INTRODUCTION

The Skywater IX Conference on Precipitation Management and the Environment held at Vail, Colorado, during the second week in November, 1976, was undertaken by the Bureau of Reclamation to assess the present status of knowledge about what might be the environmental effects of widespread or prolonged application of the techniques of precipitation management that Project Skywater is developing, and to provide information for planning. The occasion was the recent publication of reports marking the completion of three major undertakings (Knight, et al., 1975; Steinhoff and Ives, 1976; Bureau of Reclamation, 1976). These were the Medicine Bow and San Juan Ecology Projects, each a multiyear field investigation of the ecological effects of increased snowpack and seeding agents, and the draft programmatic environmental impact statement for the Bureau's research program, Project Skywater. With the completion of these tasks, the time was ripe to review what had been accomplished and to see what remained to be done.

Awareness of the need for a long range look at the possible consequences of managing the weather accumulated gradually from concerns aroused by early cloud seeding experiments. This led to the convocation by the National Science Foundation of a Special Commission on Weather Modification. Its report (National Science Foundation, 1966) noted that the scientific prospects for effective weather modification were such that the prospect for wide ranging biological and social consequences should be examined in a timely manner. Respecting biological consequences, it reported:

"Great uncertainty has been encountered regarding the biological consequences of weather and climate modification. Augmentation of rainfall over cultivated areas could partially alleviate the increasing problem of food production. However, there is an accompanying possibility that instabilities might result in the balances of biological communities. Such imbalances can be expected in the diseases and pests of man's domesticated plants and animals. In small areas of natural communities it is possible that some wild species may be severely stressed. The timing of the atmospheric intervention relative to the reproductive cycle of the various species in the community may be of more importance than the magnitude of the intervention. Both field and simulation studies of these biological relationships are therefore needed before, during and after sustained operational programs. These studies should help avoid undesirable, unanticipated and irreversible ecological changes."
Respecting social consequences, it noted that weather modification "may provoke intricate social changes" and called attention to areas where such changes might occur. These ranged from such very general topics as "the whole fabric of society" and "organization of livelihood" to such specifics as the compensation of those who might be directly disbenefitted by particular weather alterations that benefitted others. It suggested that these matters might be looked at from either of two viewpoints: the impacts of a particular modification of the weather; or the particular needs of society that might be served by tailoring weather modification to these needs. It recommended that steps be taken to study the social consequences of weather modification. Since publication of the Special Commission's report, various societal implications have been the subject of contributions to the literature (Hess, 1974; Center for the Study of Democratic Institutions, 1973), and the National Science Foundation has sponsored a study group on societal consequences.

The range of possible ecological consequences to be considered was broadened with the introduction of silver into the question. Inspired by a staff paper citing toxicity standards of various materials handled by cloud seeders (Douglas, 1967), a law professor in Arizona (Davis, et al., 1967) speculated that despite extremely low concentration of these materials once they mix with the atmosphere, and despite scientific attitudes respecting their harmlessness, "there may be legal and perhaps legislative consequences to putting any quantity of poison in the atmosphere. In effect, a nonsophisticated public will create 'political causation' ***." A Pennsylvania judge, who had apparently been awaiting just such grounds for his decision, promptly confirmed this speculation by ruling that the poisonous character of cloud seeding agents made cloud seeding subject to prohibition by local public health authorities as a menace to health (Pennsylvania, 1968). Soon thereafter, a problem analysis (Cooper and Jolly, 1969) called attention to the possible direct effects of silver iodide used as a cloud seeding agent. Although this report found little likelihood of adverse effect on terrestrial or marine environments, it pointed to the possibility that silver might selectively inhibit the growth of certain freshwater micro-organisms or interfere with biological decomposition of bottom sediments. From these beginnings, concern over silver mushroomed rapidly. Silver became a tocsin, even if not a toxin, for environmental groups already inclined to oppose weather modification for other reasons.

Skywater IX was organized into six working groups whose topics corresponded to the way the ecology projects have been divided. For each group, the Division of Atmospheric Water Resources Management appointed a convener, who in turn conscripted four or five colleagues of his own selection. A resource person was assigned from the Skywater staff to each group to answer questions that might arise about the program.

The participants were asked to address primarily the issues of long-term environmental impacts that would be raised if the technologies of winter-orographic and summer-convective precipitation augmentation (now the focus of the Skywater developmental effort) were to become widespread and prolonged. It was to be assumed that median precipitation amounts in these classes would be increased by 15 percent or less, depending upon intensity of application and technological success, with little or no operation to be expected during periods of naturally above-normal precipitation.
Suggested issues were laid before each of the groups listed in the following paragraphs, corresponding to subjects of potential importance that had not been resolved by work completed to date. These issues were:

**Abiotic processes.** - What abiotic components of the environment will precipitation management affect, and how much? What proportion of the variations they are likely to undergo may be related to precipitation management, and to what extent will the precipitation-management-related disturbances be distinguishable from those otherwise caused? What linkages transmit precipitation-management impacts from one abiotic component to another? To vegetable, animal, and socioeconomic compartments? How may important abiotic factors be efficiently characterized, parameterized, and indexed? How can erosion be related to precipitation management so as to include both its direct effects and its indirect effects through vegetation, development, etc.? What about alluviation? Are there important in-channel effects?

