2.4 Small agriculture needs and desires for weather and climate information in a case study in Colorado

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Short Abstract: A case study of the Arkansas Valley in Colorado has resulted in a calendar of what decisions are made during the annual round in agriculture in an area highly-dependent on farming and livestock production. There is also a "shopping list" of desired qualities and forms of information, as well as contents and subjects. The presentation will review those requests which are apparently least satisfied, and provide some explanation of why the requests are made. The hopes for improved information without depending on down-scaling from global circulation models will also be described, in terms of two kinds of approaches. First, help will be requested with "calibration", which is used as a loose term for information and guidance that helps rural people make the best possible use of forecasts that are focused on more heavily-populated areas, based on weather station information from other places, and interpreted for urban rather than agricultural interests. This is especially attractive where newcomers are managing increasing acreage without benefit of long residence on the land. Second, help will be requested in development of expert systems which can use forecast products, existing models and tools, and localized input information for improved prediction of variables which are of special interest to small agriculture. Emphasis will be on equity-informed approaches to private augmentation of public science, data research and predictions, in grateful response to the organizers' encouragement to challenge the audience regarding unmet needs with potentially important benefits.

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Apparently simple improvements in forecasting and forecast applications can be financially quite important. And, improved agricultural applications can help with smoothing the changes imposed by rapid urbanization in the West, which draws water from agricultural use. The pre-print extended abstract provides the interpreted synthesis of the interviews and some discussion. Related presentations on the project from which this work is excerpted are available as pre-prints by Wiener for the 2002 AMS annual meeting (focusing on methods used and social processes), 2003 annual meeting, on water banking as adaptation to climate variability, and 2004 on progress and problems with the Colorado experiment; other presentations are available at the Western Water Assessment Regional Integrated Science Assessment Project website, and the final report will be available through the Office of Global Programs, NOAA, website. Most of these have considerably more graphic content and less boring detail. The live presentation should also be considerably less dull.

Acknowledgements and thanks are noted at the end of this extended abstract, and a memorandum calling for investment in improved engineering is also attached.

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This presentation and extended abstract are based on work done in a project which has been described elsewhere by the presenter, including in the AMS 2002 and 2003 pre-prints collections, and in part in another pre-print in the 2004 collection, which is a set of slides. The purpose of this presentation is address the AMS Users Conference about what we were asked for. Descriptions of the requests made by others in Utah governments, Tribes, and the Middle Rio Grande area of New Mexico will be available the NOAA Office of Global Programs when reports are finalized and posted.

An important note: We carefully decided to NOT distinguish between predictions, forecasts, and information, for purposes of this study, so we are calling anything said about the future a "forecast", to distinguish that from other statements or monitoring etc. As with the rest of the findings, we are not precisely characterizing the issues in meteorological terms. This is not because we think this is trivial and merely technical – just the reverse: whether an answer is available already may depend on thorough understanding of what the requestor "really" wants and is trying to cope with, and that also applies to answers that might become available in the future.

As use of climate information increases, in co-development with the tools needed to respond to it, we expect that new emphases and priorities for the information users will also emerge. This report, therefore, will be snapshot of preferences at the time we inquired, rather than lasting guidance (Wiener 2002 AMS pre-print discusses this).

A. The list of forecasts requested, from the Colorado decision calendar:

Since the late Nineteenth Century it has been common in ethnography to describe the annual round of a people's subsistence activities, and in the course of describing that kind of reporting about recurrent decisions, Bill Travis suggested the handy name of "decision calendar". The goal is to establish a basis for priorities in forecasting, both in content and in timing, and the reported work in a study by Andrea Ray and Robert Webb of the Upper Colorado River water management system has also applied the approach fruitfully (see Western Water Assessment Regional Integrated Science Assessment presentations; additional reporting is forthcoming). Similar approaches, for similar commons-sense reasons, are appearing more often, and the method is commended (Wiener 2002 AMS pre-prints) for ease and usefulness.

In the table below, the numbers of the decisions made in each month correspond to the decision table, which is quite lengthy, and indexes information in the detailed reports. The "type" descriptions are:

- SF for "specific forecast", such as specific elements of weather or climate or threatening conditions
- HF for hydrologic or hydro-meteorological forecast
- GF for "general forecast", such as the long-lead forecasts of climate and temperature; or
- RF for "rolling forecast", such as where a short-term forecast such as 0-5 day flash flood potential is requested on a continuing basis through a season or specified period. This is either a special emphasis or an added dimension of the forecast.

It is likely that a more useful set of categories will be developed, and may be developed by any information provider as well, relating to their services or purposes.

