Biology and Water Science in CIRES

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Introduction

Linnaeus (1707-1778), inventor of the system of binomial nomenclature for organisms, probably would have approved of the way in which CIRES was named. There are five words in the name, but that would not have deterred Linnaeus or his successors from latinizing it as a binomial (e.g., black-bellied dew lover: *Drosophila melanogaster*, the most famous of fruit flies). The designation "Cooperative Institute for Research" accurately places CIRES generically as one of a diverse group of scientific organizations that foster research through some kind of inter-institutional collaboration, in this case between the University of Colorado and NOAA. The designation "Environmental Sciences" is more specific; it assigns CIRES a niche that is broad but has definite boundaries.

The environmental sciences do not comprise a discipline, but rather a cluster of disciplines that lend themselves to interdisciplinary cooperation, which is the main rationale for the University's commitment to CIRES. CIRES, unlike a department, is not obliged to serve any particular discipline, and thus is freer to promote interdisciplinary work than a department would be. The environmental sciences do, however, have some internal structure. One way of illustrating this structure, and of relating it to CIRES, is through a matrix that places the traditional disciplines on one axis of a grid and the three environmental media (earth, air, and water) on the other axis. The scientists found at different intersections in the matrix differ from one another in the way that they are trained, even though scientists at different intersections may share interests in certain classes of problems.
Figure 1. A matrix representing subject matter of the environmental sciences in terms of the major traditional disciplines (rows) and the three environmental media (columns). The area of the circle at each intersection of columns and rows indicates the proportionate representation among the CIRES Fellows as of year 2000. Fellows showing dispersion of expertise across one axis or another are represented in terms of fractional allocation of effort.
The matrix in Figure 1 is filled in with circles, the areas of which indicate the
distribution of CIRES Fellows within the environmental sciences as of year 2000. A
matrix also could be prepared from a list of all scientists in CIRES rather than from a list
of CIRES Fellows, but it would look qualitatively similar to the one shown in Figure 1.

The rows of Figure 1 show that CIRES is, across disciplines, most strongly
committed to physics, as might be expected from the origin and development of the
Institute. Chemistry also is strongly represented, but is very much secondary to physics
in terms of representation among the Fellows. Biology is tertiary and social science is a
distant last place (one position).

The distribution of Fellows across disciplines would have been considerably
different prior to 1990. At that time, biology would have appeared in Figure 1 much in
the way that social science does now, and social science would not have appeared at all.
The balance between physics and chemistry probably would have been much as it is
today, however.

With respect to columns in Figure 1, which represent the three environmental
media, the atmospheric realm is by far most strongly represented. Studies of the solid
earth are also very strongly represented, mostly because of the strength of geophysics,
reflecting the origins of CIRES. The development of CIRES along lines of greatest
interest to NOAA explains the strength of commitment to atmospheric studies, which
overtook studies of the solid earth in terms of representation among the CIRES Fellows
or by other measures of activity within CIRES relatively early in the history of CIRES.

The combination of rows and columns produces an interesting mix of strengths
across the possible combinations of disciplines and environmental media. For example,
the strength of atmospheric studies does not extend to biology and social sciences. Weakness of commitment to atmospheric biology is reflective, however, of the tendency of biologically-oriented subjects to be identified with aquatic and terrestrial media rather than the atmosphere, although trace gas work such as that pursued by CIRES Fellow Ray Fall can be classified largely as biology. Aquatic studies are poorly represented across the board. Perception of this weakness by the CIRES Fellows and administration was the general rationale for a major new commitment to studies involving the water cycle, as explained below. Studies of the solid earth are strongly committed to physics, but also there is significant commitment to biology, as explained below. Chemistry of the solid earth, as might be pursued by a chemically-oriented soil scientist or any of a number of types of geochemists is, however, almost absent from CIRES. CIRES does benefit, however, from the presence of Lang Farmer, a well known isotope geochemist.