**Vegetation.** - How should attention be balanced between specific impacts, e.g., on certain crops or forage areas, and general principles governing vegetational processes? Are there particular index species that may be representative of large groupings? How do vegetational provinces differ one from another in ways important to precipitation-management impacts? What value system is it appropriate to apply in assessing vegetational changes? How does risk of weeds relate to rate of change of climate? Are weeds and pests a greater problem in moist climates, or in dry ones?

**Animals.** - As precipitation management operates through more and more complex chains of cause-and-effect, in combination with more and more other independent sources of disturbance, how can we handle the intermingling of precipitation-management-related impacts with others? What is the relationship to alternatives for animal management, such as feeding the elk?

**Societal.** - Since the anticipated precipitation changes are not expected to change the structure or functioning of societal institutions, the issues relate to derivative impacts. Can we methodically and rationally predict changes in societal institutions and their functioning that would result indirectly from precipitation management? Can sociology model social responses to precipitation management to a degree of precision useful for prediction of behavior? Should Skywater adopt the goals and methods of this model concept? Can we identify and quantify stresses and responses by societal institutions to precipitation management? Can benefits and disbenefits to individuals be identified? Can the disbenefitted be compensated? How should costs be distributed? To what extent do responses such as the scapegoat reflex spring from the nature of precipitation management, and to what extent from pre-existing cleavages in society? How can they be mitigated?

**Seeding agents.** - Should the need for silver monitoring be reassessed, and purposes and methods redefined? What are the needs for further research on biospheric impacts? Should studies be made of areas long
impacted by industrial silver contamination? What issues should monitoring be designed to resolve? How widespread and how sensitive need monitoring be?

**Environmental overview.** - What priority should be assigned environmental issues of precipitation management in comparison with other environmental issues affecting the same regions? In comparison with other aspects of precipitation management? How may resources for investigation of them be justified and obtained? How should assessment of precipitation-management-related impacts be interfaced with assessment of other, generally much more powerful impacts, on the same environmental system? What is the validity and limitations of an investigatory method relying on extrapolation from the effects of greatly exaggerated impacts, e.g., increasing snowpack tenfold by means of snow fences? How should we bridge from studying impacts on organisms to assessing impacts on ecosystems and environments?

All this was the baggage brought to Vail.

**SUMMARY REPORTS OF THE WORKING GROUPS**

1. **Abiotic processes** (Dr. Charles F. Leaf, Convener)

   The abiotics group developed the analytical framework shown in figure 1 to show the interactions that relate events at the atmospheric level - precipitation-to those occurring at the terrestrial level - microclimate, erosion, avalanches, and water yield - and on down to the aquatic level - fluvial geomorphology and water quality. The weight of the interconnecting arrows shows not how strong the linkages are but how well understood they are. A sensitivity matrix was prepared showing, for each of these abiotic events, the settings wherein they are most important, the processes through which they operate, and the magnitude of the expected response to prolonged precipitation augmentation. Figure 2, an abridgement from the group's report, shows the portion of the matrix for which detectable responses were expected, given a prolonged precipitation augmentation of 20 percent, together with an estimate of the state of the art with respect to measurement of the responses.

   This matrix suggests that, when all forms of response are considered, alpine areas will show the most readily detectable responses to precipitation management. This assessment of alpine response requires clarification, however, since the assessment by the abiotics group was at variance on this point with the San Juan Ecology Study. It has to do with the difference between impacts of winter snowpack augmentation and summer shower augmentation. The San Juan study showed surface erosion, mass wasting, and consequent effects on water quality and fluvial sediment yield to be mostly associated with summer showery rainfall. After further discussion with Dr. Leaf, it became obvious that, if the assessment were restricted to winter snowpack augmentation, the expected response in the above-mentioned categories would not be detectable. This would then leave forests as both the largest and the most important setting in which responses to winter snowpack augmentation might be detectable and sometimes important. For summer-
<table>
<thead>
<tr>
<th>ENVIRONMENTAL ISSUE</th>
<th>Erosion</th>
<th>Avalanches</th>
<th>Microclimate</th>
<th>Water Yield</th>
<th>Water Quality</th>
<th>Fluvial Geomorphology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmental Setting</td>
<td>Surface Erosion</td>
<td>Mass Wasting</td>
<td>Snow Duration</td>
<td>Soil Moisture</td>
<td>Duration</td>
<td>Moisture</td>
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<td>2 (1)</td>
<td>2 (2)</td>
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<tr>
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<td>2 (1)</td>
<td>2 (2)</td>
<td>1 (2)</td>
<td>2 (3)</td>
<td>1 (1)</td>
</tr>
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<td>1 (1)</td>
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<tr>
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<td>2 (3)</td>
<td>2 (3)</td>
<td>2 (2)</td>
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</tr>
<tr>
<td>Unstable Stream</td>
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<td>2 (2)</td>
<td>2 (2)</td>
<td>2 (2)</td>
<td>2 (2)</td>
<td>2 (2)</td>
</tr>
</tbody>
</table>

1 — detectable but insignificant
2 — readily detectable, sometimes important
(1) — mostly empirical
(2) — partly deterministic
(3) — well-developed

FIGURE 2. Sensitivity matrix for abiotic issues
time shower augmentation, the agricultural setting claims this pre-eminence and is also the setting in which the state of the measurement art is most advanced.

Among the environmental issues, those of water yield and fluvial geomorphology are expected to show the most readily detectable responses in the largest number of settings, with mass wasting in second position, but this prominence would be greatly weakened if summer shower augmentation in alpine settings were stricken from consideration. All the other issues have remarkably even scores. The state of the art is seen as weakest in avalanches, snow duration, and chemical water quality, strongest in water yield and physical water quality.

