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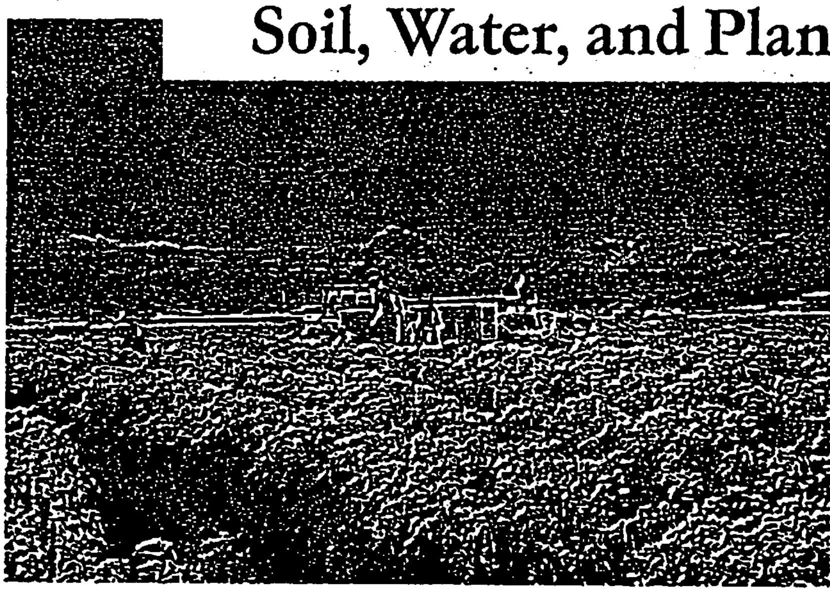
Global Change and Agriculture: Soil, Water, and Plant Resources



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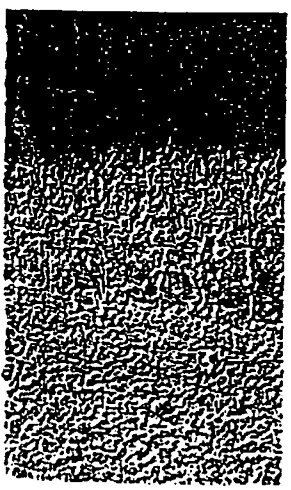

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Integrating USDA–ARS Hydrology, Biogeochemical and Ecosystems Research

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Introduction

Environmental concerns facing the world today include such issues as increasing atmospheric CO_2, global climate change, desertification, regional drought and flooding, limited supplies of water and other natural resources, and decreasing quality of these resources from pollution. Scientists in the fields of hydrology, biogeochemistry and ecosystems research are addressing these issues by making measurements and developing simulation models that will give policy makers and resource managers a better understanding of the changing natural environment. Conducting research experiments and developing models at larger spatial scales beyond the laboratory or field scale, required for policy makers generally requires a multi-disciplinary approach and necessitates cooperation between hydrologists, biogeochemists and ecologists (abbreviated H, BGC and ECO). Such cooperation not only pools expertise toward a common goal, but also allows most efficient use of limited human and budgetary resources. The result will be more complete resource management tools and a deeper comprehension of the complex processes affecting the our biosphere.

Cooperation between ARS scientists in three scientific fields (H, BGC and ECO) could be particularly fruitful. The Hydrology group of ARS can bring specific strengths to cooperation through its expertise in experimental watershed research and complex computer model development. However, hydrologists have much to gain from close cooperation to better understand biotic watershed factors and biogeochemical interactions. Since these scientists share common interests but have different expertise and are at different locations, situations often occur in which:

1. similar field measurements are made in different ecological biomes;

2. simulation models are developed to address only a specific part of an environmental process; and

3. individual experiments are conducted at different locations with some duplication of effort and expense.

With strategic cooperation between the three groups, it may be possible to:

1. share similar data sets for model calibration and validation;

2. merge component models into composite simulation models that could address larger issues; and

3. conduct large-scale, multidisciplinary experiments that could both decrease the costs of experimental measurements and benefit all ARS scientists with data sets acquired by experts in each discipline.