Raw set of forecasts requested, from Colorado decision calendar

(Explanation of "type" below; Wx/Cx is characterization as weather or climate forecast, with loose characterization of weather as including periods up to 14 days ahead)

Number	Subject **MONTH**	Type	Wx/Cx
	OCTOBER		
10-1	ONDJFM FLOWS	HF	Cx
10-2	ONDJFM CLIMATE AND FLOWS	GF, HF	Cx
10-3	HIGH ALTITUDE FREEZE-UP DATE	SF	Wx
10-4	LOCAL WEATHER, WINTER SEASON CLIMATE	SF, GF	Wx

10-5	LOCAL HARD FREEZE DATE	SF	Wx
10-6	CLIMATE EXTREMES, COMING YEAR CLIMATE	GF	Cx
	NOVEMBER		
11-1	NDJFMA FLOWS, RESERVOIR LOSSES	HF	Cx
11-2	0-14D LOCAL FLOWS, HARD FREEZE DATE	SF	Wx
11-3	RAIN AND SNOW EVENTS, 0-7D, 0-14D	RF	Wx
11-4	CLIMATE EXTREMES, COMING YEAR CLIMATE	GF	Cx
11-5	COMING YEAR CLIMATE	GF	Cx
	DECEMBER		
12-1	0-7D, 0-28D FF, PC, FAST MELTING SNOW EVENTS	RF	Wx
12-2	CLIMATE, ESPECIALLY SNOW WATER YIELD	GF, HF	Cx
12-3	CLIMATE FORECAST, OWN AND COMPETITOR REGIONS	GF	Cx
12-4	CLIMATE FORECAST, OWN AND COMPETITOR REGIONS	GF	Cx
	JANUARY		
1-1	SNOW WATER YIELD, MAMJJAS FLOWS, ARKANSAS	HF	Cx
1-2	CLIMATE, OWN AND COMPETITORS' – LONG LEAD	GF	Cx
	FEBRUARY		
2-1	0-7D, 0-14D, 0-28D, PRECIPITATION, HIGH WIND, FF	RF	Wx
2-2	0-7D PRECIPITATION	RF	Wx
2-3	THREATS TO YOUNG LIVESTOCK	RF	Wx
	MARCH		
3-1	0-7D,0-14D FLASH FLOOD, THREATS, HIGH WIND	RF	Wx
3-2	SNOW WATER YIELD, MAMJJAS FLOWS	HF	Cx
3-3	SNOW WATER YIELD, 0-28D PRECIPITATION, FLOWS	HF	Wx, Cx
3-4	MELT TIMING, STORM PROBABILITIES	RF, HF	Wx. Cx
3-5	LONG-LEAD FOR GROWING SEASON (MAMJJAS), OWN AND COMPETITOR'S REGIONS	GF	Cx
3-6	THREATS TO YOUNG LIVESTOCK	RF	Wx
	APRIL		
4-1	0-7D, 0-14D PRECIPITATION, FLASH FLOOD, FLOWS	RF HF	Wx
4-2	0-7D, 0-14D PRECIPITATION, FLASH FLOOD, FLOWS	RF, HF	Wx
4-3	SNOW WATER YIELD, AMJJAS FLOWS, RESERVOIR LOSSES	HF	Cx
4-4	0-7D, 0-14D PRECIPITATION, HIGH WIND	RF	Wx
4-5	THREATS TO YOUNG LIVESTOCK	RF	Wx
4-6	GROWING SEASON CONDITIONS	GF	Cx
4-7	0-7D, THREATS LOCALLY AND AT DESTINATION AREA	RF	Wx
4-8	MJJAS FLOWS, SNOW WATER YIELD, LONG-LEAD	GF, HF	Cx
	MAY		
5-1	0-7D PRECIPITATION, HIGH WIND,	RF	Wx
5-2	0-7D, 0-14D PRECIPITATION, FLASH FLOOD	RF	Wx
5-3	MAXIMUM CREDIBLE LONG-LEAD FORECAST	GF	Cx
	JUNE		
6-1	0-7D PRECIPITATION, FLASH FLOOD	RF	Wx
6-2	0-7D THREATS (ESPECIALLY HAIL), WIND, HUMIDITY	RF	Wx
6-3	0-7D PRECIPITATION, WIND, HUMIDITY (DEW EMPHASIS)	RF	Wx
6-4	SNOW MELT TIMING, FLASH FLOOD, FLOWS IN UPPER ARKANSAS	RF	Wx

	JULY		
7-1	JAS FLOWS, LONG LEAD SEASONAL	HF	Cx
7-2	0-7D FLOWS, UPPER ARKANSAS	RF	Wx
7-3	0-7D PRECIPITATION, WIND, HUMIDITY (DEW)	RF	Wx
	AUGUST		
8-1	0-7D PRECIPITATION, FLASH FLOOD	RF	Wx
8-2	0-7D PRECIPITATION, WIND, HUMIDITY (DEW)	RF	Wx
	SEPTEMBER		
9-1	0-7D PRECIPITATION, FLASH FLOOD POTENTIAL	RF	Wx
9-2	SNOW AND WATER YIELD NEXT 12 MONTHS	HF	Cx
9-3	CLIMATE, OWN AND COMPETITORS' – NEXT 12 MONTHS	GF	Cx

B. Discussion of requested predictions from the decision calendar

In order for this work to be most useful to NOAA resource and strategic planners, several questions should be answered, even if the answers tend to change with time. First, how many of the requests are collapsible into a smaller set, due to being the same in some way or ways? Second, what are the relative values or priorities for the requests?