The foregoing commentary on strengths and weaknesses of commitments to various intersections in the matrix of Figure 1 cannot be taken as a criticism of the present status or development of CIRES. It is not essential that an institute with such broad scope as CIRES commit its resources uniformly to all subjects that fall under the umbrella of its name. Nevertheless, an explicit depiction of the distribution of effort is cause for reflection. Uneven distribution of commitments to specific kinds of subjects are partly historical, but nevertheless require a good supporting rationale if they are to remain as characteristics of the Institute.

The purpose of this chapter is to review and, to the extent possible, explain how biology, which is a row in the matrix of Figure 1, and aquatic science, which is a column in the same figure, have developed within CIRES.
The leading edge of the wedge for Biology in CIRES was Ray Fall, who became a Fellow in 1981 as a result of the efforts of Robert Sievers, CIRES director at that time. Fall took his Ph.D. in biochemistry at UCLA and subsequently did postdoctoral work at the Washington University School of Medicine. His early work dealt with protein structure and, though virtually any science related to life can be by some logic environmental, appears to have been impressive but without any particular environmental slant. Environmental flavor crept in during the 1970s, however, in the form of his work on biodegradation (Fall et al. 1979). 

The environmental slant in Fall's work steepened in 1988 with his studies of ice nucleation, which is a property of bacteria of considerable interest in the natural environment and also to agricultural practices that are threatened by ice formation (Parody-Morreale et al. 1988). During the late 1980s, coincident with a sabbatical at the NOAA Aeronomy Lab, which is well represented in CIRES, Fall moved into studies of chemical emissions from living plants (Fall et al. 1988); this subject had come into strong focus nationally as the U.S. attempted to distinguish natural from the anthropogenic emissions of gases to the atmosphere. Some of Fall's work was done in collaboration with CIRES Fellow Fred Fehsenfeld. Their joint work illustrates nicely the beneficial complementarity of the collaboration of biologically- and chemically-oriented branches of the environmental sciences. Subsequently, Fall collaborated with CIRES Fellow Russ Monson, a plant physiologist, on emission of isoprene and other substances from plants.

References characterizing the work of individuals are indicative rather than comprehensive.
(Monson and Fall 1989). This work has continued through the 1990s (Fall and Wildermuth 1998).

An interesting recent development is Fall's work on the dependence of emission rates from plants on agricultural processing (de Gouw et al. 1999) or freezing of plant tissues (Fall et al. 2001). Thus, Fall has passed from classical protein biochemistry to collaborative studies of the relationship between emissions from plants and chemical composition of the atmosphere.

Biology can be thought of as a spectrum of sub-disciplines based on level of organization, extending from the molecular to the biospheric (Figure 2). Fall's position on the spectrum is firmly toward the molecular end, but his work has had special significance through his search for biochemically-oriented problems that are of major environmental significance beyond the molecular level.

CIRES did not rush to embrace biology. Seven years after Ray Fall joined CIRES, Bill Lewis was recruited as a second biologist on the Council of Fellows (1988). Lewis received a Ph.D. from Indiana University in zoology with emphasis on limnology, the study of inland waters. After postdoctoral work at the University of Georgia, he entered the Department of Environmental, Population, and Organismic Biology (EPO Biology). Lewis, like Fall, already had been a member of a CU department for quite a few years before joining CIRES. Fall encouraged Lewis to stand for consideration as a Fellow. In doing so he was probably representing especially the interests of the atmospheric chemists, who saw a connection between their own interests and Lewis's work on atmospheric deposition in Colorado. Lewis and colleagues first documented
Figure 2. A diagram showing a classification of the biological sciences according to levels of organization and a depiction of the main interests along the biological spectrum of the five biologically-oriented Fellows of CIRES as of year 2000.
strong anthropogenic influences on precipitation chemistry at high elevation in Colorado (Lewis and Grant 1980), where the air was thought previously to be mostly pristine. Mapping of atmospheric deposition in Colorado showed that oxides of nitrogen and sulfur generated mainly at low elevation were neutralized by particulate alkalis at low elevation, but had a strong acidifying effect on precipitation in montane environments because the particulate alkalis were lost from the air as it passed to higher elevation, where precipitation is most likely (Lewis et al. 1984).

