ARROYO

Vol. 3 No. 1

April 1989

Much Studied, Often Discussed, Climate Change Remains an Open Issue

The changing of the Earth's climate, which is a topic of increasing concern, is a complex issue. Much more than a meteorological phenomenon, climate is a force that helps define our social environment, as well as our relationship to the natural world. Therefore, the effects of climate change—whether parts of the earth are becoming wetter or drier, or hotter or colder—would be broad and profound.

Climate change is a natural and recurring process. Recently, however, it has attracted special attention because of concern about the so-called "greenhouse effect." In brief, a greenhouse effect results when carbon dioxide (CO_2) and other greenhouse gases in the atmosphere trap solar heat. The Earth's atmosphere then acts like the glass in a greenhouse, and a warming of the Earth's climate could result. Because of a recent and rapid buildup of CO_2 in the atmosphere the greenhouse effect, which has always been part of the Earth's system, could now have a more significant and possibly worrisome influence on the Earth's climate.

As a result, climate change—its extent, its global occurrence, its effects and, indeed, whether permanent climate changes are in fact occurring—is a topic of intense investigation. Scientists are examining past and present environmental conditions to better understand how the

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climatic system works. At the same time social scientists are studying climate change to understand its implications for public policymaking.

Scientists are now gathering and analyzing a great and varied range of information about climate change in an effort to improve our understanding and predictive abilities. Included among these scientists are researchers at Arizona universities. They include geoscientists, hydrologists, geographers, ecologists, atmospheric physicists, tree-ring researchers and political scientists. Together they are working to better understand the occurrence, extent and impact of present and future climate changes.

Since Arizona researchers are involved in a range of climate change studies, the issue will be reviewed by discussing various research projects that address key climate change concerns. A review of this research will help convey the multidisciplinary focus of climate change studies; their global, regional and local concerns; and their involvement with broad spans of time, past and future as well as the present.

Much more climate change research is being done in Arizona than is described in this newsletter. The projects that are included were selected to represent the range of research being done in climate change studies, as well as to bring out some of the chief concerns associated with the issue.

Broad Implications of Climate Change

The work of Arizona researchers will be more fully appreciated if the broad implications of climate change are first discussed. An issue of far-reaching implications, climate change, when viewed in a broad perspective, is ultimately concerned with complex relationships involving climate, the Earth and its resources, and social, political and institutional activities. It is this complexity that challenges climate change researchers.

A scenario will help demonstrate this complexity. If the Earth's temperature rose, the snow line or freezing elevation would occur at higher altitudes. This in turn would have an effect on the supply and management of water resources in the Southwest.

(Although many speculate about climate change in Arizona and the Southwest, little knowledge exists about its effects, extent, or even its occurrence in the region. Scientists, even those who believe that a global greenhouse warming trend is in progress, do not claim to be able to predict the precise amount of warming, nor its regional distribution and effect. As a result, the following is a hypothetical situation.)

If the snow line or freezing elevation were to rise in Arizona and the amount of precipitation remained the same, less moisture would be stored as snow in the White Mountains or the Mogollon Rim during the winter months. Instead, winter precipitation in these locations would fall as rain or quickly melt off causing winter floods along major tributaries of the Salt and Verde Rivers.

Further problems would develop when western streamflows during April through June are greatly diminished for lack of late snowmelt from the higher elevations. Agricultural areas in the Southwest that rely on this seasonal flow would be adversely affected. Other sources of water for agricultural uses would be needed for areas downstream of reservoirs or small storage facilities.

Streamflows might be further reduced through an increase in the evapotranspiration rate. Plants would use increased moisture because of the higher temperatures, with an additional moisture loss resulting from increased evaporation. As a result, even less water would be available as runoff from watersheds.

The change in the hydrologic runoff pattern would have severe consequences for water supply systems with a finite amount of storage, such as the Salt River Project. With increased winter runoff, storage facilities would fill, and excess water would need to be spilled. This would result in less water available for year-round use. Additional groundwater may need to be pumped, and strict conservation measures may be required.

More dams might be proposed to create larger reservoirs for storage in certain areas. The success of such proposals, however, would involve changes in present attitudes, since the construction of large-scale water projects is presently in disfavor. Approved during a previous era, such projects were later found to have excessive economic and environmental costs and, as a result, became socially and politically unacceptable. If additional water storage capacity were needed, possibly the economic and environmental costs would be reconsidered.