The abiotics group recommended that quantification of impacts on abiotic components should proceed by further application of the principles and analytical framework it had arrived at, and that these same factors should guide the selection of research priorities as shown in the sensitivity matrix. They recommended further that the interfaces between abiotic components and other components such as vegetation should be pursued through further development of the same analytic approach.

2. Vegetation (Dr. James L. Smith, Convener)

The vegetation group separated its deliberations according to the two precipitation-management tasks being pursued under Skywater, summer-convective rain enhancement in the predominantly grassland and cropland province of the Great Plains, and winter-orographic snowpack enhancement in the predominantly forest province of the mountains, with their peripheral scrublands.

High Plains. - The most important issues were seen as the effect of precipitation management on crop and range production, land-use patterns, and vegetational changes. Effects on pests and soils, and offsite effects, were seen as visible but less important.

It was recognized that expectation of benefit to crop and range production is the primary reason for precipitation management efforts in the Great Plains. The effect of rainfall, acting through indirect effects on temperature, relative humidity, soil potential, fertilization, and soil moisture, is very important as a determinant of crop and range production; but the relationships among these need to be better defined. An effort should be made to consolidate information from all completed studies and extend them into new areas.

The vegetation of the Great Plains is being and will be determined by allocation of the land among different types of crops and native range, and by differences in cropping practices among continuous or alternate cropping, minimum tillage, fallowing, and irrigation. The effect of precipitation management on land allocations and cropping practices, and hence indirectly on vegetation, may become important, especially if it were to lead to abandonment of water and soil conservation practices. In parts of the northern plains, vegetation and rainfall are interrelated in the saline seep problem that has been taking considerable land out of production.

Changes in the community composition of native vegetation, and crop selection according to moisture, will probably cause changes in quality and quantity of range and crop species, with consequent changes in animal habitats.
These changes would lead, eventually and indirectly, to changes in soil texture and organic matter, availability and distribution of nutrients, and the distributions of pests and animal populations, which should be assessed as methods for addressing them become available. Possible offsite effects include shifts in competitive advantage of various sites, and effects of additional municipal and industrial water on the regional economy and demand for and production of energy. Of particular concern are the effects that precipitation management in one area may have on precipitation distribution in downwind regions.

Mountain ecosystems. - For winter-orographic snowpack augmentation, a matrix table of concerns, sensitivities, and state of the art was prepared, an abbreviated version of which is shown as figures 3 and 4. Better knowledge of the distribution of augmented snowfall with altitude, its redistribution on a local scale by drifting, and the effect of these variables on local duration of snow cover was identified as a key need, constituting the basis for analysis of effects on vegetation at high elevations.

Somewhat lower in importance are the productivity of high meadows and of low-elevation vegetation, decomposition, nutrient loss, and susceptibility to insects and disease. Concern for species-composition changes, forest productivity, nutritive value of vegetation, land use changes, species diversity, plant growth, phenology, reproduction, and endangered species were noted but rated minor in priority.

Offsite impacts were of high concern with respect to changes in land use and associated changes in vegetation types, with lower priority assigned to endangered species, vegetative productivity, growth, reproduction, and species. Concern was also noted for the possible offsite effects on vegetation if migrating big game were to be forced onto winter range unusually early in the season, causing overuse of the vegetation resource, and a delayed beginning of the precipitation-management season was recommended where this might prove to be a problem.

3. Animals (Dr. Harold Steinhoff, Convener)

Assumptions made were that snowpack augmentation would reach 30 percent except for cutbacks in seasons with abnormally heavy snowfall, without change in the pattern of snow distribution and only microscale effects on temperature connected with longer duration of snowcover, with corresponding shortening of the growing season. Offsite use of the added meltwater was presumed. For summer-convective rain augmentation, the same 30 percent increase was assumed except for seasons with abnormally heavy natural rainfall, with no effect on severe local storms or hail.

In making the analysis, species selected for their importance were considered the receptors of environmental impact, and agencies of change were seen to proceed through an effects web from the direct effects of rain and snow; through indirect effects on vegetation, on animal/animal interactions, and on socio-economic parameters; and through seeding agents. Considering each key species as an issue, criteria bearing on its importance were considered to be the agencies of change, the likely magnitude of change in terms of species biomass, the importance of a change in terms of "who cares," its validity as an issue (valid if concern is based on large changes, invalid if based on trivial ones), and
## Vegetational Issues - High-Elevation Sites

<table>
<thead>
<tr>
<th>Vegetational Issue</th>
<th>Snow Distribution</th>
<th>Meadow Productivity</th>
<th>Low-Elevation Productivity</th>
<th>Forest Productivity</th>
<th>Decomposition</th>
<th>Nutrient Loss</th>
<th>Pests and Diseases</th>
</tr>
</thead>
<tbody>
<tr>
<td>More Water</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>3</td>
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<td>2</td>
<td>2</td>
<td>1</td>
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<td>2</td>
</tr>
</tbody>
</table>

### Level of Concern
- 1 - Low
- 2 - Moderate
- 3 - High

### State of the Art
- 1. Methods or data unavailable
- 2. Mostly empirical, uncertain
- 3. Well-developed, deterministic

Figure 3. Vegetational issues at high-elevation sites.
### ENVIRONMENTAL ISSUES - LOW-ELEVATION, OFF-SITE

<table>
<thead>
<tr>
<th>Vegetational Issue</th>
<th>Land-Use Change</th>
<th>Vegetation Type Change</th>
<th>Growth, Reproduction, Species Composition</th>
<th>Vegetation Productivity</th>
<th>Endangered Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agency of Change</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>More Water</td>
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<td>1</td>
<td></td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Snow Duration</td>
<td></td>
<td></td>
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<td>1</td>
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<tr>
<td>Air and Soil</td>
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<td>Temperature</td>
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<td>Silver</td>
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<td>Level of Concern</td>
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<td>2.3</td>
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**Figure 4.** Vegetational issues at low elevations and off-site
answerability—whether the changes are expected to be observable, measurable, and relatable to precipitation management. The result was an effects web and a sensitivity matrix, shown in abridged form in figures 5 and 6.