1. The common requests:

a. Hydrologic and hydro-climatic forecasts

Prediction of spring and summer flows, or snow-water yield, in MAMJJAS, for example, depending on the month when requested, appears in requests almost all year, [1-1, 3-2, 3-3, 4-3, 4-8, 7-1, 7-2, 9-2], and requests for prediction of winter flows appeared in several of the other months [10-1, 10-2, 11-1].

Therefore, one might collapse this as **generic request for a rolling prediction of flows**, (meaning, a continuing or frequently up-dated prediction), perhaps combining methods or offering several combinations of ensemble forecasting, ESP-style as used by River Forecast Centers, monitoring and SNOTEL information, etc. (We note that this also indicates desire for the products of hydro-climatology research underway at several of the Regional Integrated Science Assessment projects.)

The particular interest in flow forecasts surely relates to our focus on water management decisions, but even so there was surprisingly higher interest in forecasts of water supply than of general climate. This may have been biased by our focus on irrigated agriculture, as well, though range management interests in flow are substantial, because of stock watering needs. On the farm, general forecasts requested were essentially for "my coming year versus my competitors' coming years". One professional consultant said that even if he expected a really good crop of corn, if he knew everyone else would have a good year too, he might not plant any. There may be a lurking question of what sectors or activities are affected by "climate in general" as opposed to climate-driven outcomes such as flows. To the extent that specific outcomes are most important to potential users, research orientations may be affected.

b. Forecast threats to livestock, flash flood, and other forms of weather forecast applications or extensions

In general, we heard requests for rolling weather forecasts, or specific event or condition weather forecasts for something in every month except January, and we presume blizzards would still be of interest then. The inference we draw relates to the quality and usefulness of the forecast information that people get in our study areas; this is described in section 2 above in this report.

Request for prediction of **flash flood threats** occurs from March through September [3-1, 4-1, 4-2, 5-2, 6-1, 8-1, 9-1]. For reasons described in detail in the state and synthesis reports, irrigation ditches are vulnerable to flash floods. Ditches also seek to capture free water. Request for prediction of **threats to livestock** relates to the period of calving and lambing, February, March and April (though there is some counter-cyclical Fall calving), and timing of moving stock to summer ranges that are usually at higher altitudes, and moving them back "down" as late as possible, in October and November, April and May (depending on place and elevation for stock moving). A calf with an illness can often be treated for about the amount of profit likely from the entire operation for that animal; when margins are thin, costs become critical.

Two other kinds of weather forecasting are also especially wanted in the calendar results. These concern the forecast of weather conditions relevant to timing of some kinds of **farming operations**. One Spring day, one of the authors had a sad conversation in a small town, encountering a man who said he'd just seen thousands of dollars of beet seeds fly away in a wind-storm. More often, surprises in weather can result in damage to soils and access from bad timing of rain or snow melting. Untimely precipitation can also interfere with fertilizing, herbicides, and pesticides, increasing wasteful runoff and pollution as well as costs and perhaps requiring re-application.

This list might also include **"the baling forecast"**, which would actually be a forecast of certain conditions affecting alfalfa, and also other hay crops (though these are somewhat less sensitive to baling conditions). Alfalfa is important for irrigators because of its ability to use "extra" water for more growth, or stop growth and stay healthy in dry periods, and provide income two to four or even five times a year for three or four years after establishment. Alfalfa is grown on more acres than any other crop in the Southeast Colorado Water Conservancy District lands. Alfalfa must be adequately dried to avoid molding in bales, but not too dry to bale badly. Prices in 2000 and 2001 ranged from $45 to $120 per ton, (there were some much higher prices in the 2002 drought) depending on quality; there are also increasing sales at higher prices for delivered and stacked bales for horses. The quality depends on the stage of growth of a plant when it is cut, and the environmental conditions during curing and baling. For many farm-ranch operations, a good year or a bad year can result from the quality of the alfalfa bales sold; for others, the crop is important fodder for wintering livestock. High quality irrigated acreage is increasingly being used in vertically-integrated agribusiness for feed in dairies located far away.