If major and extensive new water projects were to be built strong federal backing would likely be needed. This could result in the reappraisal of another current development. The federal government has been reducing its support for new large water development projects and has become less involved with issues associated with water resources. As a result, states are more actively engaged in managing their water resources. This trend toward decentralized state decision making in water affairs would most likely be effected if the federal government again needed to contribute extensive financial backing for water projects.

Other activities that could be affected by a change in the hydrologic runoff pattern would include hydroelectric power production, recreational activities and instream flows to support fish and wildlife.

The above scenario is one among

many that might occur with an increase in temperatures. Many other regional climatic possibilities exist. The discussion, however, is meant to emphasize that climate change, whatever form it may take, is not without significant economic, social, political and institutional consequences.

The Greenhouse Effect

Much of the current interest in climate change is the result of debate about the greenhouse effect. This debate involves questions about the occurrence of the phenomenon, its extent and its present and future effects on climate.

In brief, a greenhouse effect results when the Earth's atmosphere traps heat transmitted from the Earth's surface. Sunlight first passes through the atmosphere to strike the Earth, with some of its energy reradiated back through the atmosphere at a longer wavelength. Certain atmospheric gases, including water vapor and CO_2, then absorb some of this energy causing a greenhouse effect. A greenhouse effect is natural and supports life.

But concern about the greenhouse effect is presently mounting because scientists have found that the atmospheric gases that cause the effect are increasing. For example, scientists have measured a current 0.4 percent annual increase of atmospheric CO_2 and have determined that a 25 percent increase of CO_2 has occurred during approximately the last century.

Chlorofluorocarbons, methane, nitrous oxide and numerous other greenhouse gases are also increasing in the atmosphere. With an increase of such gases in the atmosphere more energy is absorbed, heightening fears that the expanded greenhouse effect will raise global temperatures.

Various human activities are responsible for the buildup of greenhouse gases in the atmosphere. For example, the burning of fossil fuels to support industrial development is a major contributor of CO_2 to the atmosphere. Also, increased CO_2 in the atmosphere is partly the result of deforestation. As trees are destroyed to create more farmlands less CO_2 is converted into oxygen.

William D. Sellers, professor of atmospheric sciences at the University of Arizona, studies atmospheric records to determine the effects of increased CO_2. He has found that the most noticeable atmospheric change occurring is a cooling of the stratosphere or the upper atmosphere. Sellers believes that this cooling, which has been one to two degrees Celsius during the past 30 years, may be the the result of the buildup of greenhouse gases.

Many anticipate the cooling of the upper atmosphere, along with a warming of the lower, as greenhouse effects. Although Sellers has noticed upper atmospheric cooling, he has not yet found any significant evidence of a warming of the lower atmosphere. As a result, Sellers does not believe that conclusive evidence exists that the Earth's surface is presently warming from a greenhouse effect.

Further, Sellers has studied Arizona temperatures that have occurred since 1895, the earliest year of accurate temperature records. He has noticed that Arizona temperatures have been above the long-term average since 1976 but are still lower than temperatures that occurred at the turn of the century. As a result, he is unable to determine whether the present warm spell is the result of greenhouse warming or whether it is a natural variation.

San Ildefonso pottery design of leaf clusters with distant rain

Climate Change and the Study of the Past

While some scientists study current conditions to determine the presence of a greenhouse effect, others focus on past situations to better understand climatic dynamics and the possible effects of greenhouse warming. In fact, much research related to climate change focuses on the past, for the climate that prevailed in the past provides clues to what may occur in the future. Further, by reviewing past environmental conditions, scientists are better able to distinguish human-caused climate changes from those that occur as part of natural fluctuations. Important questions can then be better answered. For example: Are recent climatic events, such as the summer heat of 1988, harbingers of a new global climate being brought about by the greenhouse effect, or do they fit into a natural and recurring weather cycle?

Information about the past also has a direct and specific use. Computers are being used extensively to develop and operate models which simulate the complex interactions of numerous variables that together create global climatic conditions. Included in the models are such variables as the amount of solar energy entering the Earth's upper atmosphere; the relative position of the sun and Earth as it affects the seasonal variance of solar energy reaching the Earth; and the transfer of heat between ocean surfaces and the air.