Issue species accorded low priority or none at all included white-tailed deer, prairie dogs, blackfooted ferrets, ducks, geese, swans, sharptailed grouse, pheasant, quail, and rare and threatened species (of which 12 were named as considered), and invertebrate pests.

High-priority species. - Pronghorns are found only in North America. At first abundant, they became nearly extinct at the turn of the century and have been brought back by careful management. They are adversely affected by encroachment of civilization, and would be affected by development of more land, more people, and more industry.

Elk and mule deer migrate to winter range when snow depth at high elevations increases. Early migration may result in increased use of winter browse and ultimate deterioration of critical winter range, which would be aggravated if snowpack augmentation should extent to lower elevations, where the winter range itself lies. It is important to determine if augmented snowfall does extend to lower elevations, and restrictions of early season operations should be considered.

High priority was accorded to effects on animals in streamside habitats not because of expected changes in the waterflow but because of expected impact of more people, more agriculture, more industry, more development, all of which would tend to reduce the available habitat. The same high priority was accorded to effects of development on other animal habitats.

Second-priority species. - Small mammals are important as the food base for most predators and raptors, and as competitors with livestock for forage. Augmented precipitation will favor some species and disfavor others, with changes in relative species abundance hard to predict but overall effects moderate. Land conversions will be very important for most small mammals.

Songbirds are the special focus of many nature lovers, and their ecological role is important. Precipitation management would affect them if it were to delay the nesting season or increase exposure to adverse weather during nesting, or if it were to delay or reduce the availability of important food resources such as insects and fruits. The impact might be greatest on species whose nesting seasons are genetically timed.

For sage grouse, increased winter snow cover would tend to reduce forage, but increased summer rainfall would tend to improve their habitat with respect to cover and forage. Nesting mortality could be increased if heavy May and June rainstorms were increased. Land use changes that reduce habitat pose the most serious threat.

Species composition among raptorial birds will change if a large geographic region is subject to habitat conversions (land use changes) as a result of precipitation management. Swainson's and ferruginous hawks are expected to give way toward red-tailed hawks, marshhawks, and American kestrels. Great horned owls may find increased habitat in tree plantings associated with more human dwellings.
The diagram illustrates the effects of increased snow depth and more rain on animal issues. Increased snow depth leads to:  
- Less movement of animals
- Less winter range
- Fewer animals

Increased rain leads to:  
- Cooler soil in spring
- Later sprouting
- Less biomass production
- Less food
- Fewer animals
- More animals

Increased rain also affects:  
- More water onsite
- More water downstream
- More habitat
- More industry
- More agriculture
- More people
- More habitat
- Fewer animals

The diagram is labeled as Figure 5: Animal issues effects web.
<table>
<thead>
<tr>
<th>Issue Species</th>
<th>Effect-Web Names</th>
<th>Magnitude</th>
<th>Importance</th>
<th>Validity</th>
<th>Answer-Ability Research</th>
<th>Type of Research</th>
<th>Hypothetic Connection with Pcpn Mgmt</th>
<th>Priority for Research</th>
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<tbody>
<tr>
<td>Pronghorn</td>
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<td></td>
<td>More agriculture</td>
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</tr>
<tr>
<td></td>
<td>More Industry</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
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<td>8</td>
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<td>Field</td>
<td>Yes</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>Less food</td>
<td></td>
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<tr>
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<td>9</td>
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<td>Yes</td>
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<tr>
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Figure 6. Animal issues sensitivity matrix
CONCLUSIONS

In its summary, the animals workshop group re-emphasized its concern for the effect that development and changes in land use potentially flowing from precipitation management would have on animal habitats.

4. Socioeconomics. (Dr. W. Henry Lambright, Convener)

The Bureau of Reclamation is seen acting as an innovator where a national policy toward precipitation management is lacking and various barriers to its widespread adoption are present. The goal of the socioeconomic workshop group was to identify the actors and gauge their stakes. The consumers of precipitation management were identified as direct users and affected bystanders, in onsite, offsite, downstream, and other settings.

Incentives and barriers. - The incentives for adoption of precipitation management are the anticipated economic benefit, plus the environmental aspects of "clean" power and high-quality water, and the power of a political constituency desirous of it.

The principal barriers to widespread adoption are the heterogeneity of needs and concerns among potential users, lack of an adequate water-pricing mechanism to determine who pays for what benefit, lack of demonstrated capability or a scientific consensus supporting its validity, lack of sensitivity to people or of a mechanism for compensating the disbenefitted, and that no one level of government is appropriately situated to take action.

Institutional framework for adoption and use. - If it is to make optimal decisions, an institutional framework must represent both users and bystanders, must co-operate with other institutions, must be supplied with appropriate economic and environmental assessments of probable outcomes, and must monitor all systems.