Lewis developed a dual program, one component of which focused on tropical aquatic ecosystems and the second on aquatic ecosystems of Colorado. His original interest in atmospheric deposition was connected mainly not with acidity, but rather with nutrient cycling, and especially that of nitrogen, which has important regulatory effects on the metabolism of aquatic ecosystems. This interest continued, as indicated by Lewis's recent work on estimation of global nitrogen yields from land surfaces to oceans by way of inland waters under pre-disturbance conditions (Lewis et al. 1999, Lewis 2001). Lewis's interests and those of his students also have consistently involved the analysis of foodwebs centered on the mechanisms controlling of energy flow through foodwebs and factors limiting foodweb efficiency (Lewis et al. 2001).

Lewis's tropical work included a long-term research project on the Orinoco River floodplain. The general thesis of this work was that, contrary to initial impressions of intractable complexity, the main biogeochemical and biological processes occurring on natural floodplains can be to a large extent explained by deterministic relationships between these processes and geomorphic or hydrologic influences (Lewis et al. 2000).
Lewis also has worked on other topics, including the evolution of sex (Lewis 1987) and relationships between science and policy in the United States (Lewis 2001).

Like Fall, Lewis had a position with the University involving a faculty line rostered with Arts and Sciences rather than with the Graduate School, which is the administrative home of CIRES. In 1995, Lewis's position was changed so that it was rostered with the Graduate School rather than with Arts and Sciences, although Lewis continued to teach for EPO Biology. Lewis had served as Director of the Center for Limnology in the College of Arts of Sciences since 1986. The Center, with Lewis continuing as Director, moved to CIRES physically and administratively in 1995. This move represented a new level of administrative commitment within CIRES to the development of water science, more of which is explained below. Research at the Center for Limnology has been primarily centered on functional analysis of aquatic ecosystems and aquatic communities, as indicated in Figure 2.

In 1990, Shelley Copley became the third biologist in CIRES. Unlike Fall and Lewis, she was hired into a position rostered in the Graduate School rather than in Arts and Sciences and became immediately a Fellow of CIRES. The search that resulted in her hiring, however, was collaborative with the Chemistry Department, which served as her home for purposes of teaching assignments, graduate admissions, and personnel actions related to promotion and tenure. The search was not motivated by a desire to expand representation of biology in CIRES. Instead, it was broadly cast as an attempt to hire an environmentally-oriented chemist with superb qualifications. The result could have been a hire with negligible connection to biology, but Copley's field of interest proved an excellent reinforcement for biological interests within CIRES.
Shelley Copley took her Ph.D. in biophysics at Harvard University and MIT and joined University of Colorado after a two-year post doc at CU under chemistry professor Tad Koch. The consistent thread in Copley's research has been investigation of mechanisms by which bacteria degrade refractory compounds, particularly xenobiotic compounds. Her work in this area has both basic and applied significance.

Biodegradation of xenobiotics is revealing in an evolutionary sense in that degradation mechanisms for these compounds must have evolved since the beginning of the industrial age, or even more recently in the case of xenobiotics only recently introduced. The microbial acquisition of metabolic competency for biodegradation of these substances occurs through natural selection and can be explained mechanistically by the modification of preexisting enzymes and metabolic pathways to accommodate a novel substrate. Copley has shown how this process works for halogenated organic compounds, which are notoriously refractory (Copley 2000, 1999, 1997). Her work has both experimental and conceptual components.

Copley also has collaborated with Ray Fall in studies of bacteria as sources and sinks of isoprene (Fall and Copley 2000), as an extension of Fall's earlier work on the emission of isoprene by plants. This is a good illustration of the types of collaboration that occur easily within CIRES.

