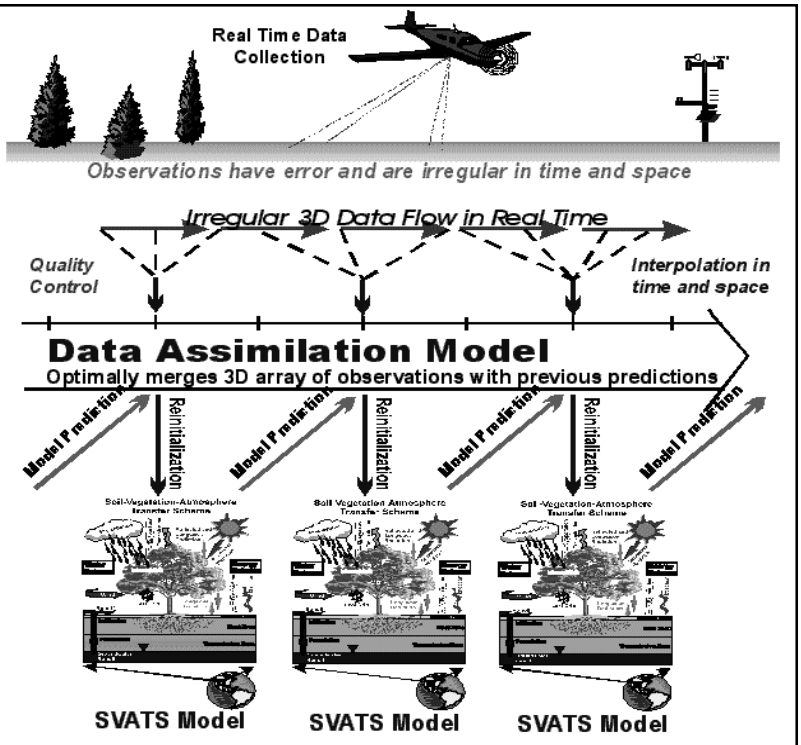

Figure 2: The land-surface data assimilation process.

controlled by any single organization or scientist, but rather, the scientific steering is judged by the community. However, the project began at a subgroup meeting at the 1998 NCAR CSM meeting, and there is a plan to implement the CLM into the NCAR CSM this year. The CLM development philosophy is that only proven and well-tested physical parameterizations and numerical schemes shall be used. The current version of the CLM includes superior components from each of three contributing models: LSM (G. Bonan, NCAR), BATS (R. Dickinson) and IAP (Y.-J. Dai). The CLM code management is similar to *open source*, in that, use of the model implies that any scientific gain will be included in future versions of the model. Also, the land model has been run for a suite of test cases including many of the PILPS (Project for the Intercomparison of Land Parameterization Schemes) case studies. These include FIFE (Kansas, USA), Cabauw (Netherlands), Valdai (Russia), HAPEX (France), and the Amazon (ARME and ABRACOS).

Justification for Using an Uncoupled LSM: There are strong justifications for studying an LSM uncoupled from atmospheric and ocean models. Coupling the LSM to an atmospheric model allows for the study of the interaction and feedbacks between the atmosphere and land surface. However, coupled modeling also imposes strong land surface forcing biases predicted by the atmospheric model on the LSM. These biases in precipitation and radiation can overwhelm the behavior of LSM physics. In fact, several NWP centers must 'correctively nudge' their LSM soil moisture toward climatological values to eliminate its drift. By using an uncoupled LSM, one can better specify land surface forcing using observations, use less computational resources, and address virtually all of the relevant scientific questions. The physical understanding and modeling insights gained from implementing distributed, uncoupled land-surface schemes with observation-based forcing has been vividly demonstrated in recent GEWEX retrospective off-line land surface modeling projects known as PILPS-2c and the Global Soil Wetness Project (Koster and Milly, 1997).

Land Surface Data Assimilation: Charney *et al*. (1969) first suggested combining current and past data in an explicit dynamical model, using the model's prognostic equations to provide time continuity and dynamic coupling amongst the fields. This concept has evolved into a family of techniques known as *four-dimensional data assimilation* (4DDA). "Assimilation is the process of finding the model representation which is most consistent with the observations" (Lorenc, 1995). In essence, data assimilation merges a range of diverse data fields with a model prediction to provide that model with the best estimate of the current state of the natural environment so that it can then make more accurate predictions (See Figure 2). The application of data assimilation in hydrology has been limited to a few one-dimensional, largely theoretical studies (i.e., Entekhabi *et al.*, 1994; Milly, 1986) primarily due to the lack of sufficient spatially-distributed hydrologic observations (McLaughlin, 1995). However, the feasibility of synthesizing distributed fields of soil moisture by the novel application of 4DDA applied in a hydrological model was demonstrated by Houser *et al*. (1998). Six Push Broom Microwave Radiometer (PBMR) images gathered over the USDA-ARS Walnut Gulch Experimental Watershed in southeast Arizona were assimilated into the TOPLATS hydrological model using several alternative assimilation procedures. Modification of traditional assimilation methods was required to use these high density PBMR observations. The images were found to contain horizontal correlations with length scales of several tens of kilometers, thus allowing information to be advected beyond the area of the image. Information on surface soil moisture was also assimilated into the subsurface using knowledge of the surface-subsurface correlation. Newtonian nudging assimilation procedures were found to be preferable to other techniques because they nearly preserve the observed patterns within the sam-

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pled region, but also yield plausible patterns in unmeasured regions, and allow information to be advected in time.

Land Data Assimilation Schemes (LDAS): The characterization of the spatial and temporal variability of water and energy cycles is critical for the improvement of our understanding of land surface-atmosphere interaction and the impact of land surface processes on climate extremes. Because accurate knowledge of these processes and of their variability is important for climate predictions, most NWP centers have incorporated land surface schemes into their models. However, errors in the NWP forcing accumulate in the surface and energy stores, leading to incorrect surface water and energy partitioning and adversely affecting related processes. This has motivated the NWP centers to impose ad hoc corrections to the land surface states to prevent this drift. *Land Data Assimilation Schemes* (LDAS), which are uncoupled land surface schemes that are forced primarily by observations, and are therefore not affected by NWP forcing biases are currently under development. This research is being implemented in near real time using existing LSMs by NCEP, NASA, Princeton University, Rutgers University, the University of Maryland, and the University of Washington at a 1/8th° (about 10 kilometer) resolution across the United States to evaluate these critical science questions. The LDAS are forced with real time output from numerical prediction models, satellite data, and radar precipitation measurements. Model parameters are derived from the high-resolution EROS vegetation coverages.