The role of governmental institutions is to respond to expressed interests and concerns and to balance needs against constraints. At the community level, expression is shaped by referenda, committees, hearings, notices, etc.

Economic institutions are concerned with estimated direct benefits and costs, lower order and indirect economic effects, and means of funding the decision making activities.

Legal institutions need to identify and prove water developed by precipitation management and establish ownership of it; provide a mechanism for compensation of the disbenefitted, perhaps using experts to establish causation; and address problems of interstate compact and international treaty limitations.

Conclusions and recommendations. - Precipitation management should be treated socioeconomically as a new resource having its own peculiar characteristics, not as a modification of an old one, de-emphasizing environmental impact analysis and leaping to "what could be." Attention needs to be paid to the institutional problems of innovation, and to the constraints that must be overcome.
It is recommended that a technology assessment should be undertaken to approach precipitation management from the viewpoint of the problems to which it might be applied. Models of water markets and market relationships should be developed, geared to price and ownership. A mechanism should be provided to compensate those who suffer loss.

5. **Seeding agents** (Dr. Donald A. Klein, Convener)

Nested within the week-long workshop was a 2-day meeting of a study group that is preparing a report to the National Science Foundation on the status of research on seeding agents, allowing interaction with a substantially larger group of experts.

The goal was to consider who raises issues relative to seeding agents, what issues they raise, and how the group, as scientists, responds to these issues. These elements were assembled in matrix form, of which figure 7 is an abridgment. (The number values in the line "magnitude of effects" was added to the original matrix by interpretation of the discussion of individual issues and may depart in minor respects from the intention of the group.) The environmental issues have been placed in order of decreasing level of concern among issue-raisers, and the issue-raising groups are listed in order of the number of issues that each raised in the complete matrix.

**Responses to issues.** - Direct toxicity of silver has highest priority among lay groups not familiar with current research findings. There appears to be no real threat.

The "general damage" category relates to possible toxic effects in the legal sense. Because the agents are used in such small quantities, real effects are probably insignificant. Public concern is probably based on misunderstanding, not on actual damages.

The issue of impacts on the soil-sediment-aquatic continuum and related processes of sewage treatment has as its major point of concern the possible effects of transient seeding-agent levels on primary production of algae. Direct effects on fish are considered of minor scientific concern. An additional concern is effects on anaerobic methane production and denitrification, but current evidence suggests the effect is insignificant. The possibility that sewage treatment may concentrate silver should be recognized.

Although seeding agents can have little effect at the concentrations at which they are applied, concentration by biological or physical means, transformation into more toxic or available forms, or synergistic interaction with other metals, might potentiate adverse effects, the possibility of which merits further examination.

Plants vary in their capacity to accumulate silver, but do not show toxic effects at concentrations found in nature. Accumulator species, if identified in a seeding area, might be useful for monitoring animal and human food chains although, as noted earlier, direct toxicity does not appear to be a real threat. Laymen and environmentalists have shown more concern that plant scientists.
### Priority of Issues

1. Important  
2. Secondary  
3. Minor  
4. Insignificant

### Magnitude of Effects

<table>
<thead>
<tr>
<th>Environmental Issues</th>
<th>Biological</th>
<th>Chemical</th>
<th>Industrial</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Direct Toxicity Fish, Aquatic Insects</td>
<td>General Damage to Organisms</td>
<td>Soil-Sediment Aquatic Sewage</td>
</tr>
<tr>
<td>Scientists in Applied Weather Modification</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Environmental Groups</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Lay Public</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Legislators, Politicians</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Regulatory Bodies, EPA, OSA, State, Professional</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Industrial</td>
<td></td>
<td></td>
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<tr>
<td>Magnitude of Effects</td>
<td>4</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Recommended Action</td>
<td>Monitor</td>
<td>Public Education and Information</td>
<td>Study Transient Imposition Monitor</td>
</tr>
</tbody>
</table>

**FIGURE 7. Issue-Sensitivity Matrix**
Despite intensive research, no effect of seeding agents has been found on fish, domestic animals, game animals, or endangered species, and no detriment to them is likely. Public concern appears to be undeserved.

Though the methodology of silver analysis is adequate for detecting its presence in very small concentrations, methods for identifying the chemical compounds in which it occurs are lacking. Effective means for obtaining representative samples of air, water, and soil are needed for monitoring. Methods to determine if precipitation comes from a seeded storm could clarify some legal problems.

Some industries use differential crystallization of minerals by solar evaporation in brine ponds as an extractive process. Concern lest silver from cloud seeding inhibit separation of the desired chemicals appears unjustified.

No seeding agent other than silver iodide was seen as raising important issues or as requiring any action other than possibly monitoring eutrophication of public water supplies in an area of heavy use of nitrogenous hygroscopic agents.

Conclusions. - Environmentally, the use of seeding agents should have no significant effect, and there is no evidence of unacceptable changes in biological systems due to them. However, users should be aware that new studies may alter this assessment. Although cloud seeding represents only a small fraction of environmental dispersion of silver, other dispersers are not likely to support research in the field.

Recommendations. - A running review of pertinent literature should be undertaken. Possible concentrations of and biological responses to silver should be monitored. Analytical methodology for silver should be improved. Chemical, physical, and biological concentration phenomena, and the effects of any such concentration on organisms, should be studied. The possibility that silver may potentiate other metals should receive attention. Cooperative studies with the Photographic Manufacturers Association and the Silver Users Association should be supported.