These three modes of interaction—sharing existing data sets, exchanging and merging models, and conducting multidisciplinary field experiments—have the greatest potential for H, BGC and ECO group cooperation. In this presentation, we attempt to define several critical issues facing hydrology with specific research examples that could be much more effectively addressed via integration among our three research groups. A summary of some of the expertise, historical data, and resources that the ARS Hydrology Group has to offer will then be discussed. Finally, a more detailed discussion of potential mechanisms for collaboration is presented.

Critical Issues Facing the Hydrologic Sciences

In a recent report on "Opportunities in the Hydrologic Sciences", the National Research Council (1991) presented these five unranked scientific priority research areas which have the greatest potential to improve our understanding of hydrologic science:

- *chemical and biological components of the hydrologic cycle;*
- *scaling of dynamic behavior;*
- *land surface-atmosphere interactions;*
- *coordinated global-scale observation of water reservoirs and the fluxes of water and energy; and,*
- *hydrologic effects of human activity.*

The first research priority area clearly illustrates the importance placed on integration of H, ECO and BGC scientific efforts. Ecosystem structure is often strongly tied to water availability and, in turn, the ecosystem itself is an active and often regulating influence on the hydrologic cycle. As hydrologists are often trained primarily in the physical sciences, their research is strong in physical processes and weak in ecological feedbacks. An example is the estimation of evaporation in the hydrologic cycle. The physical process of changing water from a liquid to a vapor through heat exchange has been thoroughly modeled and is well understood. The more realistic process of evapotranspiration (the sum of evaporation from the soil and transpiration through plants) is less well-understood and could be improved by cooperation between the H and Eco groups. The synergy of information on plant growth and physiology with knowledge of energy and water balance could improve estimates of ET for heterogeneous, vegetated ecosystems. Understanding these and more general, long-term, interactions between the hydrologic cycle and ecosystems will be critical to discerning, predicting and developing mitigating and adaptive strategies in the presence of global change.

Improved understanding of the link between aqueous biogeochemistry and the physics of water movement is likely to provide the key to understanding the pathways of water through the lithosphere. From a long term perspective, chemical analysis of water with long residence times in soils and aquifers, may provide insights into historical climate conditions, and thus be very useful for global change related research. On shorter time scales, isotopic research has provided significant insights into the processes of runoff generation by providing the ability to differentiate between "new" (rainfall translated to runoff in a very short time period) and "old" (water held in macropores or the soil matrix for a longer period of time) water from a storm hydrograph (Pionke et al., 1988; Nolan and Hill, 1990; McDonnell et al., 1990). Further collaborative research in this area has the potential to greatly enhance a number of hydrologic models.

The second NRC (1991) research priority, "Scaling of Dynamic Behavior" arises logically from both the need to understand and apply research at large spatial scales in aggregation and from a disaggregation perspective for understanding subgrid-scale processes and subpixel properties of remotely sensed images. The scaling issue is important and relevant to ecology and biogeochemistry and economy of effort will be enhanced by collaboration among the groups.

"Land Surface-Atmosphere Interactions" is an urgent research priority that can only be addressed through collaborative efforts. "Our knowledge of the time and space distributions of rainfall, soil moisture, ground water recharge, and evapotranspiration are remarkably inadequate, in part because historical data bases are point measurements from which we have attempted extrapolation to large-scale fields" (NRC, 1991). Progress in extrapolation to large spatial scales has been and will continue to be greatly enhanced through coordinated multidisciplinary experiments (discussed in more detail below) which capitalize on integration of data from remote sensing tools to measure land surface properties over large areas. To strengthen large-area understanding, using remote sensing, the linkage between use of remotely-sensed data and the input and validation requirements of environmental process simulation models must be improved. There are two reasons for current weaknesses in this linkage: 1) the model developers generally don't have expertise in the use of remotely-sensed data (and those with expertise in remote sensing generally don't develop simulation models) and 2) the simulation models are discretely continuous in time and not in space, whereas remotely-sensed images are discretely continuous is space but not in time. Though the latter issue tends to discourage cooperation, it really expresses a complementarity that should encourage integration of the tools. That is, model developers from the H, BGC and ECO groups could use remotely-sensed maps of land surface characteristics for input to and validation of their models; and remote sensing experts could combine simulation models with their one-time measurements of surface conditions (evaporation, plant cover, soil moisture) to understand current states and predict future conditions.