A real-time LDAS system is currently in place (see http://ldas.gsfc.nasa. gov), that uses near-real time NCEP Eta model analysis fields, along with observed precipitation and radiation fields to force several different land surface models in an uncoupled mode (see Figure 3-5). Forcing, parameter, resolution, and prediction specifications for this North-American LDAS were carefully chosen by the interinstitution LDAS working group.

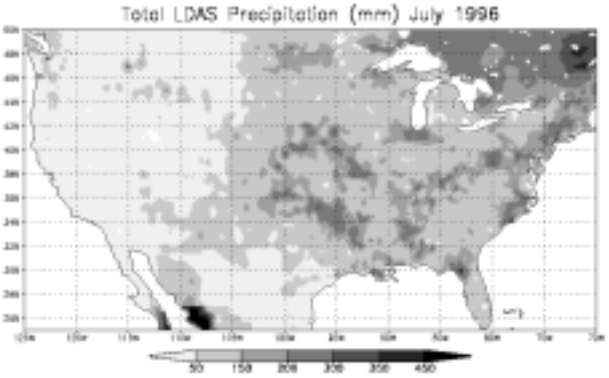

Figure 4: A continental United States 1/8 degree LDAS soil moisture field.

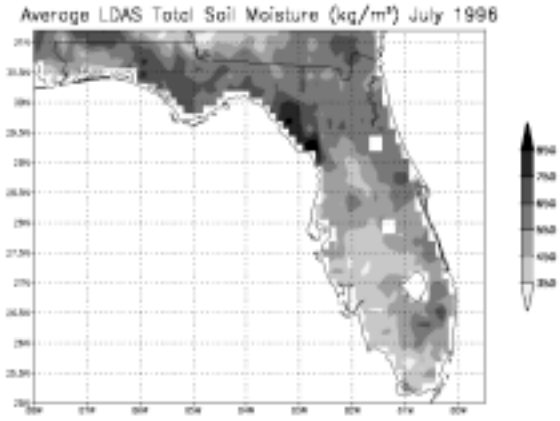

Figure 5: A 1/8 degree LDAS soil moisture field from Florida.

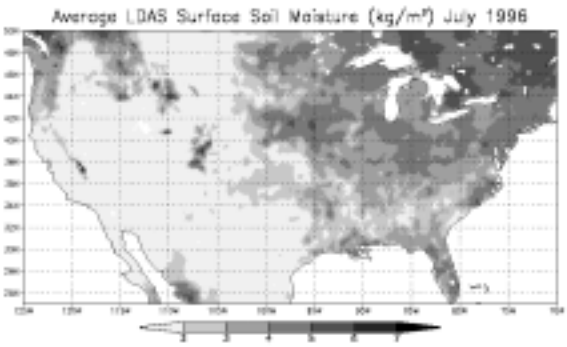

Figure 3: A continental United States 1/8 degree LDAS merged Eta model, NEXRAD Doppler radar, and gage precipitation field.

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CURRENT PROJECTS

Assessing the Scientific Basis of the Total Maximum Daily Load Approach to Water Pollution Reduction

At the request of Congress, the WSTB has initiated a superfast-track study to review of the quality of science used to develop and implement Total Maximum Daily Loads (TMDLs). The TMDL program, part of the Clean Water Act, requires states to (1) identify sources of pollution to "impaired" water bodies, (2) quantify the relative contributions to different pollutant loadings and their origins, and (3) implement management practices would reduce pollutant loadings and thus achieve water quality standards. New rules for the program were written by EPA in 2000, but will not be implemented until October 2001, during which time Congress is seeking input on the program from the WSTB. The study will investigate the scientific basis underlying the development and implementation of Total Maximum Daily Loads (TMDLs) for water pollution reduction, focusing on (1) what information is needed to determine TMDLs for impaired waters, (2) the sufficiency of knowledge about point and nonpoint sources of pollution, (3) the state of monitoring and modeling to assess and predict pollutant loads, and (4) the effectiveness of management approaches in controlling nonpoint source pollution.

In order to meet a June 1, 2001, deadline imposed by Congress, the first phase of the study is being carried out by a committee of seven experts: chairman Kenneth Reckhow, Duke University; Anthony Donigian, AquaTerra; James Karr, University of Washington; Jan Mandrup-Poulsen, Florida DEP; Vladmir Novotny, Marquette University; Richard Smith, USGS; and Christopher Yoder, Ohio EPA. Len Shabman, WSTB's visiting scholar from Virginia Tech, is providing additional expertise. The first of two committee meetings was held January 24–26, 2001 in Washington, DC. Multiple presentations from a wide variety of stakeholder groups addressed the committee during the two-day open session. The second meeting, to be held in closed session, is scheduled for March 8–10, 2001. The first phase of the study is being funded by EPA.

The second phase of the study draws heavily from the WSTB's proposed study of nonpoint source pollution. It will be conducted by an expanded committee of 15 members who will meet approximately six times. Funding for Phase 2 is being solicited from multiple federal agencies in addition to EPA. For further information or to make nominations for the Phase 2 committee, contact Laura Ehlers at 202-334-3422 or *lehlers@nas.edu*.

Agenda for Water Resources Research in the 21st Century

The WSTB has sent its report about water management challenges of the 21st century and the adequacy of the water research arrangements to meet those challenges to external review. The

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Paul R. Houser is the head of the Hydrological Sciences Branch at NASA's Goddard Space Flight Center, Greenbelt, MD.

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prepublication version of the report is due for release sometime this winter. The report outlines key water resource challenges of the next two decades, identifies broad areas that should receive immediate emphasis in water resources research planning, and describes some ways in which the setting of water research agendas, the conduct of water research, and the levels of investment devoted to such research might be improved in the next decade or so. This activity was motivated by board members' concerns that water resources of the United States are likely to be subjected to more intense and broader arrays of pressure in the 21st century than they were in the 20th century. The nation's ability to confront these challenges successfully and manage a critical resource under pressure will depend, in part, upon the availability of new knowledge and new technology. For information, contact Laura Ehlers at 202-334-3422 or *lehlers@nas.edu*.