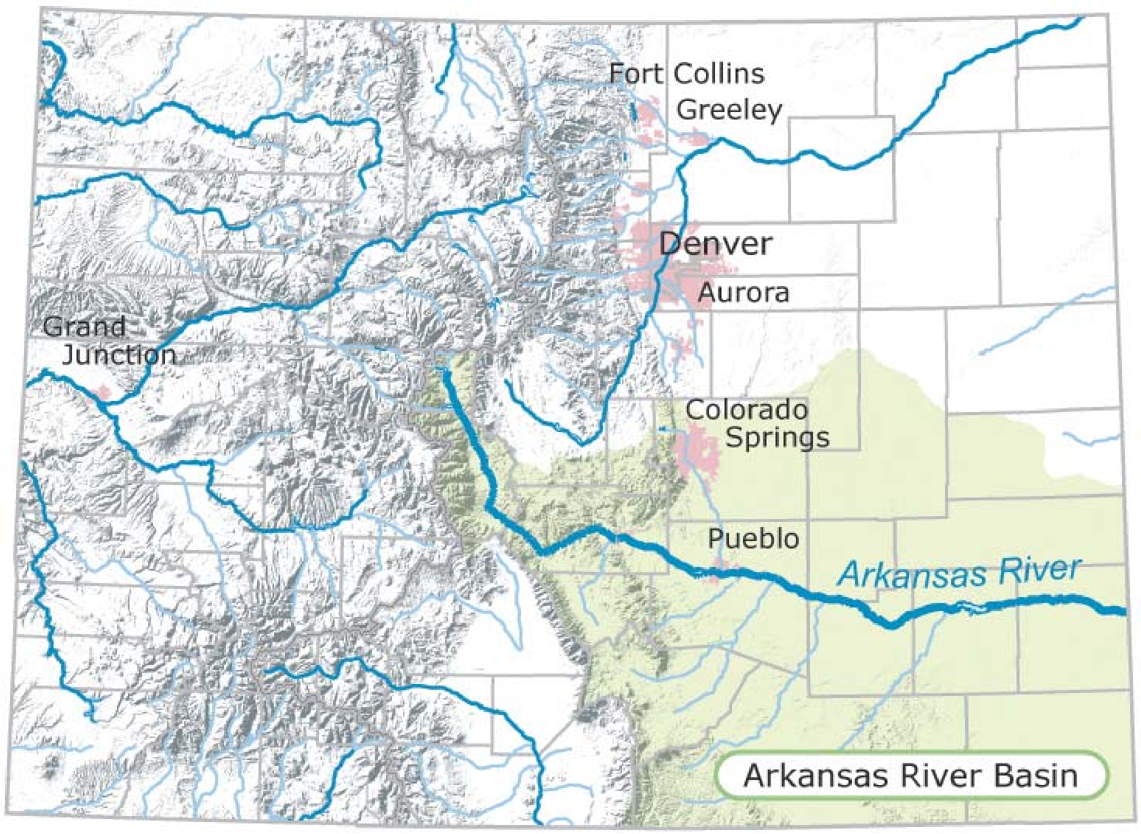
The price of a bale or ton of alfalfa can be halved by baling conditions alone, regardless of the nutritional quality at time of cutting. Farmers, therefore, often keep some desperate hours waiting for the dew to be just right for baling, often working through the night. And surprises in rapid drying due to high winds and temperatures can be as expensive as rain at the wrong time. Wetted crops may have to wait for drying again, and the delay in this step can reduce the size of future cuttings. Alfalfa may be cut four times in the Valley if things go well, providing cash income during a time when expenses have been incurred and harvests are not in yet, but it depends on the age of the stand as well as the field and weather. There are a few other points to note. First, alfalfa is remarkably flexible, in its ability to grow more rapidly in response to added irrigation or precipitation, or to go dormant in dry times. So, water may be allocated much more flexibly than in the case of crops such as corn or soybeans. Second, alfalfa is usually planted every three or four years in the Valley, so it can be quite low in cost in a given year, depending on the farm's rotation. Third, alfalfa is almost always useful for local sales, if not used on the farm itself, or can be sold for transport if it is good quality, in regional markets. In 2002, hay and alfalfa traveled all over, because of the drought, but even in normal years the Arkansas Valley sends a great deal to feedlots and dairies in New Mexico, Texas, and elsewhere. Fourth, alfalfa is a nitrogen-fixing crop which improves the soil for other crops in the rotation. Almost everyone grows some alfalfa, if only to use "extra" water if it is available, rather than waste it. And the price received can vary much more than that for other field crops, making for a good or bad year.

The information wanted is humidity, evapotranspiration, and windiness at the surface. This is also widely desired for other purposes, but we call this particular application to attention because it illustrates the significant potential benefits that might be achieved from a relatively simple application of such information, were it made available.