Although the fourth research priority of Global-Scale Observations may be beyond the scope of the ARS mission, our work in development of direct and remote measurement techniques will greatly contribute toward the validation of global-scale observation techniques. Finally, ARS and the H, BGC, and ECO groups can play a key role in advancing the last research priority, "Hydrologic (or more broadly for our efforts - Environmental) Effects of Human Activity" given our long history of assessing the effects of agriculture on the environment.

Factors That the Hydrology Groups Can Bring to Multidisciplinary Research

Perhaps one of the greatest factors that the ARS Hydrology group can contribute to a foundation of multidisciplinary research is it long history of observations on experimental watersheds throughout the United States. Renard (1993) and Goodrich et al. (1994) describe the beginnings of ARS's Hydrology efforts which date from the 1930's to address the deterioration of agricultural land from soil erosion and problems associated with increased hazard of downstream flooding. A shortage of quantitative observations was recognized as a critical problem in understanding soil erosion and hydrology. This resulted in the establishment of twenty experimental watersheds throughout the United States by the Research Division of the Natural Resources Conservation Service (NRCS).

The initial network of experimental watersheds was expanded both in numbers and spatial scale over the years to collect a variety of basic hydrologic and associated data. Over 600 watersheds have been operated by NRCS or ARS. A comprehensive database of 333 of these watersheds is maintained at the Hydrology Laboratory in Beltsville, Maryland, and 140 watersheds are currently active and collecting a variety of data. USDA (1982) provides a description of the data acquisition programs and an assessment of the data quality at many of the experimental watersheds. For the active watersheds, Table 1 contains the distribution of watersheds drainage areas, length of record and their primary land use. Figure 1 illustrates the geographic location of active and closed ARS watersheds.

According to Renard (1993), the experimental watershed program has led to, and made possible, the development of a wide

Table 1. Characteristics of Active ARS Watersheds (based on Jan. 1, 1991 figures, from DeCoursey (1992).

Size		Length of record		Primary land use	
hectares	No.	Years	No.	Type	No.
<4	58	10	20	Crop	30
4–40	28	10–20	30	Pasture/range	59
40–405	20	20–30	42	Mixed	46
405–4050	19	>30	48	Meadow	1
>4050	15			Pasture/meadow	3
				Woodland	1

array of hydrologic, water quality, and erosion/sedimentation models. "Such models have been hypothesized, parameterized, and compared to such watershed data" (Renard, 1993). He goes on to provide a more detailed description of many of the major models developed by the Hydrology Group in cooperation with other ARS scientists. The CREAMS (Chemical, Runoff, Erosion and Agricultural Management System: Knisel (ed.), 1980) and WEPP (Water Erosion Prediction Project; Nearing et al., 1989) models provide excellent examples of the benefits of a multidisciplinary, multilocation research effort.

Not only have the experimental watersheds provided a wealth of experience and data on which modeling efforts can be formulated, they have provided ideal locations to conduct multidisciplinary experimental campaigns. The watersheds typically have an extensive historical data base, a large percentage of both the logistic and instrumentation infrastructure required to carry out such experiments, and research staff with an extensive historical knowledge of the watershed and