Copley changed her departmental affiliation from Chemistry to Molecular, Cellular, and Developmental Biology (MCD Biology) in year 2000. Both departments are very strong, but MCD Biology has a much stronger representation of individuals who are directly interested in the types of processes that Copley studies.
Shelley Copley has been the key unofficial representative of biological interests within CIRES. In a CIRES retreat during 1997, she organized a presentation intended to persuade the CIRES Fellows that they should consider recruiting additional biologists to be Fellows of CIRES, on grounds that the biological component of environmental sciences is strongly connected to other components of historical strength within CIRES. Her presentation was well received by CIRES Fellows, although subsequent change has occurred fairly slowly. As a means of consolidating biological interests across divisions, Copley organized a Biology Supergroup, which has been quite successful in its seminar series dealing with subjects that are directly biological or that are strongly connected with biological aspects of environmental science.

Carol Wessman became a Fellow of CIRES in 1991 following her Ph.D. work at the University of Wisconsin Madison and a postdoctoral position with the CIRES Center for the Study of Earth from Space (CSES). A Byzantine administrative process at CU solved several problems simultaneously and resulted in Wessman's hire, which was highly beneficial to CSES and to CIRES. Events leading up to Carol's hire began with the staffing of CSES, which was created by Alex Goetz, a Fellow of CIRES. Goetz's vision involved recruitment of new faculty spanning a range of disciplines that would give the Center broad capability in the application of remote sensing to analysis of the environment. Because terrestrial vegetation is readily sensed remotely, and because it is a key environmental indicator that potentially yields substantial information extending well beyond mere indications of land cover (Wessman 1989, 1988), Goetz wanted to recruit a biologist with interests in remote sensing for one of the faculty positions designated for expansion of CSES. The position was filled through the hire of William
Bowman from Duke University, but the match of interests between Goetz's program and Bowman's research was poor. The Institute of Arctic and Alpine Research (INSTAAR) happened to be looking for a full-time director with a faculty line about the time that this mismatch within CSES became evident. Also, Carol Wessman, who was present as a post doc within CSES, appeared to be admirably well suited for the niche that Goetz had visualized. Bill Lewis, who was Chair of EPO Biology at the time, brokered an arrangement whereby Bowman vacated the faculty line within CSES (CIRES) and was transferred to INSTAAR with a tenure-track position in EPO Biology and an assignment to serve as director of the Mountain Research Station. The open position thus created within CSES was filled with Carol Wessman. So many signatures were required for this arrangement to occur that the Academic Vice Chancellor dubbed it the "cosmic agreement." The good fit between CSES and Wessman has been fully confirmed by the passage of time.

Wessman has strong expertise in ecosystem science and landscape ecology (Burke et al. 1998). She also has widely recognized knowledge of methods for developing new applications of remote sensing data and geographic information systems to study ecological phenomena (Bateson et al. 2000). Thus, she is one of only a few individuals in the U.S. with well-balanced abilities to deal with the complexities of remote sensing and GIS technology while also working at the state of the art in ecological analysis of ecosystems and landscapes.

Climatologists are preoccupied with the problems of downscaling, i.e., converting global models to the analysis of phenomena at the regional or local level. Ecosystem scientists, on the other hand, are more frequently occupied with the problem of scaling
up, i.e., making observations on specific ecosystems and generalizing them or testing them against the behavior of landscapes or regions. Satellite imagery is a long recognized tool for scaling up, but it is useful insofar as spectral information can be converted to information on structure and function of ecosystems. The contributions of Wessman and her students to the solution of this problem have been diverse and considerable. They include the mapping of deforestation and vegetational change (Hudak and Wessman 2001, 2000). They also include use of spectral data to resolve canopy structure (Asner et al. 1998) and absorption of photosynthetically-active radiation (Asner et al. 1998), as well as other landscape-scale phenomena such as fire and grazing (Wessman et al. 1997).