These weather forecast requests should be considered in light of the shopping list requests for help in making local application of forecasts (weather and climate) that are already being made for other areas or at larger scales. We call this "calibration", to distinguish it from down-scaling of the forecasts. Instead, this process would involve providing information to help users make judgements normally made on the basis of long experience in a place. Old-timers can tell what a Pueblo forecast means for some place north of Las Animas, if the frontal passage is identified, for instance. But where the conditions are more localized, as in convective thunderstorms, guidance is often reduced to hunch or instinct. This is further discussed in the "shopping lists" section. We hope that much of this can be done quite economically.

c. General climatological forecasts

Research into potential applications of the long-lead seasonal forecasts from NCEP and others was a primary purpose of this work (and its funding). Given the relatively obvious utility of such information, it is not surprising that there was considerable interest. In terms of the calendar of decision-making, however, we found some fairly distinct opportunities for application. For the benefit of the Arkansas Valley, December and March may be the most important times for issuing a new long-lead forecast, because of the financial, water and agricultural decision-making under way at these times. This seems to be confirmed by the enterprise budgeting information, and when expenses are incurred (see section below on agricultural financial calendar). These are relatively short periods when forecasts are most useful – when decisions are adjustable to use them. This is not to say that long-lead forecasts would be undesirable in other times; in the calendar above we note requests in September through January, and again March through May, but conditions affecting prices, market/sales decisions, and future prices are always interesting. When the best issue-times would be for Yuma, or the Central Valley of California, would surely be different. Perhaps this study will help establish an approach to answering such questions.



For the Ute Mountain Utes and the Southern Utes, as an illustration, the timing of most-wanted forecasts may be different. The Tribes are not far apart, but the interests of the small Southern Ute (and Pine River Indian Irrigation District neighbors) livestock operators involve bottomland haying, small irrigation operations, and much higher elevations than the highly technical large-scale agricultural operations of the Ute Mountain Ute Farm and Ranch Enterprise. January forecasts of the coming water yield are universally wanted, and March forecasts are also relevant to the irrigation district, but which later forecasts of conditions are most wanted is not as clear. The December-issued forecasts could become more important as financial sophistication increases in the Pine River/Southern Ute area, or the future may include more people supporting their farms and increasingly recreational farming in that area.

An example of the differences in farm ability to respond to information also comes in regard to the baling forecast described above. The state-of-the-art Ute Mountain Ute Farm and Ranch Enterprise cannot interfere with the cutting and baling crew schedules, because the costs of a poor result from a few days' baling is less than the cost of disruption of the rest of the schedule. This would not be true for most farms in the Southern Ute and Arkansas Valley areas.

Summary of near-term requests not as clearly related to the decision calendar

In order to get more information than that which was easily related to the annually recurring decisions in the calendar, we probed for other concerns and requests. The following "shopping lists" synthesize what we found in the Arkansas Valley, with some additions from other areas in the study. Sources of some of the requests are identified, if the point was made by an official; other requests are not identified to individuals. We also include here some additional information to further explain some points which appear in the calendar as well as on these lists.

We distinguish between short term requests, in the sense that the request may be fulfilled in the near future; these are numbered here. Those which may be farther away, "long-term requests", are lettered.

1. Flash floods, threats and basic monitoring information gaps

We found a widespread complaint that the lack of basic climatological and hydrological information – literally baselines in some cases – will hamper use of new information and forecasts. "Threats" information is largely apparently within the scope of conventional weather forecasting, but actually outside the geographic scope of adequate efforts or coverage. Flow monitoring is clearly valuable, and the capacity to detect and respond to surprises is limited.

1A. Threats examples – A surprise blizzard:

Request: In October of 1999 there was a surprise blizzard in Eastern Colorado, which demonstrated the value of improved warning, or **"threats"** awareness. Thousands of bushels of corn were lost and many cattle died from drowning in ditches while being driven by high winds and snow. The cattle could have been moved with more additional notice; they were not far away from farms, and the corn could have been harvested with somewhat more notice. An advisory was issued at noon, warning at 3 PM, and the storm was very heavy by 7 PM. It was said to be a "classic Albuquerque low". Warnings that short didn't save much trouble. With a week, cattle could have been moved, corn taken in, and alfalfa baled before it got wet and lost a lot of quality. With even a couple of days, cattle could have been saved. How much warning could be given is unknown, but these agricultural advisors hope it could be better. **During the event**, there was little or no news or forecasting about what the storm was doing, and how conditions would change; this again cost potentially valuable opportunities to take steps that were soon foreclosed when the clearing weather turned to blizzard conditions again.

Calving, lambing, and stock moving (also appears in calendar)

Threats information of several kinds would be very useful for range and livestock management. First, there are critical periods for livestock: when to move the animals **down** from the higher ground to winter pastures, and **calving/lambing** times. For each of these, forecasts a week to perhaps two months ahead would be very good, because the response to threat information can be slowed by the realities of rounding up cows, for instance, and the response can be critically expensive even if it is successful. The longer the lead time, the less likely to be emergency or expensive.