The models are used to simulate past and present climatic situations, as well as to help predict future conditions in response to selected changes in input variables, such as an increase in CO_2. The accuracy of a model can be determined by comparing simulated data of a past period with information about the same period obtained through research. The degree of similarity between the simulated and researched information determines the accuracy of the model and its use in other situations.

Basically, however, the study of past atmospheric conditions helps scientists to better understand the Earth's total climatic system. Climate is the result of the complex workings of the lithosphere, the physical climate system, and the biosphere as each evolves, changes, and interacts. Data and information about the climatic past contributes to an understanding of the entire process.

Judith T. Parrish, associate professor in the UA geosciences department, studies global patterns of ancient Earth climates that occurred up to over 200 million years ago. This time period stretches beyond what some researchers believe is directly relevant to an understanding of present and future climatic dynamics.

Parrish believes, however, that it is essential to study ancient climate, especially during periods of extreme conditions, to increase our understanding of the total climatic system. An understanding of these conditions will help researchers who now confront the possibility that the earth system may again experience extreme conditions, this time, however, through human intervention.

Parrish's work includes studies of the late Cretaceous period, which occurred between 65 and 97 million years ago. At this time vast coal and oil reserves were deposited. It was also a time of high global temperatures, possibly caused by a high CO_2 level in the atmosphere, a condition that may be developing today.

To determine the temperatures at that time, Parrish, along with a paleobotanist, studies fossil vegetation from the north slopes of Alaska. Alaska was selected as a site because climate change more strongly affects polar regions than lower latitudes. During the late Cretaceous period Alaska was closer to the pole than at present.

The fossils are analyzed for climatic information. The size and types of trees from the period provide evidence of moisture as do rings from tree fossils. Broad leaf fossils are especially helpful because they provide a quantitative measure or index of temperatures. With climatic conditions known for that high latitude and during a specific time, global temperatures can then be calculated.

Parrish is also studying climatic conditions during the period when the present continents were aggregated into a single land mass or supercontinent now called Pangea. This was a period between 165 and 285 million years ago. Since climate is more extreme in midcontinent than closer to its edges, the climate in the interior of Pangea was very extreme and exerted a dominant global climatic force. A study of this extreme climatic condition enables researchers to better understand the climatic system under far less intense conditions.

Various Methods to Study Past Climates

Some researchers examine the more recent past by a specialized study of various signs and signals of past climatic activities. These include desert varnish, tree rings, and fossilized pollen. The various indicators are sensitive to different environmental conditions and together form a composite picture of past climatic events.

Ron Dorn, professor of geography at Arizona State University, studies desert varnish to understand very long-term cycles of environmental change in the desert. Desert varnish is atmospheric fallout or dust that accretes to a rock surface. A concentration of manganese and iron cements the varnish to the rock. The relative amounts of manganese and iron present in the varnish indicate how alkaline the atmospheric fallout was when a layer of desert varnish was deposited.

A high manganese concentration indicates low alkaline fallout which, in turn, indicates a time of abundant moisture. Conversely, if the manganese concentration is low, the desert dust is more alkaline indicating drier conditions. (Dust from the Sonoran Desert is presently very alkaline.)

Surface layers of desert varnish represent the present, and layers are correspondingly older as they are taken further from the surface. Dorn is able to establish a timeline by collecting varnish from lava flows that have been dated, for example, to one million years. He then knows the date of the oldest layer of varnish and, assuming a uniform rate of deposition, he can determine how many alkaline fluctuations occurred over a million years. This represents an extensive record of climate change in a desert environment.

Desert varnish provides other important climatic information. Dorn is presently analyzing desert varnish to help establish an analog between a past situation and a possible future greenhouse condition. Desert varnish forms on ventifacts, which are wind-abraded rocks.

By studying the layering of varnish on ventifacts, the wind direction at the time the rocks were formed can be determined. The record of wind direction as preserved by the varnish on the ventifacts enables researchers to reconstruct wind circulation. Such information is intended to be compared with contemporary climatic signals to help determine if greenhouse conditions are presently influencing the Earth.

Dorn is studying ventifacts that formed about 5,000 years ago during a warm period in the mid-Holocene. Some believe this period shares conditions with those that may develop in a future greenhouse situation. Dorn is conducting this research in collaboration with the ASU Laboratory of Climatology.