Russell Monson is the most recent addition to the biologists among the CIRES Fellows (1999). Monson can be classified as a plant ecophysiologist, but he has done a considerable amount of synthetic and collaborative work that has taken him well into the realm of plant population ecology (Figure 2) and beyond. Like Fall and Lewis, he was recruited as an established faculty member in an academic department (EPO Biology); his faculty line remains in Arts and Sciences. He joined the University of Colorado in 1982 after having obtained a Ph.D. in botany from Washington State University.

Monson's work on the ecophysiology of plants began with studies of photosynthesis and water economy in desert plants (Monson and Szarek 1979, Monson and Smith 1982). His early work also included extensive comparison of C3 and C4 plants (physiological categories of plants that have different types of photosynthetic carbon metabolism); some variations on these themes have continued in his work up to recent years (Monson 1999). During the 1980s, Monson collaborated with Ray Fall on the
study of isoprene emissions from vascular plants (Monson and Fall 1989), and this work has continued in various forms (Monson et al. 1995, Lerda et al. 1997). He also has worked on other volatile organic substances released from vascular plants, and on the general ecological significance of volatile emissions from plants (Litvak and Monson 1998). He is widely recognized as an authority on the contributions of plants to volatile organic compounds in the atmosphere. His work on trace gas fluxes has reached a valuable synthetic phase involving extensive collaboration (Monson and Holland 2001).

Monson and collaborators also have studied uptake of amino acids from soils (Raab et al. 1999). This work has contributed to the understanding of organic nitrogen sources in sustaining the nitrogen metabolism of plants, which often have been treated as being completely dependent on inorganic nitrogen to sustain protein synthesis.

Monson's addition to CIRES not only filled in an important gap in the representation of the biological sciences in CIRES (Figure 2), but also cemented a scientifically compelling linkage between atmospheric chemistry (Fehsenfeld, NOAA Aeronomy Laboratory), biochemistry of plant emissions (Fall), and ecophysiology of plants (Monson). Although a member of CIRES for only a few years, Monson is already regarded as a leading advisor to CIRES on matters related to biological sciences. He is currently serving as Chair of EPO Biology, and has headed a University-wide review process on the future of biological sciences on the Boulder Campus.

The future of biology in CIRES is uncertain. The record shows incremental increase in commitment to biology within CIRES over the last ten years, but primarily through internal rather than external recruitment. The CIRES Fellows supported an attempt at additional external recruitment through a job search for a microbial ecologist.
This search occurred in 1997 and again in 2000 and in 2001. The first search, which was conducted jointly with EPO Biology, failed when the two units disagreed on the top candidate. The second and third searches, which were conducted in collaboration with MCD Biology, also failed, even though CIRES found candidates in both searches that it viewed with satisfaction. Failure of the searches was due to the judgment of MCD biologists that there was no candidate among the interviewees who could meet the special combination of disciplinary specifications and experience of a new faculty member in MCD Biology.

Microbial ecology is an obvious avenue of advance for biological science in CIRES. Microbes are directly tied to metabolic processes that govern the composition of the atmosphere, an established theme within CIRES. Microbes also are responsible for transformation of xenobiotic compounds, a subject of central interest to Shelley Copley's research group, and for biogeochemical processes of direct interest to the Center for Limnology. Thus, a microbially-oriented environmental biologist would broaden CIRES biologically by adding a field of specialization not yet represented, and at the same time would complement existing work in CIRES. Although this logic has been convincing to the CIRES Fellows, the difficulty of filling the position has been frustrating and may have blunted enthusiasm for developing biology further within CIRES.

Water Science in CIRES

CIRES has passed frequently through comprehensive reviews as required by the University and by the contract between CIRES and NOAA through the University.
These reviews, which have involved self study as well as analysis by external reviewers, have consistently shown CIRES to be a vigorous institute with diverse capabilities, a healthy rate of growth, excellent visibility, and high scientific impact. In the face of reviews such as these, motivation for any major change has understandably been quite low. Thus, the general mindset of the CIRES administration and CIRES Fellows has been to expand in areas of excellence and to diversify very gradually in areas of study that are connected as directly as possible to established areas of excellence.