High winds can be very expensive for planting, due to lost seed and misdistribution of seed. This calls for good localized weather forecasts. Storm cell motions would be useful, also; the radar images for the cities would be great for the planting times.

1B. Ditch threats from flash floods (also appears in calendar)

Ditches can be threatened by unexpected precipitation, while **"free inflow"** from tributary areas can be used to conserve other supplies. So there is great interest in avoiding having a full ditch when a flashy event occurs, and less urgent interest in avoiding wasted inflows which cannot be used or stored under some conditions.

Describing John Martin Dam and Reservoir operations, an informant noted that management during serious flood events depends on maintaining dam safety first, and reducing damages from high flows as the next priority. Above the reservoir, **inflows from unmonitored** tributaries, including canals and ditches, may add to releases from upstream reservoirs and flows from gauged stretches. Downstream, the inflows from un-gauged tributaries may already be creating high flows, so that releases from John Martin might be reduced if possible. Better weather coverage and precipitation estimation in the whole catchment would be ideal, though practicality is another issue. She emphasized the importance of best possible information in emergency situations where on-scene persons may have to make hard choices; the manual and guidance can only be useful with the necessary understanding of what is happening.

This emergency manager is especially interested in knowing about threats such as **flash-flood conditions, a week ahead** or a little more. The time frame comes from the time it takes water to move down the river from upstream reservoirs, and the time it takes to get water out of canals and ditches. The direct application in dam operations would be to smooth out changes in releases. **Releases** from the reservoir are usually planned a week ahead, for the benefit of downstream recreation safety, and agricultural users of the bottomlands. Slow and gentle changes in the flow levels below the dam are always preferred. On the **reservoir, recreation** is increasingly important, and this may be increased by new State investments recently proposed. Safety for boaters and staffing for emergency responders is important and affects staffing for other activities.

The use of week-ahead information would be improved by coordination with real-time flow measures. These are used as much as possible but more gauges would always be nice.

Because of the hydrologic and topographic **situation magnifying flash flood hazards** in particular, and the sometimes challenging weather of the Eastern Plains, it would be good to have forecasts of unusual levels of threatening conditions.

1C. Basic flow monitoring

Basic forecasting improvements for rural areas could benefit people. Although Colorado has relatively better stream gauging than most states, the network is very limited in flash flood usefulness. It does well for riverine slow-rise flooding, but increased gauging would help with flash flood threats. Can NOAA help with USGS to **plan and place gauges most effectively**?

The floodplain managers want improved **gauge information before, during and after snow-melt**, especially for warning of unusually rapid melt-off. Additional automatic warning systems might be cost-effective; can a live operator be automatically notified that conditions are abnormal. Also, **GIS-integration** of the gauge readings should be more available. The 1999 Southeast Colorado flooding had been poorly identified even while it was in progress, and was not appreciated until it was a very large event. The network of gauges in Colorado is relatively good, compared to other states, but still not very good for events that are not slow-rise riverine flooding.

1D. Surprises

The **threats and surprises forecasts** – conditions that allow surprises and nearer-term chances of a surprise – may actually have much larger value in **"shoulder seasons**" when extremes are not anticipated, than when such events are expected. This may be of interest in terms of allocation of forecaster efforts and resource allocations; we have no information on the annual calendar for the National Weather Service or other parts of NOAA, though fiscal year considerations are probably important in planning.

Emergency management training is also important, including are informally called "get there exercises" in which people literally go through the motions under surprise constraints, to realistically simulate disasters and the accompanying wash-outs, loss of communications, failed equipment, and so forth. Simulations can always be improved with **better scenarios**. Although most of the emergency management situation is outside of NOAA's scope, one area of special interest is provision of **"what's coming"** information to local officials. In a real case, some officials were uninformed of multiple flood crests moving down a reach, which could have led to very sad results without good luck from almost accidental radio monitoring by someone with better incoming information. The time and money needed are always a problem for everyone in the rural areas. The threats of cascading flash floods and canal failures are quite serious in the lower Arkansas, given the long narrow valley topography.

1E. How these relate:

The common problem is limited support for a variety of basic management tasks because of insufficient monitoring of stream flows and weather conditions. We are struck by how widespread these feelings are; see also the requests for more SNOTEL information and stations. The point may be that these requests support more basic observations and data operations that are already well understood. In the Drought year of 2002, the lack of basic information was especially lamented, in part because of the dramatic downward revisions of water availability estimates. The very high rates of sublimation and high-elevation soil moisture deficits unexpectedly changed the snow-pack to run-off ratio in most places (see Luecke et al., 2003, "What the Current Drought Means for the Future of Water Management in Colorado", available from <www.cotrout.org> DiNatale, p.c. 2003)

2. Soil moisture and evaporative losses information

There were several different requests for information and forecasting, and climatology support. These concerned potential benefits from better management of soil water and small water storage, as well as large reservoir losses.