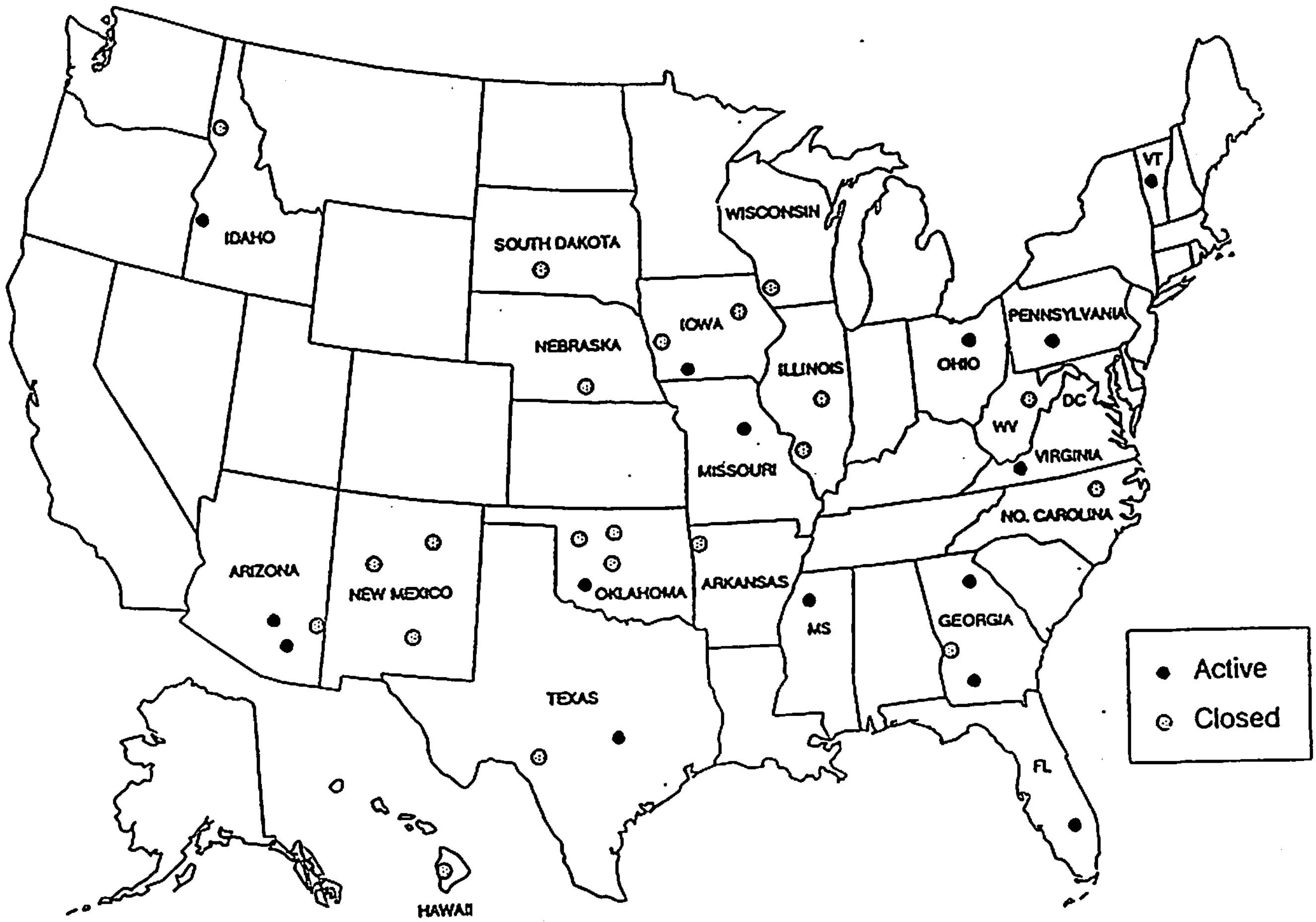

Fig. 1. Location of active and closed ARS watersheds as of January1, 1992.

their response mechanisms. Thus by conducting experiments on ARS watersheds, significant capital expenses are saved and more research can be accomplished for an incremental marginal cost.

This has been recognized by other agencies such as NASA, USGS as well as a variety of university and international collaborators which have participated in multidisciplinary field campaigns over a variety of ARS Experimental Watersheds (such as MACHYDRO '90 over the Mahantango; MONSOON '90 (Kustas and Goodrich, 1994) and Walnut Gulch'92 (Moran et al., 1993) over Walnut Gulch; and 1992 and 1994 campaigns over the Little Washita). In addition, a number of ARS scientists have participated in a large number of field campaigns in other locations throughout the world. The experience of participating in, designing and implementing these large-scale, multi-disciplinary experiments could help other H, BGC and ECO scientists design future experiments at other locations for a variety of research objectives.

Proposed Mechanisms for Collaboration

The first step toward collaboration between the H, BGC and ECO groups is increased awareness of, and cooperation with, other ARS scientists with complimentary research interests. This would include awareness of the interests and projects of other ARS scientists, current models and models being developed, existing data bases from multidisciplinary experiments, and planned multidisciplinary experiments. This awareness will logically follow from the periodic interdisciplinary ARS meetings of the H, BGC and ECO groups, but it could be enhanced by activity on the Internet. A logical and easily implemented procedure to facilitate Internet information exchange would be a system to house a simple network accessible scientist database at the Water Data Center of the Hydrology Laboratory at Beltsville, MD. This center already maintains water data bases and is set up for access via the internet. A simple approach would be for each scientist in the H, ECO, and BCG groups to annually update a prescribed form stating contact information, something about their background, what they are currently working on, and what they plan in the near future with several keywords.