During 1997, at the instigation of CIRES director Susan Avery, CIRES held a retreat. This atypical or even unprecedented activity stimulated some unusual forethought, perhaps because it was self directed rather than externally directed in response to the formal requirements of program review. Some of the CIRES Fellows, and notably Fred Fehsenfeld, concluded that the retreat should include some consideration of major programmatic issues packaged as specific proposals. After informal discussions, Fehsenfeld, with encouragement from others including director Avery, presented a proposal for expansion of CIRES programmatically into the area of water science. The rationale for this proposal was twofold. First, partly due to accidents of ontogeny, the aquatic branch of environmental sciences had been very weakly developed in CIRES as compared with the atmospheric branch and the branch dealing with the solid earth. Second, increased emphasis on water science could be devised in such a way as to be entirely complementary to existing programs, i.e., it did not necessarily imply compromise of existing strength to development of an entirely new enterprise. Fehsenfeld's presentation was carefully crafted and very persuasive; he received a sound endorsement of his proposal from the CIRES Fellows at the retreat.
The CIRES water initiative was strongly embraced by CIRES director Susan Avery, who pushed for its rapid development. Rapid programmatic development required a new and preferably continuing commitment of external funds that could be broadly applied to diverse subjects in water science. Even with new external funding, the acquisition of new faculty lines at the University would be impractical over the short term. Therefore, it was also decided that the program should be initiated by mobilization of the current personnel of CIRES with interests in water science and by organization of the University of Colorado's considerable capabilities in the field of water science outside CIRES. Director Avery assumed personal administrative control of the program, and appointed CIRES Fellow Bill Lewis to serve as organizer.

A number of group decisions shaped the early development of the CIRES water initiative. The decision-making group varied somewhat through time, but consistently included Avery and Lewis as well as Randall Dole and associates in the NOAA Climate Diagnostic Center (CDC), Roger Barry and associates of the National Snow and Ice Data Center (NSIDC). It was decided that the CIRES water initiative should be based on a regional, end-to-end view of the water cycle (Figure 3). This would allow liberal inclusion of the expertise of CDC in climate and the expertise of NSIDC in linkages between climate and hydrology. The Center for Limnology then could cover the environmental quality aspects of the program. The main deficiency internally for CIRES
Figure 3. Schematic diagram of the scope of the CIRES Western Water Initiative.
was in the field of social science, including demographic and economic drivers of water use, vulnerabilities of society to irregularities in water availability, and other matters that cannot be ignored in the West, where water is intensively managed for consumptive use.

The region of interest for the CIRES water initiative was defined as the Interior West, which encompasses the prolific water source areas of the southern and south-central Rockies as well as the adjoining plains to the east, where water is intensively used and managed (Figure 4). Thus, the region of interest is an excellent arena for studying relations between climate and the availability of water and the hydrologic, environmental, and social issues that arise as water is intensively used.

The gap in social sciences was to be filled by recruitment of social scientists from the CU Boulder Campus. William Travis of the Geography Department, a specialist in demographic trends and land use, and Charles Howe, a member of the Economics Department and specialist in the economy of water, were brought into the program at an early stage.

Conceptual development of the water program in CIRES to a large extent was tailored to the capabilities of CIRES and the research interests of CIRES Fellows who would be logical participants in a water-oriented program. The development of the program fortuitously coincided, however, with the expansion of a program within NOAA that appeared to offer good prospects for core support of the initiative. This program, which was developed within the Office of Global Programs (OGP) at NOAA, consisted of a set of regional assessments typically involving some combination of climate and water. The program was framed very loosely and was intended to operate through
Figure 4. Depiction of the scope of focus for the CIRES Western Water Initiative.
The underlying concept was to allow universities, in collaboration with scientists from NOAA or other agencies, to approach the topic of regional assessment in an innovative way. While there were no rigid requirements, the assessment clearly was aimed at developing integrated views of natural resources in relation to climate in a multi-disciplinary manner, with a view toward developing products or tools that would be of interest to users of information on water or other resources affected by climate. The program was intended to operate in the mode of research, however, and was not intended to perform extension service on a routine basis.