Review of the Florida Keys Carrying Capacity Study

The joint Ocean Studies Board (OSB)/WSTB committee was formed in December 2000 in response to a request by the U.S. Army Corps of Engineers (Jacksonville District) to review the Florida Keys Carrying Capacity Study (FKCCS) and the accompanying Carrying Capacity Analysis Model (CCAM) that is under development by the State of Florida. More specifically, the committee will evaluate the scientific methods, principals, and data that form the basis for the FKCCS and CCAM. The goal of the FKCCS is to "determine the ability of the Florida Keys ecosystem to withstand all impacts of additional land development activities." The FKCCS examines three study categories: (1) natural resources, including ecosystems, species of concern, and water quality; (2) the social environment, including regional economic impacts, quality of life, community character, and sustainable tourism; and (3) human infrastructure, including hurricane evacuation, water supply and other needed services such as schools, law enforcement, etc. The FKCCS will create an inventory of available data to examine these three study categories. It will also create a planning tool in the form of the CCAM to attempt to determine the level of land development activities that will avoid further adverse impacts to the Florida Keys ecosystem.

The committee attended a 2-day meeting on the FKCCS and the unveiling of the draft CCAM in Key Largo on January 9–10, 2001 and met in closed session on January 11, 2001 to form the basis of an interim ("letter") report that must be completed by early March 2001. The committee will meet again in Florida during the summer of 2001 to deliberate and prepare a final report on the revised FKCCS and CCAM. The committee is chaired by Scott Nixon of the University of Rhode Island. The committee also includes George Dalrymple, Everglades Research Group, Inc., Homestead, FL; Robert Deyle, Florida State University; Wayne Huber, Oregon State University; Mark Peterson, University of Southern Mississippi; Stephen Polasky, University of Minnesota; Norbert Psuty, Rutgers University; Malcolm Rivkin, University of Maryland; and Daniel Sheer, Water Resources Management, Inc., Columbia, MD. For more information, contact Mark Gibson at 202-334-3422 or *mgibson@nas.edu*.

Risks from Toxicants and Pathogens in Biosolid Fertilizers

The Board and Environmental Studies and Toxicology and WSTB has recently formed the Committee on Toxicants and Pathogens in Biosolid Fertilizers to review the risks and risk-assessment methods used by EPA for establishing regulatory standards for chemical pollutants and pathogens in sludge applied to land as fertilizer. The study will consider whether approaches for assessing risks from chemical and pathogenic pollutants should be integrated and, if so, approaches for integration will be recommended. It will also build on the 1996 WSTB report *Use of Reclaimed Water and Sludge in Food Crop Production*. The committee's first meeting has been scheduled for March 7–8 in Washington, DC. The committee is chaired by Thomas Burke of The Johns Hopkins University. The committee includes Robert Cooper, BioVir Laboratories, Inc., Benicia, CA; Lawrence Curtis, Oregon State University; Charles Haas, Drexel University; Carolyn English, Cytec Industries, Inc., Stamford, CT; John Kaneene, Michigan State University; Greg Kester, Wisconsin Department of Natural Resources; Thomas McKone, Lawrence Berkeley National Laboratory, Berkeley, CA; Ian L. Pepper, University of Arizona; Suresh Pillai, Texas A&M University; Frederick Pohland, University of Pittsburgh; Robert S. Reimers, Tulane University; Rosalind Schoof, Gradient Corporation, Mercer Island, WA; Donald Sparks, University of Delaware; and Robert Spear, University of California, Berkeley. For further information, contact Susan Martel at *smartel@nas.edu.*

Restoration of the Greater Everglades

The committee on the Restoration of the Greater Everglades Ecosystem (CROGEE), formed at the request of the Secretary of the Interior, Bruce Babbitt is providing a scientific overview and technical assessment of the many complicated, interrelated activities that are occurring at the federal, state, local, and non-governmental levels. In addition to strategic assessment and guidance, the commiteee provides more focused advice on technical topics of importance to restoration efforts. The committee met on October 19-21, 2000 in Miami, FL and held a workshop on proposed pilot projects to test the feasibility of large-scale Aquifer Storage Recovery (ASR). The report from this workshop, *Aquifer Storage and Recover in the Comprehensive Everglades Restoration Plan: A Critique of the Pilot Projects for ASR in the Lake Okeechobee and Western Hillsboro Areas,* was recently released.

Results are summarized elsewhere in this newsletter. The committee continues to work with senior Everglades scientists on the development of performance measures for restoration. This was the major theme of its recent meeting held in February 1-3, 2001 at Everglades National Park.

Additionally, most of the committee members also attended the Greater Everglades Ecosystem Restoration Conference held December 11-15, 2000 in Naples, FL. The committee's next meeting is tentatively scheduled for April 26-27 in Key Largo, FL.

James Davidson of the University of Florida (retired) chairs the committee. For more information, contact William Logan at 202-334-3422 or *wlogan@nas.edu.*

Drinking Water Contaminants

The joint WSTB/BEST Committee on Drinking Water Contaminants has sent its third and final report, *Classifying Drinking Water Contaminants for Regulatory Consideration*, for review. The prepublication report is due to be released in late February 2001 and an expanded description and summary of it will be provided in the next WSTB newsletter. The committee previously released *Setting Priorities for Drinking Water Contaminants* and *Identifying Future Drinking Water Contaminants* in early and late 1999, respectively. This last report recommends a process to identify and prioritize various types of potential drinking water contaminants (including chemicals and microorganisms) for inclusion on future Drinking Water Contaminant Candidate Lists (CCLs). The report also responds to EPA's Office of Ground Water and Drinking Water (the study sponsors) request that the committee explore the feasibility and provide related recommendations for developing methods to group related waterborne pathogens into categories for regulatory consideration. Deborah Swackhamer of the University of Minnesota chairs the committee. For more information, contact Mark Gibson at 202-334-3422 or *mgibson@nas.edu.*