Soil Moisture Request: For this recently-established highly technical farming operation, infiltration of water is a problem because of soil chemistry here; several measures are used to monitor, and some amendments improve this, but more information is wanted. They want to substitute telemetry for the intimate knowledge a small farmer would have after many years. They want more weather information , such as wind and relative humidity, to help with this. They have purchased their own high-quality weather station but want to get more detail and smaller-area information. It is important that they already have the flexibility in their equipment and management to use small-area information for adjustment of irrigation and amendments. They are also interested in considering collaboration with NOAA and others on long-term projects.

Fall soil moisture levels and **changes over the winter** are useful but currently not well enough measured or known. (This might not be within NOAA's areas but using the climate forecasts and improved weather forecasts might be easier and more productive if there was better soil moisture information.)

Soil Moisture request: Range management can benefit from better soil moisture information, particularly if it can be based on remote sensing and modeling with weather information and forecasting. The agricultural community is under-equipped with monitoring and insufficiently inclined to monitor. But there is increasing interest in soil moisture and measures, and therefore increasing benefit can be expected from information. The open ranges of the Eastern Plains are underserved; the only readily available information is coming from COAGMET, and is expressly oriented for crop, rather than range. In addition, managers trying to keep livestock watered are often faced with the problems of short-term prediction of stock tank levels and losses, which affect how far cattle and sheep are from water and therefore where they can be grazed. A mistake requiring trucking water can be expensive.

Forecasting of soil moisture might be possible or more effective with increased local monitoring to match with observed weather conditions, and eventually soil information as well. Because the climate forecasting is advancing, local calibrations of the information should not be neglected. **Ground-level wind information** is missing and very important. People have been frustrated in otherwise successful efforts to adequately model soil moisture and erosion relationships by lack of wind data, and monitoring at appropriate heights.

Better **forecasting of evaporative losses and solar radiation**, and better forecasting of solar radiation (cloudiness?) as well as windiness is requested. Agricultural extension people have mentioned that this kind of forecast might be useful for farming as well. The Colorado Water Conservation Board also wants this; many commercial and municipal users pay for private consultants to advise them on conservation measures such as lawn watering requirements.

The manager of a canal told us in 2001 that a number of private operations were providing soil moisture measures and irrigation recommendations to farmers trying to conserve their water. In 2002, there was little measurement mentioned, due to the extreme drought, but the interest in this service may increase as result of the carry-over soil moisture deficits in much of Eastern Colorado in 2003 (see Drought Monitor website).

An additional source of interest may appear from increasing calls for improving agricultural irrigation efficiency, such as the Department of the Interior and Department of Agriculture combined "Water 2025 Initiative" (see website), announced in Spring 2003. This expresses increasing pressure to transfer agricultural water to municipal uses and concern for the impacts on rural areas affected by transfers.

In general, while evaporative losses are a known concern for large reservoirs, smaller operations may be more sensitive, and the economic impact of irrigation at wrong times, running short, or wasting water that does not benefit urban users was suggested to be significant.

3. Calibration, storm patterns and general weather patterns

There is a great deal of "local knowledge" in ranchers with very long histories in a place, who can mentally make the calibration from some weather news about a better monitored or served place, such as nearest big city, to adjust that for their own location. Everyone does that to some extent, but there are a huge number of newcomers on small rural acreage who do not have the experience to do it well. This is part of the "**calibration need**". The challenge is to apply high technology to substitute for long experience, and complement it. There are several approaches, but they probably all are some form of increased correlation of available measures, such as daily wind fields and weather maps, with increased density and strategic sampling of local conditions in representative areas. The other part of "calibration" is ground-up information that correlates to modeling and large-area observations, so as to develop practical down-scaling for places of concern.

Two particular needs identified were for better data acquisition from rural places that "get the weather first", and better identification of the **typical storm and frontal tracks** that bring weather. These are certainly interactive and will help each other. Several scientifically trained informants independently mentioned how there are several "usual" patterns that bring weather of concern to their areas, and they wish these were more carefully observed. They expect that these local (multi-county scale) patterns could be usefully integrated with forecasting for larger scales, to get better predictions and more effectively localize forecasts. This is intuitively done by people in rural areas seeking to apply their experience to extrapolate from forecasts and weather radar information from places better served, and would seem to be an area ripe for progress in the near future.

This request fits neatly with other comments on the ease of use of **visual loops** of mapped storm tracks, and how people would like to see "it's here now, moving westward about 25 mph, will get to there by noon, then next place by sunset…" And, in fact, several people mentioned how the Hurricane Center has set the standard for easy to see information, with probability cones ahead of the storm, arrows and such visuals.