The planning group for the CIRES water initiative decided that the match of its objectives with the OGP regional assessment program was irresistibly good, and thus embarked on an effort to write a pre-proposal that might lead to development of a long-term funding base for the CIRES water initiative, which had assumed by this time the name "Western Water Initiative" or "Western Water Assessment." The pre-proposal was completed in 1998 and was funded by NOAA OGP.

After the funding of the pre-proposal by NOAA OGP, the CIRES Western Water Initiative was successful each subsequent year in obtaining additional support. CIRES hired a full-time research assistant, Diana Perfect, to maintain communication among the research groups and maintain liaison with NOAA OGP in Silver Spring, Maryland. She was an invaluable asset to the development of the program, but departed for an attractive position with NOAA in Washington during 2001. Following the funding of the pre-proposal and the first year of full support, Lewis stepped down from the organizing role, which was subsequently taken over by a management team consisting of six of the main
participants and directed by Susan Avery. As of year 2001, the initiative had been invited to submit a five-year proposal, which would provide more continuity if it is funded.

The Western Water Initiative's research program has developed strongly along several lines, and it is still developing. Climate, which is important to the initiative in that it is a key control over water availability in the Interior West, has been treated analytically by NOAA CDC personnel as potentially predictable with increased lead time through relationships involving synoptic climate variation such as that associated with the El Niño Southern Oscillation (ENSO) or the Pacific Decadal Oscillation (PDO). Relationships between climate and ENSO have been investigated most thoroughly. Results to date have shown that the relationship between ENSO and climate characteristics is more complicated in the Interior West than it is in the Southwest. CDC has made some headway, however, in development of conditional predictions. In addition, CDC personnel have put considerable effort into downscaling GCM modelling to a regional scale that would be useful in the Interior West (Dole 2001).

On the hydrologic front, researchers from NSIDC have worked intensively on linkages between climate and hydrology (Clark and Hay 2000). The linkages can be identified in useful form only through models that take into account a wide variety of variables that control the delivery of snowpack to stream channels. Both the timing and the amount of the hydrologic influence from a given amount of snowpack involve climatic variables such as temperature and solar irradiance. In addition, topography plays a role. NSIDC is collaborating with USGS in this modelling effort.
Studies on environmental quality focused initially on relationships between climate variability, low stream flows, and water quality (Saunders and Lewis 2001). Control of climatic conditions by synoptic influences suggested that standard practice for identification of critical low flows for purposes of water quality protection were flawed insofar as the window of analysis for hydrologic variables is too narrow to represent extremes of low flow. Correct estimation of low flows is important because the low flow that is estimated for purposes of wastewater discharge permitting is assumed to be available for dilution of waste. Overestimation of the low flow means that insufficient dilution may be available for dilution of waste from point sources. Low dilution threatens aquatic life and water supply for municipalities and agriculture. An analysis of extended hydrologic records including episodes of drought showed that typical analysis in support of permitting for wastewater discharges is flawed, especially when the hydrologic record is shorter than ten years. Records shorter than ten years are, however, the rule rather than the exception. Thus, regulators may need to anticipate error in the estimation of low flow from any analysis involving a short record.

The environmental quality group also has expended considerable effort on studies of the relationship between climate variability, water management, and stream metabolism. Stream metabolism is under the control of flushing flows, which move fine organic material that is accumulated in the streambed during periods of low flow. The probability of flushing flow is a byproduct of water management and climate variability. The working hypothesis, which is supported by initial findings, is that extended intervals of low precipitation suppress the likelihood of flushing flows, thus producing unusual and undesirable metabolic conditions in rivers of the plains. Occurrence of these conditions
can be moved into the realm of probabilistic prediction through a linkage with the hydrology group and the climate study group of the initiative.