Researchers at the UA's Laboratory of Tree Ring Research are studying tree rings to reconstruct the history of climate and water supply. The laboratory is recognized worldwide for its work in this field, which is called "dendroclimatology."

Trees usually grow a new layer of wood annually just under the bark. If a cross section of a tree is examined, a distinctive pattern of rings is observed, each ring consisting of a separate layer of wood. The rings are datable to their exact year, and each records climatic information. As a result, dendroclimatology is able to precisely date climatic conditions recorded by the rings.

Researchers obtain various kinds of climatic information from the rings. To determine the amount of moisture during various years, the rings are carefully measured. Wider rings indicate years of greater moisture. Thin rings reflect dry years.

Further climatic information is obtained by analyzing X-rays of tree rings. X-rays allow researchers to interpret wood density. Since wood density is affected by temperature, an analysis of a ring provides information about the temperatures that prevailed during the growing season of a tree.

David M. Meko, associate staff scientist at the UA Tree Ring Laboratory, along with Charles W. Stockton, professor of dendrochronology at the laboratory, have studied tree rings in the western United States to determine if variations in runoff have been consistent throughout the region over time. Although no long-term runoff records exist, runoff can be inferred from tree rings.

This research indicates that the entire region experienced a wet period in the early 1900s which peaked at about 1915. After that time runoff dropped significantly, with the duration of dry conditions depending upon geographic variables. Drying continued longer in southern locations, with Arizona still feeling the effects in the late 1950s. Dry conditions continued for shorter periods of time in northern locations. They generally ended in the late 1930s in Montana. This swing between dry and wet was the most extreme of the time period covered, 1700 to 1960.

The research provides no definite evidence of regular cycles of wet-and-dry periods in the West. In the south and central areas of the West, however, certain variations occur, usually every 20 to 25 years. They are not regular enough though to establish a predictive pattern.

The study of tree growth has an additional application to the study of climate. Some scientists believe that an increase of CO_2 in the atmosphere might result in additional tree growth. Laboratory research indicates that additional tree growth has, in fact, occurred in the mountainous regions of the West. Researchers believe, however, that it is the result of high precipitation in the late 1970s.

Analog Found for Study of Greenhouse Conditions

Two Arizona researchers analyze pollen to determine climatic histories—Owen K. Davis from the UA geosciences department and S. Scott Anderson of the Northern Arizona University Quaternary Studies Program. They collaborated together on an Environmental Protection Agency (EPA) project to study fossil pollen to identify a modern analog for a past condition. The study will help determine what future climatic conditions might prevail in central California, if the area is affected by greenhouse warming.

To obtain climatic information from pollen an index or measure needs to be established to relate pollen to climatic variables. This is done by measuring the pollen rain in modern vegetation zones under different climatic conditions. For example, pollen rain would be measured in the Sonoran Desert, in piñon juniper woodlands, ponderosa pine forests, and other vegetative zones.

Once extensive information is gathered about modern pollen rain in various vegetative zones it is matched with climatic data from those same areas. Through statistical analyses pollen and climate can then be related. An index is thus established that can be used to interpret pollen from fossil records.

This technique was used in the EPA study. The study would establish how plants actually responded during a period with temperatures that are expected to be achieved in the future through greenhouse warming.

The researchers examined pollen from meadows and lakes in central California. They determined that about 9,000 years ago the climatic conditions were probably fairly similar to what might be expected in 100 years, if the greenhouse effect is fully operative.

The conditions identified by the two researchers matched the results of a computer simulation of the environment at that time. The researchers found that instead of today's fir and pine forest, pine and open vegetation would dominate.

Analogs are useful tools, but Davis cautions that they have limitations. He explains that the global warming of 9,000 years ago occurred because of increased solar energy concentrating on the northern hemisphere. This increase was balanced by a decrease of solar energy in winter. During the next century, however, the warming is expected to occur year-round, summer and winter.

The researchers also identifed policy implications of climate change in the central Sierra Nevada. Decreased timber production could be expected, resulting in lost revenue. Also, a general rise in temperatures would attract tourists to the higher elevations of the Sierra Nevada at a time when the area would be more susceptible to ecological damage. As a result, the number of tourists allowed in the area might need to be regulated. Further, reduced precipitation in the western Sierra might encourage the planning of additional reclamation projects to store water.