Bioavailability of Contaminants in Soils and Sediments

The committee on bioavailability of contaminants in soils and sediments will assess broadly the current scientific understanding of processes—both in the environment and in the human body—that affect whether chemical contaminants present in soils and sediments at contaminated sites are bioavailable to humans, animals, and plants. The second meeting of the committee was held on September 14–15, 2000 in Woods Hole, MA. At its meeting, the committee heard from its six regional EPA representatives about their policies on bioavailability. EPA's Mary Reiley described the role of bioavailability in setting sediment quality criteria. Briton Steve McGrath discussed new techniques for measuring metal phytoavailability, and Monty Elder described a risk communication case study in Oklahoma where bioavailability was considered in determining cleanup goals. At the committee's third meeting December 13–14, 2000 in Irvine, CA, the committee heard from USACE scientist Todd Bridges about management of contaminated sediment, and from UC Riverside's Al Page about the role of bioavailability in setting standards for sludge disposal. Larry Goldstein described EPRI's new technique for measuring bioavailability with DNA adducts in tissue, and Hans Stroo of ThermoRetec presented results from a suite of bioavailability tests used at a Manufactured Gas Plant in Santa Barbara. The committee is chaired by Richard G. Luthy of Stanford University. For more information, contact Laura Ehlers at 202-334-3422 or *lehlers@nas.edu.*

Environmental Remediation at Navy Facilities

The second meeting of the Committee on Environmental Reme-diation at Navy Facilities–Phase 2 was October 29–31, 2000, in Jacksonville, FL. This committee is advising the Navy as it proceeds with the cleanup of contaminated soils, sediments, and groundwater at naval bases and other relevant defense facilities. This phase of work will focus on the latter stages of hazardous waste site management. At its meeting, the committee heard from Navy remedial project managers about the use of several innovative technologies for cleaning up contaminated sites, including bioslurping, enhanced bioremediation, and source removal coupled with monitored natural attenuation. It also took a half-day field trip to several hazardous waste sites at Navy installations in the Jacksonville area. The committee will meet five times during its tenure, with the third meeting scheduled for February 28–March 2, 2001 in San Diego. That meeting will focus on Navy efforts to manage contaminated sediments and innovative technologies used at West Coast facilities. The committee chair is Edward J. Bouwer of Johns Hopkins University. For more information, contact Laura Ehlers at 202-334-3422 or *lehlers@nas.edu.*

Missouri River Ecosystem Science

The U.S. Army Corps of Engineers constructed and operates six mainstem dams on the Missouri River. Due partly to drought in the basin in the late 1980s and early 1990s, and due partly to concerns over aquatic habitat degradation, the Corps considered many options for revising its Missouri River dam operations policies. One recommendation (from the Missouri River Basin Association) to the Corps was that a solid scientific knowledge base was essential for improved river management. This WSTB committee has been charged to characterize the historical and current ecological status of the Missouri River and floodplain ecosystem, and review scientific research on the river-floodplain ecosystem. The committee will also identify appropriate institutional arrangements for improving ecosystem monitoring and research, and identify institutional arrangements that can enhance adaptive management of the river-floodplain ecosystem. The committee held its fourth meeting in Pierre, SD on October 13-14, 2000. The committee spoke with Chuck Berry, South Dakota State University (Brookings, SD) and Brigadier General Carl Strock, Commander of the Corps of Engineers' Northwestern Division (Portland, OR). The com-mittee's fifth meeting will be held in Irvine, CA on February 16-17, 2001. Steve Gloss of the University of Wyoming chairs the committee. For more information, contact Jeffrey Jacobs at (202) 334-3422 or *jjacobs@nas.edu.*

Opportunities to Improve the National Water Quality Assessment (NAWQA) Program

The committee recently held its fourth meeting (rescheduled from No-

vember 9–10, 2000) on January 29–30, 2001 in Washington, D.C. At the meeting, the committee reviewed the developing draft report and held open discussions with representatives of USGS/NAWQA to help identify and resolve remaining issues and assign work necessary to complete the report. The USGS National Water Quality Assessment program is a perennial program, launched in the early 1990s, to describe the status of, trends in, and factors affecting the water quality conditions. The WSTB has provided advice to the USGS regarding the establishment and development of this program on three previous occasions. The current study will make recommendations for improvements as the NAWQA Program enters its second 10-year cycle of monitoring. The final committee meeting will be held in May or June of this year at the Beckman Center, Irvine, CA or another suitable west coast location. The committee's report is slated for release in Fall 2001. George Hallberg of the Cadmus Group, Inc. chairs the committee. For more information, contact Mark Gibson at 202-334-3422 or *mgibson@nas.edu*.

Privatization of Water Services in the United States

Water supply and sewerage services were initially privately owned and operated in many U.S. cities. With the growth of large cities and stronger governments, local government entities eventually assumed ownership and operation of most of the nation's water service facilities. But a range of economic, regulatory, and fiscal factors have driven many municipalities to consider the prospects of privatizing parts or all of these services. Many U.S. cities today lease various parts of their water supply and wastewater treatment systems to private operators. But while it holds promise for improving water service deliveries and cutting costs, the long-term consequences of U.S. water service privatization are not clear. This committee is reviewing water service privatization in the U.S. in light of its economic and fiscal, regulatory, public service and public health, environmental, and water quality implications. The committee held its fourth meeting in Woods Hole, MA on October 2-3, 2000. The committee will hold its fifth meeting in Irvine, CA in April, 2001. Charles Howe of the University of Colorado chairs the committee. For more information, contact Jeffrey Jacobs at (202) 334-3422 or *jjacobs@nas.edu*.

Riparian Zones: Functions and Strategies for Management

The joint WSTB/BEST Committee on Riparian Zones held its fourth meeting in Blue River, OR, on September 25–26, 2000. The meeting was preceded by a half-day training session from BLM scientist Wayne Elmore on the Proper Functioning Condition method for assessing riparian areas. Later that day the committee took a field trip to multiple sites in the Mac Creek and MacKenzie watersheds to observe the role of large wood in riparian functioning and to assess stream segments using PFC. During the meeting, the committee heard presentations from the Jim Sedell about the role of the U.S. Forest Service in protecting riparian areas, particularly in the Northwest, and from Fish and Wildlife Service scientists Dennis Peters and Chuck Elliot about their new system for mapping riparian areas in the west. The rest of the meeting was spent in closed session discussing the contents of the committee's report. The committee's charge is to describe the nature and functioning of riparian zones and assess the condition and trends of riparian habitats with respect to water quantity and quality. It will also review criteria for the improved management of riparian lands and for mitigation of impacts on such habitats by identifying conflicting policies or objectives and suggesting methods for resolving them. The final committee meeting, February 22–23, 2001 in Washington, DC will be devoted to refining the report and debating conclusions and recommendations. For further information, contact Laura Ehlers at 202-334-3422 or *lehlers@nas. edu*.