6. Environmental Overview (Dr. John Marr, Convener)

Within the context of an "ecosystem" overview, the following issues were identified and discussed.

The terminology problem. - An issue is a controversy with implied uncertainty as to which among alternative feasible outcomes will eventuate, while a problem is generally an issue with a unique solution. Environment implies focus on the surroundings of a place or object, while ecosystem implies living matter together with what affects its form and function. In discussing these matters it is important to use simple terms in a consistent manner. A glossary of precipitation-management terms would be useful.

Possible initiation of long-term trends. - Even though precipitation augmentation might initially increase ecosystem productivity, this might be followed by a decrease. Possible causes of such a decrease include leaching of
nutrients initially in the soil to horizons no longer available to plants; invasion of grassland by shrubs and trees, reducing forage production; an increase in fungus and insect pests; and erosion which, once accelerated by increased precipitation, might continue at a higher rate. All theoretically possible long-term changes should be monitored.

**Linkage with conservation activities.** Precipitation management needs to be linked to water use through management co-ordination that embraces agriculture (including irrigation technology), forest watersheds, and storage management (evaporation reduction).

**Regional concept.** If results of ecological studies are to be extrapolated from one site to another, stratification is needed that permits the landscape to be partitioned according to its important properties. In declining order of importance, the important properties are climate (principally precipitation); geomorphic class (according to a classification such as that of Hammond); natural vegetation; dominant plant taxa; land use; and habitat type. This stratification leads to partitioning into individualized geomorphic regions with homogeneous properties which can be generalized throughout the subregion. The generalization may be extended to other subregions to the extent to which they resemble each other in their important properties. Methods are available for systematic expression of the degrees of similarity.

**Transfer of information.** The theme is generalization from a particular experiment to new situation. Two methods of generalization are recognized. Classification goes by important similarities, assuming a corresponding similarity in underlying processes, qualified by differences in geologic substrate and weather patterns. Dynamic models are analytic-mathematical expressions of understanding or hypotheses applied to the subject matter. They may be validated by experimentation on two levels of generality, that of total system behavior and that of specific interaction. In ecosystem studies, focus on nutrient cycling is to be preferred to that on energy flow.

Models for most natural ecosystems can predict within about 20 percent for most data. Predictions are limited by errors accumulating from imperfect knowledge of processes and natural variabilities. A model that verifies over a span of 10 to 25 years can be considered as validated. One way of applying the model concept would be to analyze carbon gain in a game of interspecies competition.

The problem of extrapolation may be approached by learning how a set of components critical to ecosystem functioning changes with precipitation, validating the model in one area and then carrying it over to other areas. Critical components include primary above-ground production, primary production by important species, decomposition, soil moisture and runoff, fixation and leaching of nitrogen, phytosociology and species diversity, cations, and invertebrates. Year-to-year and area-to-area variations present a problem.

Ecosystem studies should be repeated in similar but not identical regions, relating goodness of predictions with similarity between regions.

Process-oriented ecosystem studies should observe the following principles. The degree of resolution needed depends on the objective, as to whether all
processes or only significant ones are to be included, using standard techniques for interrelating species, decomposition, runoff, nitrogen fixation/leaching, etc. Complexity and uncertainty will ordinarily limit the number of components to the most important few. Budget restrictions will also limit the number of components.

A substantial part of the effort, such as 20 percent, should be allocated to the setting of objectives. Processes, not initial conditions, should be the focus of measurement programs; after five iterations of a process model, initial conditions lose significance. All important analytic levels, from abiotic to vegetation, animals, etc., should be combined into a single comprehensive systems analysis.

Programs of education and information. - Programs of public education and information should be continued and expanded.

IMPLICATIONS FOR THE SKYWATER PROGRAM

The results of the Skywater IX Conference remain at this time to be better digested before being converted into elements of its research programs. The following remarks are therefore preliminary and tentative in nature.

The Conference has presented conclusions and recommendations on two levels. The first level is that of the direct effects of precipitation management on rain, snow, and snowpack, and the spread of these effects, by processes that are more or less well understood, through the complex webs of life within the ecosystem involved. Here we have our work cut out for us and the road is reasonably clearly marked. The issues on this level are suitable for incorporation more or less directly into the Skywater Program, to be undertaken as priority and opportunity indicate.

The universal need, affecting all environmental impact assessments, is for more precise expectation of just what changes precipitation management may bring about in the distribution of precipitation in space and time, and in certain other important parameters of the precipitation, such as its duration and intensity. These objectives are inseparable from the main experimental investigations of Project Skywater and do not constitute a separate environmental task. A peculiarly environmentally oriented extension of this task may however be identified; application of the experimental results to construction of a stochastic climatology describing changes in the magnitude and frequency of occurrence of meteorological events of environmental significance under a regime of precipitation management. The Conference results highlighted the importance of finding out whether seeding for snowpack augmentation at high altitudes affects the precipitation at lower altitudes. They also identified the importance of determining the nature and magnitude of offsite changes in precipitation, especially downwind of the primary operational area.