As mentioned earlier, one mode of interaction could be participation in multidisciplinary field experiments. This action would not only allow ARS to expand it's research to cover larger scales and more integrative problems, but also to allow scientists in the H, BGC and ECO groups to benefit from expertise in other disciplines. Examples of such ARS-sponsored experiments in Arizona include the Maricopa Agricultural Center (MAC) experiments which attracted up to 50 participants from 25 organizations for farm management research (special issue of Remote Sensing of Environment, Vol 32, 1990), the ongoing Free Air CO_2 Enrichment (FACE) experiment which united 50 scientists from 8 countries (special issue of Agric. For. Meteorol., Vol 70, 1994), and the Monsoon'90 experiment in which over 20 scientists addressed interdisciplinary rangeland issues (special section of Water Res. Research, Vol 30, 1994).

A large-scale interdisciplinary research program is currently in the planning stage in Arizona and could provide an immediate avenue for integrating H, BGC and ECO research. The Semi-Arid Land-Surface- Atmosphere (SALSA) Program (Goodrich, 1994) builds on the Monsoon'90 efforts at the Walnut Gulch Experimental Watershed to larger spatial scales as well as broadens disciplinary treatment. For this program the following three "umbrella" questions have been posed under which more specific scientific objectives are being developed.

1. Can the processes of desertification from anthropogenically induced cross border differences in land use and land cover apparent from spaced based imagery be quantified and what are the subsequent impacts on, and feedbacks to, basin hydrology, ecology and land-atmosphere interactions?

2. Can the understanding of desertification from cross border anthropogenic activities be extended to scenarios of future climate change to predict long-term sustainability for agriculture and human populations in semi-arid regions?

3. Can remote sensing, coupled with meteorological, hydrological, and ecological models be used to quantify and improve our estimates of available water supply in semi-arid regions with steep topography (and associated biome diversity) and isolated riparian corridors?

The formulation of this type of multidisciplinary umbrella serves to encourage wide participation yet provide a starting focal point to develop truly integrative research.

Another promising mechansim for collaboration is cooperative modeling efforts. This is possible with a variety of scientists working at different locations with strategic planning and a small number of meetings. The need for these type of efforts is ever more evident as we must address more complex problems that encompass multiple disciplines as well as economic constraints. As noted above, CREAMS is an excellent example of successful collaborative effort.

Currently, several collaborative modeling efforts are underway and new software tools are aiding them. The Root Zone Water Quality Model (RZWQM Team, 1992a, b) is addressing the integrated treatment of water, energy and gas fluxes to soil, plant and climate processes and thus provides an ideal focus for collaboration between the H, ECO, and BGC groups. Development of the Modular Modeling System (MMS) through the multiagency TERRA Laboratory is another excellent example (Leavesly et al., 1992; DeCoursey et al., 1993). In this system, processed-based computer modules for different hydrologic, ecologic or biogeochemical processes can be inserted in the system under certain programming constraints. Once modules are placed in the system they can be readily linked to other modules as well as draw on data base, model optimization and graphic utilities that are part of MMS. A prototype Decision Support System (DSS) (Yakowitz et al., 1993) utilizes a suite of natural resource and economic models and multi-objective decision theory to aid in decision making where conflicting or clear-cut goals are present. All three of these efforts will greatly benefit from collaboration among the H, ECO and BGC groups. It must also be stressed that the benefits can flow in both directions as individual scientists can often acquire powerful, more realistic, models to address more focused research efforts.

Conclusions

Three modes of interaction between the H, BGC and ECO groups were identified: sharing existing data sets, exchanging and merging models, and conducting multidisciplinary field experiments. The most promising avenues for encouraging interaction are ongoing meetings of the H, BGC and ECO groups, increased internet activity including home pages and archived data sets, multidisciplinary field experiments conducted at ARS watersheds, and complex modeling efforts.

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