Mitigating Wetland Losses

The joint BEST/WSTB Committee on Mitigating Wetland Losses is currently preparing its report for review. The study evaluates the effectiveness of wetland restoration and mitigation practices in replicating predisturbed wetland functions and ecological attributes. During the final meeting on December 7-9, 2000 in Washington DC, the committee reviewed its draft report, conclusions, and recommendation. Joy Zedler of the University of Wisconsin chairs the committee. The project sponsors are the U.S. EPA, U.S. Army Corps of Engineers, U.S. Fish and Wildlife Service, and the National Marine Fisheries Service. For more information, contact Suzanne Jacobson at sjacobson@nas.edu or David Policansky at *dpolican@nas.edu.*

Studies in Hydrologic Science

The joint WSTB/BASC Committee on Hydrologic Science held two workshops last fall. The first, held on September 21-22, 2000 in Boulder, CO was on the "Predictability and Limits to Prediction in Hydrologic Science." Presentations covered basic research, model formulations and behavior, observing strategies, and transition to operation predictions. A preliminary draft of this report will be completed by mid-February 2001. The second workshop "Towards Integration of Hydrological and Ecological Sciences" was held on October 26-27, 2000 in West Palm Beach, FL. Shared concepts, data and tools, approaches to the problem of scaling, and influence of human activities on environmental processes at all scales were the topics of the workshop. A draft report from this workshop was prepared.

A third workshop on groundwater fluxes across interfaces is being planned for later this year.

The committee will hold its next meeting in Washington, DC on February 15-16, 2001 to further develop the workshop reports. Dara Entekhabi of the Massachusetts Institute of Technology chairs the committee. For more information please contact William Logan at 202-334-3422 or *wlogan@nas.edu.*

USGS Water Resources Research

The Committee on USGS Water Resources Research is currently reviewing the National Water-Use Information

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Program (NWUIP). The committee recently released the report *Investigating Groundwater Systems on Regional and National Scales*. They met at Woods Hole, MA in October 12-13, 2000 and had discussions with USGS personnel from the Chief Hydrologist's office, their northeast region water-use coordinator, and a statistician. The next meeting in March 8-9, 2001 in Washington, DC will be the first chaired by David Maidment of The University of Texas in Austin, who replaced Kenneth Bradbury of the Wisconsin Geological and Natural History Survey in Madison. For more information, contact William Logan at 202-334-3422 or *wlogan@ nas. edu*.

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Aquifer Storage Recovery

injection volumes, and the lack of information concerning the relationships among storage zone properties, recovery rates, and recharge volumes.

To address some of these issues, the USACE and SFWMD proposed ASR pilot projects in the Lake Okeechobee and Western Hillsboro areas (Figure 1). The Committee on Restoration of the Everglades Ecosystem's (CROGEE) charge was to examine a draft of their plans from a perspective of adaptive management. As part of this process, the CROGEE organized a workshop with SFWMD and USACE personnel and other interested parties in Miami, Florida in October 2000. The major recommendations of the committee were as follows.

Regional Science Issues. Because of the scale of the proposed ASR, regional hydrogeologic assessment is critical. The proposed regional study should include (a) the compilation of available data for a regional assessment, (b) development of a regional-scale groundwater flow model, (c) drilling, sampling, geophysical logging, hydraulic testing, and water quality sampling of exploratory wells in key areas, (d) seismic reflection surveys, and (e) a rational, multi-objective approach to ASR facility siting during the final design phase.

Water Quality Issues. ASR water may be used for agriculture, ecosystems, or drinking water, each having their own regulations and water quality concerns. Thus, considerations must be broader than simply meeting existing water quality criteria. Water quality studies should include (a) laboratory and field bioassays and ecotoxicological studies, (b) studies to characterize organic carbon of the source water and anticipate its effects on biogeochemical processes in the subsurface, and (c) laboratory studies to evaluate dissolution kinetics and redox processes that could release major ions, heavy metals, arsenic, and radionuclides from the aquifer matrix.

Local Performance/Feasibility Issues. In keeping with the principle of adaptive assessment, the pilot projects should be viewed as a way to learn about the hydrogeologic and well construction characteristics that control the relationships between storage intervals, recharge volumes, and recoverability. The pilot tests should include (a) sampling at discrete depths and in a variety of directions from the recharge well to delineate preferential flow paths and mixing between recharged and ambient water, (b) tests to compare effects of short and long sections of open borehole on well performance, and (c) recharge cycles for periods on the order of a year or more during cycle testing.

General Issues. With an improved understanding of ASR systems, it should be possible to develop ASR system designs that then can be compared to other storage options in terms of overall performance. This would include a comparison of losses from surface evaporation and subsurface storage, improved estimates of the number and distribution of ASR wells required, and estimates of energy costs for operation over the anticipated project life.

Figure 1: Locations of the Lake Okeechobee, Western Hillsboro, and other planned ASR sites. Wells shown are schematic. Source: Project management plan for Lake Okeechobee.

William Logan is a Staff Officer with the Water Science and Technology Board.

Dr. Perry McCarty Delivers 10th Abel Wolman Distinguished Lecture

Dr. Perry McCarty, Professor Emeritus of Stanford University, delivered the 10th Abel Wolman Lecture on January 22, 2001. His lecture began with a brief review of technical advances of the 20th century such as filtration, disinfection, biological treatment, and advances in the understanding of waterborne pathogens and environmental impacts of chemical pollutants. Unfortunately, these advances have been outstripped by the rate at which we have created new environmental problems. This calls for greater scientific understanding, because we often find ourselves unable to convince the public that our level of understanding is adequate to protect them. With fear of the unknown being stronger than fear of the known, the public often prefers a cautious approach. Reducing uncertainty through better understanding will help to minimize the excessive and costly regulation that this "precautionary principle" could lead to.

Some of our greatest reasons for optimism are the revolutionary developments in molecular biology in the last half of the 20th century. The creation of genetically modified bacteria for degrading contaminants shows great potential, although regulatory and public acceptance is slow. However, the greatest promise for molecular biology may be in its application for monitoring and analysis. Our ability to selectively amplify DNA now allows determining the presence of only a few microorganisms of a given species in a drop of water. Another developing tool of molecular biology is the identification of the most important microorganisms within a system, and their function and activity.