In areas of snowpack augmentation, the most important link with the vegetational environment has been pinpointed as the duration of snowcover. This factor has great variability in both space and time, from place to place on a
very fine scale, and from time to time on an annual scale. Furthermore, snow-cover duration is affected greatly by weather events that occur after the precipitation-management season has ended, especially post-season snowfalls and rainfalls and amounts of cloudiness and wind. It is affected to a lesser extent by in-season weather variables that are independent of precipitation management such as the stratigraphy of the snow resulting from a particular sequence of storm accumulations, and redistribution of the snow by wind. It appears feasible to model the melting of snowcover up to the time of its disappearance in terms of mass and energy fluxes, and to verify the model's adequacy by comparison with observations at a few representative sites. It would then be possible to calculate the durations of snowcover, with and without snowpack augmentation, for a wide variety of sites and for a wide variety of stochastically generated snowmelt seasons, thus generating an expectation for the main statistical parameters of snow duration and the dependence of them on snowpack augmentation.

The aspects of vegetational gradients that can be associated directly with gradients in precipitation amount or snowcover duration are likewise approachable within the Skywater context. The Uinta Ecology Program, begun last year under contract with the Utah Department of Conservation and Natural Resources and Brigham Young University, and the studies being pursued for Skywater by the Pacific Southwest Regional Forest and Range Experiment Station of the U.S. Forest Service are of this sort. A transect study of vegetational gradients across the High Plains is in prospect.

Issues related to direct effects on animals appear to be tractable on a project-by-project basis, and they are being approached this way in the Sierra Cooperative Pilot Project. The small number of species considered important and the existence of game-management alternatives suggest the limited nature of the practical problems involved.

As we examine the bundle delivered to us by the socioeconomic group, we find that the items focus around concern for the sociology of the investigative and innovative process in which Skywater is engaged. It is clear that our advisers wish us well, and they would like to help us change for the better the institutional setting within which we are striving to develop the technologies of snowpack augmentation and summer-convective shower management. We shall heed well what they have said, though how we may translate it into action remains uncertain. There are certain modes of action within a bureaucracy that can prove embarrassingly self-limiting.

What we have sought and not found is some indication of the impact that widespread and prolonged precipitation management might have, through more or less well understood processes, on the structure and functioning of societal and economic institutions viewed as components of the total environment, whether we or others were to be the agents of innovation but definitely presuming that application will not be our function. In this lack we see four possible answers. Perhaps, despite the clarity and prominence with which the NSF Special Commission raised the problem more than a decade ago, we failed to express our concern for it in an adequate way. Or perhaps the workshop group, in its eagerness to be helpful and its conviction that what it had to say about institutional arrangements for research are important, did not hear the need we expressed. Or perhaps there simply is no adequate basis for presuming that precipitation management
will upset any of the existing societal or economic institutions. Finally, there may be concern for the impact of weather modification but no way of getting at it within the present state of the art. The Special Commission's question is still on the table, and we shall still look for a way of dealing with it.

The issue of seeding agents clearly is taking on a new perspective. Always precautionary rather than substantive in nature, the issue has now boiled down to investigation of possible concentration processes operating in nature, chemically, physically, or biologically, that might locally increase the availability of silver. It is clear also that the best setting for undertaking the field phases of such studies will be where there have been releases of silver into the environment on a vastly larger scale than any resulting from cloud seeding, that is, releases from industrial processes and through the use of silver-bearing fertilizers. Thus, while weather modification may continue to be the issue that keeps silver in the spotlight, the potential environmental impacts, if any, will arise otherwise. These conclusions are quite in keeping with the messages received. The efforts at silver monitoring have discovered large fluctuations in background levels of silver without identifying any component attributable to cloud seeding. No field evidence of any effect of silver on an organism has been found, whether from natural or anthropogenic origins, nor in areas having natural silver concentrations many orders of magnitude greater than average, except possibly within a few metres of a ground-based smoke generator. Neither the Environmental Protection Agency nor the Institute of Environmental Health Sciences, having documented the long-continued dispersal of silver into the environment from industrial and fertilizer sources at rates at least an order of magnitude greater than cloud seeding can reasonably be expected ever to attain, has indicated concern over silver as an environmental pollutant. Finally, the seeding-agents group has recommended an effort at public education to allay the fears aroused by past speculation.

A further task of evaluation that needs to be accomplished is to scope some of the remaining speculations. If dry ice contaminated with amides might be harmful, what is the chance that one might find dry ice contaminated with amides? What process of physical concentration might be envisaged that could elevate the silver concentration significantly above background? What is known about potentiation of other heavy metals by silver, in what sorts of processes, with what sorts of results, that might be looked for in areas of past heavy industrial contamination of silver? Lacking such information, the fruits of speculation are unripe and are likely to be thought sour. With this changed perspective, the role of Skywater is likely to turn mainly toward coordination with agencies concerned with the higher silver levels resulting from industrial and agricultural contamination, accompanied by monitoring directed principally at identification of cloud-seeding silver in precipitation itself rather than in parts of the environment where the background is very much higher and more variable.

The second level of Skywater IX conclusions and recommendations is that of concerns for indirect effects coming about as a consequence of development, with increased population, increased industry, increased cropland, and so forth.

There has as yet been no identification or analysis of processes. The connection seems perhaps to have been made backward rather than forward, from deep and widespread concern about the issue of development toward any object that swims into the field of sensitivity created by that concern, whether the
connection is explicitly described or only assumed. The existence of these concerns, their depth, their pervasiveness, must be acknowledged. We cannot afford to ignore them, no matter how fantastic they may seem to us. We must be responsive, and responsible, in our reaction to them. But how?

Population, industry, agriculture, and ranching, as well as other environmental changes in the United States have a history of great dynamicism, of great sweeps of change that have run their course or been obliterated by new and different sweeps. While the sweeping changes have been forced to accommodate themselves in some measure to the realities of climate, there is little indication that climate has played an appreciable role in initiating these changes, or that it will do so in the foreseeable future. It is water demand, not water availability, that has set the tempo for water development.