The social science group (social science/user needs, SSUN) presently is directed by Professor Charles Howe, although it functions mainly through committee work involving approximately ten participants. Work of this group to date has included workshops intended to reveal the needs of water managers for various kinds of hydrologic information that might be derived as byproducts of research such as that conducted by the initiative. Studies also are being made by interview concerning the receptivity of water managers to additional information on climate or hydrology as related to climate. Potential consequences of major changes in water allocation (which presumably would correspond to changes in water law) also are being considered in the context of a widely-recognized need for greater flexibility in reallocation of water and especially under extreme climatic conditions. Finally, the SSUN group is supporting the development of a model that can take into account changes in demography, water use, economic factors, and hypothetical reallocation schemes and show the consequent changes in stream flow or water availability geographically. The focus of the model is on the South Platte Basin, where many of the Western Water Initiative studies are now centered.

CIRES has considerable expertise in water outside the Western Water Initiative. In 1988, CIRES hired Vijay Gupta, a senior hydrologist with a fine reputation for his work in the mathematical analysis of drainage networks (Gupta 2000). Gupta was one of a handful of influential U.S. hydrologists who made a successful effort to reinvigorate scientific hydrology through the creation of a new hydrologic sciences funding program.
at NSF. This was one step toward remedying the imbalance between science and engineering in hydrology (NRC 1991). In 2000-2001, Gupta was responsible for a major programmatic upgrade and redesign of funding for hydrologic sciences through NSF.

Tom Chase, who was hired as a CIRES Fellow in 1999, analyzes influences on climate from the viewpoint of land use and land cover (Chase et al. 2000). His general working hypothesis is that there is an important feedback loop between land use and climate at local to regional scales.

Aside from the CIRES Fellows, CIRES has a number of scientists engaged in studies of water but not working on the Western Water Initiative. At various phases in the development of the Western Water Initiative, there will likely be some rotation of individuals into and out of the Western Water Initiative.

CIRES made a major change in year 2000 through the recruitment of its first social scientist, Roger Pielke, Jr. Ten years previously, the advisability of recruiting a social scientist was discussed by the Fellows and, although the idea received some support, it was generally viewed as very inadvisable and unjustifiable. By year 2001, however, with the virtual insistence of NOAA OGP that policy questions be integrated into the Western Water Initiative as part of the NOAA-supported assessment program, and the development of parallel viewpoints on the part of other science-support agencies, the perspective of the Fellows had changed markedly. Endorsement for the hire of Pielke, who previously had been working at NCAR, was very strong. In 2001, he created the Center for Science and Technology Policy Research within CIRES, and began involvement in the Western Water Initiative and other programs of interest to CIRES.
Conclusion

Most of the diversification of CIRES programs over the last ten years has occurred through gradual expansion in the commitment to biology and initiation of a sustained program in water science. There seems to be no general regret among the non-biologists as to the CIRES commitment to biology. At the same time, other disciplines that have been historically much stronger than biology within CIRES make convincing arguments that excellence in a few specific areas is extremely important to the aggregate strength of CIRES and must be preserved and even extended if CIRES is to be as successful in the future as it has been in the past. This is a familiar argument often played out within academic departments as they consider hiring. In departments, however, there is a mandatory or at least an ethical commitment to diversification because instructional needs, which are diverse, must be served through disciplinary diversity among the teaching faculty. Within CIRES, this constraint is much weaker because CIRES does not have formal teaching responsibilities, even though those of the Fellows who are university faculty members teach extensively for their departments. Thus, one of the most important questions for CIRES to consider in the future with respect to both biology and water science is the value of diversification as opposed to the use of resources for those areas of excellence that are already best developed within CIRES. The direction of both the biology and water programs in CIRES will be strongly influenced by the weight of opinion among the Fellows and the CIRES administration on this matter.
References