Our technical approaches to water quality management are also changing. These include reducing our dependence on end-of-the-pipe treatment processes, practicing greater efficiency of resource utilization, recycling for multiple use, changing manufacturing processes to reduce pollution potential, and modifying products to achieve greater environmental compatibility. Examples of these include:

·Adjusting timing and quantity of fertilizer application,

·Reuse of domestic wastewater for irrigation and other non-potable uses, and

·Economic development proceeding together with environmental protection.

Finally, anaerobic processes for wastewater treatment are gaining favor. Anaerobic treatment produces fewer and better-stabilized biosolids and has lower nutrient requirements than aerobic treatment. No electron acceptor need be present or added, and many compounds including chlorinated solvents, pesticides, and PCBs are often biodegraded under these conditions. However, they also provide an example of what we *can* do, but *shouldn't* do. We may be able to engineer an organism that can convert carbohydrates directly into methane, thereby making the process more efficient. However, release of such an organism to the environment could be disastrous for ruminants, who depend on the intermediate acetic and propionic acids for their energy source.

Dr. McCarty has been widely recognized for his teaching and cutting-edge research over the past three decades in biological processes for control of environmental contamination. For a copy of his lecture, please visit the WSTB website at http://national-academies.org/wstb or call the WSTB at 202-334-3422.

WSTB REPORTS

Inland Navigation System Planning: The Upper Mississippi River-Illinois Waterway
2001
This report reviews the Corps' draft feasibility study that gauges the economic viability of extending several locks on the Upper Mississippi River-Illinois Waterway. Available from the WSTB at 202-334-3422.

Aquifer Storage and Recovery in the Comprehensive Everglades Restoration Plan
2001
This report evaluates pilot projects for ASR in the Everglades. It makes recommendations for studies of regional impacts, water quality , and system performance. Available in prepublication format from the WSTB at 202-334-3422.

Investigating Groundwater Systems on Regional and National Scales
2000
This report makes recommendations concerningthe USGS Ground Water Resources Program, which is designed to do regional groundwater assessment and science. Available for $29.00 *(see order form).*

Clean Coastal Waters: Understanding and Reducing the Effects of Nutrient Pollution
2000
This report assesses how coastal and watershed processes affect nutrient overenrichment of coastal ecosystems and recommends ways to improve research, monitoring, and management at the federal, state, and local levels. Available for $54.95 *(see order form).*

Risk Analysis and Uncertainty for Flood Damage Reduction Studies
2000
This report reviews and assesses the U.S. Army Corps of Engineers risk analysis techniques in its flood damage reduction studies. The prepublication form is available from the WSTB at 202-334-3422.

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FUTURE PROJECTS

Watershed and Water Quality Management in the Upper Mississippi River Basin

On January 23, 2001 the WSTB held a planning workshop for a future study on watershed and water quality management issues in the Upper Mississippi River Basin. The workshop was co-chaired by Congressman Ronald Kind of Wisconsin and WSTB member Jerry Schnoor. Several scientists from the Upper Mississippi and several potential study sponsors provided remarks on key water management issues and strategies in the region. The WSTB hopes to obtain full funding for the study, which it hopes to initiate late in 2000. For more information, contact Jeffrey Jacobs at (202) 334-3422 or *jjacobs@nas.edu.*

Assessment of U.S. Army Corps of Engineers' Economics and Environmental Analysis and Peer Review of Feasibility Studies

The Water Resources Development Act of 2000 (WRDA 2000) mandated two National Academies studies of Corps of Engineers planning and decision making procedures within its feasibility studies: a) a review of the Corps' state-of-the-art planning and analytical methods, and b) a review of the Corps' independent peer review procedures. The WSTB is preparing a proposal for this study, which it intends to start in mid-2001. The WSTB currently envisions the creation of four sub-panels to carry out the study: ecology and environment; economics and other social sciences; hydrology and engineering; and independent peer review. An oversight panel will provide guidance to the sub-panels and focus on integrating their findings and incorporating them into the Corps' feasibility. For more information, contact Jeffrey Jacobs at (202) 334-3422 *jjacobs@nas.edu*.

Adaptive Management in U.S. River and Aquatic Ecosystems

The concept and practices of adaptive management have attracted much attention and are being employed in some areas of the United States as an approach to improving environmental conditions, as well as resolving stakeholder differences and policy gridlock. There is, however, no widely accepted, standard definition of adaptive management principles and practices.

The WSTB has secured financial backing from the Academies to convene a planning workshop to explore the prospects of an Academies' study on adaptive management of large river and aquatic ecosystems. The WSTB intends to hold this planning workshop in late Spring 2001. Water resources planning experts and potential study sponsors will discuss the merits of the proposed study, key study questions and topics, and potential sponsors' level of interest. For more information, contact Jeffrey Jacobs at (202) 334-3422 or *jjacobs@nas.edu.*

Services and Values of Aquatic and Related Terrestrial Ecosystems

Aquatic and related terrestrial ecosystems include lakes, rivers, streams, estuaries, wetlands, adjacent riparian systems, and upland areas together with their associated flora and fauna. They perform numerous environmental functions, such as recycling nutrients, purifying water, attenuating floods, recharging groundwater, and providing habitats for wildlife. In addition, aquatic and related terrestrial ecosystems often form the basis of economic livelihood and are widely used for recreational purposes. But human activities of all kinds have increasingly led to pollution, adverse modification, and devaluation of these valuable natural resources. While ecosystem functions may be useful markers for studying the physical, biological, and chemical processes at work in aquatic resources, they are seldom experienced directly by users of the resource. In contrast, economists find it more helpful to think of the "services" of a resource—the things that create value for human users. Thus for aquatic and related terrestrial ecosystems, the intrinsic value of hydrologic, biogeochemical, and biological services can be more readily assessed.