Interpreting Recent Climatic Developments

Along with exploring the past, scientists are also investigating present conditions. For example, researchers at the Laboratory of Climatology at Arizona State University have studied the warming of the Phoenix area from rapid urbanization. They describe the Phoenix of the 1950s as an extensive agricultural community with about 2.7 million acres of farmland within Maricopa county. Agricultural activities increased the humidity of the valley which, in turn, cooled the area.

As Phoenix became more urbanized moist farmlands were replaced with hard surfaces such as pavements and buildings. These surfaces absorb heat and release it more slowly than the natural surfaces of desert lands. As a result, temperatures increase. At the same time, urban activities cause pollutants to enter the atmosphere. Polluted air absorbs radiation and reflects heat back to the Earth's surface. This becomes another source of warming. Further, the warm air that rises over the city is very stable. As a result, the city receives less cooling winds and less cloud cover.

Night temperatures are more reliable as indicators of urban heat island effects. The average summer minimum nighttime temperature during 1948-49 was 72.6° F and during 1980-84 was 80.3° F, a significant increase.

Through such techniques as the analysis of historical records and the interpretation of satellite images, researchers at the laboratory have been able to identify the shape and strength of heat islands within Phoenix. Most urban areas, especially those located in the Sunbelt, create similar conditions that increase warming in their areas. Some researchers believe that what is interpreted as a global warming is mostly the result of the more focused effects of urban heat islands.

Soroosh Sorooshian from the UA Department of Hydrology and Water Resources is also involved with a project that is concerned with current climatic conditions.

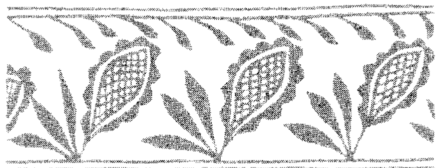
Sorooshian was recently selected by the National Aeronautics and Space Administration to participate in the Earth Observing System (Eos). Eos, which is expected to be proposed for development beginning in fiscal year 1991, is a long-term science mission to study the entire Earth system on the global scale. Sorooshian's contribution, however, will be to study climate change at the smaller, hydrologic scale.

Sorooshian is the principal investigator of a research team that also includes David Woolhiser and David Goodrich. Both co-investigators are from the Agricultural Research Service of the US Department of Agriculture. Woolhiser is also a UA adjunct professor in the Department of Hydrology and Water Resources, and Goodrich is a doctoral candidate in the same department.

Sorooshian will obtain remote sensing data from spacecraft launched as part of the Eos program. The data will include hydrologic information on such characteristics as soil moisture, vegetation cover, atmospheric vapor, evapotranspiration, precipitation and snow cover. Sorooshian will then investigate whether climate modeling capabilities presently exist to process this hydrologic information.

This project is significant since most of the current climate models focus on global-scale conditions, and hydrology traditionally is concerned with a smaller spatial scale, such as a watershed or river basin. Instead of a grid about the size of Arizona, which is what a global climate model provides, hydrologists seek more specific regional, and even local, information. Sorooshian's main concern is to develop hydrologic or distributive models that will effectively utilize the remotely sensed data.

Such a distributive model would enable researchers to study the relationship between climate change and hydrology. For example, various possibilities may result from a greenhouse effect, including increased precipitation in the Southwest. A distributive model would consider spatial and temporal variables and be able to analyze what effect increased rain might have on runoff in the state.



San Ildefonso pottery design of corn with rain

Public Policy and Climate Change

As mentioned in a previous section global climate change is an issue in the process of being defined. Research has been described that is helping define the issue by addressing various scientific concerns. A discussion of climate change, however, would not be complete without also reviewing its implications for public policy. The policy actions that are taken or not taken further define the climate change issue.

Basic to the public policymaking process are facts to support informed decisions. Enough is known about atmospheric conditions—i.e., greenhouse gases are rapidly building up—to raise the spectre of an impending crisis and alert policymakers to the need to act. Not enough is known, however, about the effects of increased atmospheric greenhouse gases to guide policymakers toward effective actions.

Policymakers therefore confront the dilemma of acting on incomplete or even conflicting information or waiting for more solid scientific support. Both choices involve risks. To act on uncertain information could lead to ineffectual and possibly dangerous policies. To wait could involve confronting a worsened situation that, if addressed sooner, could have been handled more effectively and with fewer adverse consequences.