Skywater will heed the message. Plainly, many people are deeply concerned over what development (in its many manifestations) is doing to the quality of life. If there were not heightened awareness of the problem, and heightened concern for the future, the issue would scarcely have arisen at the Conference. And somewhere in this broad land there must be sociologists who are striving to understand better what makes development tick and how it may be controlled. It behooves us to discover who these people are, to get in touch with them, and to learn enough about their work to discover whether or not the kind of input that precipitation management might make is or might be important to the processes they are studying. After all, a managed decrease in precipitation is a reasonable possibility; and if the effect of a managed water shortage on development were calculable and significant, this might become a tool for management of development. Development, however, is clearly too big and complex a beast for Skywater to tackle on its own. In connection with the general subject of development it may be germane to note the proposition that the United States has moved from an agricultural to an industrial economy and then from an industrial to an information economy. According to Robinson (1977), information and services sectors of the economy account for more than three-quarters of all employment. These are not water-intensive occupations, and it seems unrealistic to suppose that precipitation management would affect them one way or another.

The issue of the ownership of water developed by precipitation management is another that depends on open assumptions. In the western states, water rights tend to be extremely specific as to location of source and point of use, and very fine-grained in a geographic sense. Despite propositions to the contrary, it does not seem realistic to us to suppose that evaluation of the results of precipitation management will become sufficiently deterministic within the foreseeable future to be made the subject of ownership claims on such a geographically fine-grained basis or with the degree of rigor generally required by a water court. We believe it more likely, therefore, that a solution will be found to the problem outside the presently existing framework of ownership rights. For example, the sovereignty of a state might be brought into play, on behalf of the general welfare, to lay claim in the name of the state to a certain percentage of all surface waters corresponding to an area-wide, long-term evaluation of increased achieved by precipitation management, and to tax that water wherever and whenever appropriated for private use. By apportioning the public financial support given to precipitation management by taxation among the users of different water sources - direct rainfall, surface waters, and underground waters. It seems certain that the state of the art will support quantitative evaluation on such
an area-wide basis before, perhaps long before, it will be attainable on a fine-grained geographic basis.

The issue behind the issue of compensation for disbeneficiaries is that of cause-and-effect as related to particular instances of loss or injury. Several lawyers have argued that a special mechanism for compensation is necessary because the plaintiff is at a special disadvantage when he attempts to prove a cause-and-effect relationship, and they point to the lack of judgment for the plaintiff in any case so far brought to court as proof of this position. However, a very different interpretation is possible. In every such case I am aware of, the defendant has made a strong case that precipitation management did not and could not reasonably have caused the particular damage or injury complained of. For instance, in the case of Samples vs. Irving P. Krick, Inc. (1954), the defendant convinced the jury that the seeded weather systems were so far removed in space and time from those causing the flooding that it was unreasonable to infer a cause-and-effect relationship. Thus, it is quite possible to argue that the common law has operated effectively in the few instances where it has been resorted to, and that we may expect this state of affairs to continue; or at least that we should not act to supereene against the common law until it has been proven deficient. This is not to say we shall dismiss the matter from our minds. It is to say that we shall not lightly abandon the principle of causality in the name of a misplaced sympathy that could conceivably open a floodgate for baseless nuisance claims or an overweening bureaucracy as arbitrary claims settlements.

ENVIRONMENTAL OVERVIEW

Within the vegetational study, there has been a clear methodology of considering first the most fundamental processes affecting particular species of plants in particular sites, followed by some drawing of more general conclusions concerning the probable effect of precipitation management on larger communities of plants and ecosystems such as grasslands or forests. One can see in this an ascent through one or two hierarchial steps from individual organisms to associations of organisms and onward to ecosystems. Eugene Odum has pointed out (1977) as an important consequence of hierarchial organization that, as components or subsets are combined to produce larger functional wholes, new properties emerge that were not evident at the next level below. This observation leads to the question: Are there properties of environmental effect on the whole environment of a precipitation-management operation that are not evident as properties of the abiotic, vegetational, animal, and socioeconomic components viewed separately? To put the question in the pragmatic phraseology of William James, what difference will it make to the environment as a whole, in the long run, whether precipitation management is practiced or not? I did not find in the deliberations of the overview section anything that led strongly toward answers to that question. Nevertheless, I do believe some tentative answers can be stated.

First, the total environment will be a little more robust than it is now in the face of climatic shocks, especially the shock of drought, and a little more versatile and efficient in the overall application and utilization of water resources. I base this proposition on the expectation that precipitation
management will not be consistently applied, over a long period, unless the expectations of this sort of benefit do indeed become manifest. Second, as the price of having these beneficial options available, the total environment will become just a little more complex, and its components just a little more interdependent, than they are now. It seems inevitable that optimal decisions for implementation of precipitation cannot be made without making some new connections within the body of society. Third, although there will be manifest changes in some components or subsets of the total environment, especially those directly dependent on the use of water, the changes in the total environment will be weak, unorganized, indirect, complex, and unidentifiable. In the face of such powerful disturbances to the total environment as those arising from vast cultural forces such as the population explosion, the energy crisis, the green revolution, the electronic era, and the automotive age, and the enormous changes in the whole fabric of society and the organization of livelihoods consequent upon them, we have no present grounds for supposing that precipitation management will be more than a streamlet losing itself in the river.

REFERENCES