The WSTB held a planning workshop with an internal grant from the Academies in Washington, D.C. to identify major issues, important literature, potential experts, and sponsors for such a study. The workshop deliberations indicated that a full committee-based NRC study that focused on the value of aquatic ecosystem (and to a lessor extent, related terrestrial ecosystem) services, rather than functions, was both warranted and timely. Following the workshop, the WSTB developed and received approval from the National Academies to organize a study to identify and assess existing methods for defining and assigning economic values to the services of aquatic ecosystems. The assessment will also include consideration of the errors and biases characteristic of such methods and whether their increased use will lead to improved decisionmaking with respect to the environmental decisionmaking. The proposed study will be conducted by an expert committee over a 24-month period that will meet approximately six times during this period to gather information, deliberate critical issues, and write its report. At present, funding efforts for the study appear to be nearing completion and may be completed as early as spring 2001. For more information, or if you are interested in sponsoring the study, contact study director Mark Gibson at (202) 334-3422 or *mgibson@nas.edu.*

Water Disinfection Issues and Alternatives

WSTB staff is seeking funding for a new initiative that will broadly assess our current scientific understanding of water and wastewater disinfection processes and their alternatives. For a broad suite of chemical and physical disinfectants—including chlorine, ozone, and UV irradiation—this study would explore the mechanisms of microbial inactivation via disinfection and inactivation kinetics, and it will critically evaluate the methods used to quantify disinfection efficacy. In addition, it will examine how well emerging and existing disinfectants provide for residual maintenance within distribution systems and it will describe how disinfectant residuals should be managed to protect against microbial regrowth. A

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WSTB Reports

Seeing Into the Earth: Noninvasive Characterization of the Shallow Subsurface of Environmental and Engineering Application
2000
This report examined new and improved noninvasive methods for characterization of the shallow subsurface of the earth. Available for $35.00 *(see order form).*

Natural Attenuation for Groundwater Remediation
2000
This report examines natural attenuation issues about such as public concerns, scientific bases, and the criteria for evaluating its potential for success or failure. Available for $47.95 (*see order form*).

Watershed Management for Potable Water Supply: Assessing the New York City Strategy
2000
This report evaluates the New York City watershed management plan that is allowing the City to avoid filtration of its large upstate surface water supply. A broad range of conclusions and recommendations are made, many of which are applicable to surface water supplies across the country. Available for $56.00 *(see order form).*

Ecological Indicators for the Nation
2000
The report provides a framework for selecting ecological indicators, and also provides recommendations on several specific indicators for gauging the integrity of the nation's ecosystems. Available for $39.95 *(see order form).*

Hydrologic Science Priorities for the U.S. Global Change Research Program: An Initial Assessment
1999
This report makes recommend-ations for the U.S. Global Change Research Program. Two broad science areas—predictability and variability of regional and global water cycles and coupling of hydrologic systems and ecosystems through biogeochemical cycles—are identified that could augment the current hydrologic sciences content of the USGCRP. Available from the WSTB at 202-334-3422.

Downstream: Adaptive Management of Glen Canyon Dam and the Colorado River Ecosystem
1999
This report evaluates the strengths and weaknesses of the Long-Term Monitoring and Research Plan of the Grand Canyon Monitoring and Research Center. Available for $41.50 *(see order form).*

Identifying Future Drinking Water Contaminants
1999
This report summarizes a workshop based on prioritizing potential drinking water contaminants for inclusion on future Drinking Water Contaminant Candidate Lists. Available for $45.00 *(see order form).*

Water for the Future: The West Bank and Gaza Strip, Israel, and Jordan
1999
This report recommends that Israel, Jordan, and the Palestinian Authority work together to preserve aquatic ecosystems in the Middle East to ensure that an adequate supply of fresh, high-quality water is available for future generations. The report offers a range of findings and observations on water resource management options for this area. Available for $35.00 *(see order form).*

New Directions in Water Resources Planning for the U.S. Army Corps of Engineers
1999
This report identifies several ways in which the Corps might reduce the time required in water project planning. The report also recommends that the federal Principles and Guidelines for Water and Land Resources Implementation Studies be thoroughly reviewed and modernized. Available for $39.00 *(see order form).*

Hydrologic Hazards Science at the U.S. Geological Survey
1999
This report provides advice to the U.S. Geological Survey with respect to its research, interpretive studies, and data collection efforts in the area of hydrologic hazards, which includes droughts, flooding, and related phenomena. Available from the WSTB at 202-334-3422.

Improving American River Flood Frequency Analyses
1999
This report evaluates the useful-ness of various kinds of data, including historical and paleoflood data; recommends flood flow frequency distribution for the American River; and reviews recent scientific literature on climate variability and flood frequency. Available from the WSTB at 202-334-3422.

New Strategies for America's Watersheds
1999
This report provides a timely and comprehensive look at the rise of "watershed thinking" among scientists and policymakers and recommends ways to steer the nation toward improved watershed management. Available for $49.00 (*see order form*).

Setting Priorities for Drinking Water Contaminants
1999
This report provides a phased decision process for determining which contaminants on the Contaminant Candidate List are appropriate for regulatory decisions and which will require research or monitoring. Available for $35.00 (*see order form).*

Environmental Cleanup at Navy Facilities: Risk-Based Methods
1999
This report reviews and critiques risk-based cleanup methods, including those developed by the EPA and the American Society of Testing and Materials, and identifies eleven criteria that must be part of any risk-based methodology adopted

by the Navy. Available from the WSTB at 202-334-3422.

Issues in Potable Reuse: The Viability of Augmenting Drinking Water Supplies With Reclaimed Water
1998
This report looks at the issues involving the use of reclaimed water to supplement drinking water supplies. It discusses issues of water treatment technology, monitoring, and testing of reclaimed water to ensure public safety. Available for $44.95 (*see order form*).

Hydrologic Sciences: Taking Stock and Looking Ahead
1998
The WSTB used the opportunity of its 1997 Abel Wolman Distinguished Lecture to assess the vitality of the hydrologic sciences by the hydrologic community. This report is a compilation of the Wolman Lecture and four invited papers, preceded by a summarizing overview. Available for $35.00 (*see order form)*.

Innovations in Ground Water and Soil Cleanup
1997
This report provides a compre-hensive review of the status of innovative technologies for subsurface cleanup. It also recommends strategies for increasing market demand for innovative remediation technologies, standardizing the collection of pilot and field test data on these technologies, and evaluating cost data. Available for $44.95 (*see order form*).

Valuing Ground Water
1997
This report examines approaches for assessing the economic value of groundwater and the costs of contaminating or depleting this resource. It suggests a framework for policymakers and managers to use in evaluating tradeoffs when there are competing uses for groundwater. Available for $39.95 (*see order form*).

Building a Foundation for Environmental Research
1997
This report outlines a new framework for organizing the research program at EPA's Office of Research and Development. The report calls for the establishment of two kinds of research *problem-driven* research and *core* research. Available from the WSTB at 202-334-3422.

Watershed Research in the U.S. Geological Survey
1997
This report is intended to assist the USGS in improving its overall strategy for watershed research. Available from the WSTB at 202-334-3422.