For many involved in the decision-making process, however, the situation may not yet be viewed as a dilemma. Confronted with various immediate and critical issues, many government agencies and utility companies are neither concerned about acting too soon on the climate change issue nor anxiously awaiting further scientific information. For many, global change has not yet achieved the status of a looming crisis. As a result, policymaking on climate change concerns is often delayed.

Helen Ingram, acting director of The Udall Center for Studies in Public Policy at the UA, has identified various possible future public policy scenarios for climate change including *Boom and Bust,* and *Sustained Public Policy Interest* (Ingram, et al, 1989). The boom could go bust if threatened serious consequences begin to seem extreme or exaggerated. Global climate change might then take its place as another popular cause that, misinterpreted by science and buoyed up by the media, was taken too seriously. Interest in climate change might also flag if proposed policy options are politically unpopular.

Sustained Public Policy Interest, however, is also a possibility. Should this develop, should a concern about serious consequences prevail, then careful and credible policy analysis is needed to provide various options for confronting climate change concerns.

Creative efforts at policy analysis will be especially needed since the magnitude and complexity of climate change issues are often beyond traditional policy solutions. The regulatory approach that characterized much past environmental policy may not be sufficient to curb the ill effects of threatened global climate change.

Appropriate policy options would most likely need to be both preventive and adaptive. Preventive policies would involve taking actions that would reduce the amount of greenhouse gases being released into the atmosphere. Such policies might address various concerns including deforestation, and the production and use of greenhouse gases; but a main objective of a mitigative policy would be limiting the use of CO_2-producing fossil fuels. This could be done through conservation or promoting the use of cleaner, less polluting fuels or sources of energy.

If examined in a global context, however, this seemingly sound and sensible policy could be seen as unfair and inequitable. To be effective against global threats, preventive policies must be globally applied. If the emission of CO_2 were to be drastically limited, developing countries would suffer most since their economic development very much depends upon the use of relatively cheap fossil fuels. With reduced economic development, such countries would have increased difficulties in providing for the well-being of their citizens.

Adaptive policies, on the other hand, would encourage society to adjust to climate change. Usually based on the belief that climate change will be incremental and gradual, an adaptive policy presupposes a flexibility in the laws and institutions of society. Adaptive policies require that incremental changes not unduly strain society's ability to adjust.

Water policy is seen as an area that could be amenable to an adaptive policy approach. If climate change means less available water, policies could encourage social and institutional adaptation. At a basic and obvious level, conservation and efficent techniques for water use could be stressed.

At a more complex and involved level new management practices could be developed to assure flexibility of water systems. Arrangements that establish the legal ownership and use of water could be reviewed. For example, the regional and even the intrastate transfer of water, although often presently discouraged because of legal and economic impediments, could be considered as an essential adaptive strategy to confront water shortages.

As more scientific knowledge about climate change and its effects accumulates, policymakers will be better able to devise appropriate strategies to confront the issue.

Conclusion

Climate change, whether at the local, regional or global level, has always occurred and is, in fact, an ongoing process. Some now perceive it as a possible threat, however, because they fear drastic, life-disrupting changes to world climate from a developing greenhouse effect caused by human activities.

Others are more optimistic. They believe that the atmospheric buildup of CO_2 now occurring will not necessarily result in a destructive warming of the Earth. Whereas some see present evidence of the greenhouse effect in recent events like the summer heat of 1988, others view such events as part of natural climatic fluctuations.

Meanwhile scientists continue

their research. Investigating the past, interpreting the present, and projecting the future, researchers work to understand the complex relationship between climate, the Earth and its natural resources—land, water, and a diversity of plants and animals—and humans and their activities.

Policymakers interpret scientific information and guide further research efforts to help clarify policy options.

Beyond these activities and roles is possibly the greatest significance of the climate change issue—the heightened awareness of the interrelationship of humans and their environment. ▼

Reference

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Arroyo, a quarterly publication, is published by:

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Graphics: Arid Lands Design

Along with the people mentioned in the text, the editor thanks the following for contributing information to this newsletter: Robert Balling, Sandra Brazel and Randy Cerveny, *Arizona State University*; John Keane, *Salt River Project*; Vick Baker and Malcolm Hughes, *The University of Arizona*; Robert Webb, *US Geological Survey.*

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