Safe Water from Every Tap: Improving Water Service to Small Communities
1997
This report assesses the quality of drinking water in small communities and recommends a three-part strategy for improving it. Available for $44.95 (*see order form*).

Alluvial Fan Flooding
1996
This report provides an updated regulatory definition of alluvial fan flooding, presents criteria for assessing whether an area is or is not subject to such flooding, and provides examples of applying the definition and criteria to real situations. Available from the WSTB at 202-334-3422.

Freshwater Ecosystems: Revitalizing Educational Programs in Limnology
1996
This report provides an overview of the status of inland waters, the history of limnology, and key future problems that may face water resource managers. It recommends changes in limnology education and research to meet the needs of water resource management. Available for $54.95 (*see order form).*

A New Era for Irrigation
1996
This report explores the impacts of changing supply and demand conditions, assesses current and potential technologies that might help water users adapt to changing conditions, and considers how to mitigate short- and long-term problems associated with irrigation. Available for $39.95 (*see order form*).

Hazardous Materials in the Hydrologic Environment: The Role of the U.S. Geological Survey
1996
This report attempts to help shape the overall framework of the U.S. Geological Survey's research in hazardous materials science and technology and identifies general areas of scientific opportunity. Available from the WSTB at 202-334-3422.

River Resource Management in the Grand Canyon
1996
This report assesses the achievements and shortcomings of the Bureau of Reclamation's Glen Canyon Environmental Studies and reviews the final research done under the program. Available for $35.00 (*see order form*).

Use of Reclaimed Water and Sludge in Food Crop Production
1996
This report reviews the current state-of-the-practice, public health concerns, existing guidelines and regulations, and implementation issues of using municipal wastewater and sludge in food crop production. Available for $34.00 (*see order form*).

Wetlands: Characteristics and Boundaries
1995
This report analyzes present regulatory practice related to wetlands delineation and recommends changes that should bolster the objectivity and scientific validity of wetlands delineation and identification. Available for $42.95 (*see order form*).

Flood Risk Management and the American River Basin: An Evaluation
1995
This book reviews the U.S. Army Corps of Engineers' investigations of flood control options for the American River

basin and evaluates flood control feasibility studies for the watershed. Available for $29.00 *(see order form).*

Mexico City's Water Supply: Improving the Outlook for Sustainability
1995
This bilingual report addresses the technical, health, regulatory, and social aspects of groundwater withdrawals, water use, and water quality in the Mexico City metropolitan area and recommends ways to improve the balance of water supply, demand, and conservation. Available for $30.00 *(see order form).*

Review of EPA's Environmental Monitoring and Assessment Program: Overall Evaluation
1995
This final review of EPA's Environmental Monitoring and Assessment Program (EMAP) evaluates whether EMAP's goals of assessing the status of and trends in the nation's ecosystems are achievable, given the difficult scientific, practical, and management challenges of implementing them. Available for $35.00 *(see order form).*

Alternatives for Ground Water Cleanup
1994
This report evaluates the efficacy of pump and treat systems at nearly 80 contaminated sites, providing detailed case studies for several of the sites. Available for $64.75 *(see order form; print on demand).*

Ground Water Recharge: Using Waters of Impaired Quality
1994
This report examines the use of waters of less-than-ideal quality, such as treated municipal wastewater and urban stormwater runoff, as sources for artificial groundwater recharge projects. Available for $59.25 (*see order form; print on demand*).

Managing Wastewater in Coastal Urban Areas
1993
This report examines the problems of wastewater and stormwater management in coastal urban settings, recommending a system of integrated coastal management. Available for $54.95 *(see order form).*

In Situ Bioremediation: When Does It Work?
1993
This report provides direction for decision-makers and offers detailed explanations of the processes involved in *in situ* bioremediation, circumstances in which it is best used, and methods for evaluating the results of bioremediation projects. Available for $34.95 *(see order form).*

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Future Projects

workshop was held March 28, 2000, in Washington DC to bring together public and private stakeholders, generate interest in the study, and identify potential sponsors and committee members. Although several organizations expressed interest in the project, funding has not yet been committed. For more information or to suggest funding sources, contact Laura Ehlers at 202-334-3422 or *lehlers@nas.edu.*

WSTB Wins AWWA Best Paper Award

James Crook of Black and Veatch and chair of the NRC Committee to Evaluate the Viability of Augmenting Potable Water Supplies With Reclaimed Water was awarded the 2001 AWWA Water Resources Division Best Paper Award sponsored by the American Water Works Association. Former Associate Board Director **Jacqueline MacDonald**, who was study director of this NRC committee, also received the award as secondary author of the paper. The award will be presented during the AWWA Washington, D.C. Annual Conference. The paper, *Potable Use of Reclaimed Water* (authored by James Crook, Jacqueline MacDonald, and Board Member **R. Rhodes Trussell** of Montgomery Watson), which appeared in the August 1999 issue of the Journal of AWWA, was based on the committee's report *Issues in Potable Reuse: The Viability of Augmenting Drinking Water Supplies With Reclaimed Water*.

Water Science and Technology Board

The Water Science and Technology Board (WSTB) is a unit of the National Research Council, which serves as an independent advisor to the federal government on scientific and technical questions of national importance. The National Research Council, jointly administered by the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine, brings the resources of the scientific and technical community to bear on national problems through its volunteer advisory committees.

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NATIONAL RESEARCH COUNCIL MEETINGS

February 1-3	Committee on Restoration of the Greater Everglades Ecosystem *Everglades National Park, Florida*
February 15-16	Committee on Hydrologic Science *Washington, DC*
February 16-17	Committee on Missouri River Basin *Irvine, California*
February 22-23	Committee on Riparian Zone Functioning and Strategies for Management *Washington, DC*
February 28-March 2	Committee on Environmental Remediation at Naval Facilities *San Diego, California*
March 8-9	Committee on USGS Water Resources Research *Reston, Virginia*
March 8-10	Committee on TMDL *Washington, DC*
April 12-13	Committee on TMDL *Washington, DC*
April 26-27	Committee on Restoration of the Greater Everglades Ecosystem *Key Largo, Florida*
June 1-2	Committee on Privatization of Water Supplies in the United States *Irvine, California*
June 7-8	Water Science and Technology Board *Woods Hole, Massachusetts*
June 11-12	Committee to Improve the National Water Quality Assessment Report *location to be announced*