4. Form of information

4A. Generally

The **localization** of threat information for the Arkansas Valley is not very good, since watches and warnings are given for several counties at once. His ideal form of information would be a **"tracking" visual** on a map, like those presented for the public during hurricane watch and warnings. The present location of a storm cell could be shown, with a set of cones of likeliness of travel. The outer cones would have lower probability than the inner cone, if there was such information. For frontal passages, perhaps time of passage could be indicated

on the map. Also on a **map**, he would like current and perhaps recent-period loops of **radar locations** of events.
Several informants felt that **loops** were well understood and helped people see patterns.

As a general problem, local radio stations are often very competitive with each other, and with stations from the nearest big cities. They may **over-dramatize** forecasts and events, in an effort to attract more listeners and hold listeners longer. This may reduce the usefulness of weather information, especially as the listeners begin to expect such distortion.
One informant asked to have probability of precipitation events forecasts presented with a **measure of confidence** in the forecast. The box to show a measure of confidence around a dot for the most probable point was mentioned (extent of box showing something such as 1 or 2 standard deviations, or 30 percent chance of being below or above the "dot").

4B. Now versus last year versus normal

Now versus Normal versus Last Year: This was first suggested by a range scientist, and readily confirmed by many. Officials felt that this sort of comparison is what people can best relate to, with the sense of normal and the last year being interesting and mentally fresh, and of great interest compared to the present. The perspective from cattle management and marketing and range science, was based on asking, " where are the **forage grasses now** compared to last year?" And where "should" they be? This idea was very well liked by others as well.

4C. Better connection between information sources

Existing information on NOAA and other websites is not easily used, in part due to lack of connection between tabulated data and sites of origin of the data, and other geographic context. Improved linkage between sites and historical information would help (this point was confirmed often). For example, the metadata on stations does not explain why there are gaps or periods of record which end a long time ago, or where the station is located.

5. Local packages

Local packages of weather and climate information would be ideal, with place-based sets of information, from which one might link to topical information. But, it would be their preference to be able to log on to an internet source and get what they want organized by a map and perhaps then a menu of materials for that place. One relatively straightforward element might be a set of suggestions for adjustment of a forecast for a given point, (e.g. a city with a forecast office), to different elevations and perhaps directions (such as would be suggested if typical storm tracks were identified). Terrain that has predictable effects on frontal passages or storm tracks should be considered for this purpose also.

6. Improved and different snow information

6A. Generally:

Snow sublimation request:
Better information on sublimation losses of the snowpack would be useful. The losses are currently unpredictable, but with better information on this, forecasting from earlier information on snowpack might be improved. **Snowpack** is the essential forecasting datum for the big reservoir management as a whole, because it is such a dominant portion of the system's inflows. There are many desirable **sub-basin and basin** parts of these pictures that could be beneficial as well. The management questions for any given part of the river's "plumbing" vary with its inflows and the demands for outflow, so there is desire for knowledge of the **variations in local inflows**. The value of the forecasts will reflect the capacities for storage of a given runoff, and the options for use in lower places in some way, and the ability to adjust upper sources or contributors in response to variation in the normal runoff **quantity and timing**. Each facility should be considered individually. For SNOTEL sites, the aspect of the site and how well it represents the basin would be useful information for interpreting the data. Additional sites should be considered for increasing representation of snowpack concentration and probable melt timing.

6B. Timing

Management of irrigation water might be improved by longer anticipation of timing – especially of **unusually rapid or early melt-off**. The water systems in Southeast Colorado and Wyoming, for example, cannot accommodate a rapid run-off without compromising flood safety criteria. The result is that water may be "lost" and unused, or stored below where it is needed or would have highest value. To the extent that forecasts can inform users of different probabilities of rapid run-off, there may be currently unconsidered opportunities to avoid losing the possible high flows.

6C. More and better SNOTEL sites

There is agreement that increased SNOTEL monitoring would be helpful. They would like better wind information as well. The lack of monitoring of mountain conditions seems to be very widespread. More easily accessed and used information is wanted on the location and representativeness of the SNOTEL sites from which information is well reported. Can there be more information on relations between the sites and the larger-scale outcomes under different weather patterns? "Old-timers" in the field know where the sites are and "have a feel" for some of this, but it is not easily acquired.

7. Frost dates

Frost dates request – for travel and earthen ditches
The "normals" are already available, we think, from information on the website (easily accessed for station data, but what about interpolations for other areas?), but there is also interest in forecasts for unusual dates. However, the reason mentioned was the onset of two conditions: the hard freeze prevents further work on ditches, in the Fall, and the onset of mud makes travel more difficult and damaging, and some work much more difficult. (Driving on mud can dramatically increase erosion, for example.) Soil temperatures are useful for this, rather than for timing of planting.

Request – Frost Dates forecast for crop management**:**
In order to take advantage of unusually early or late frosts, and reduce losses from unusual frosts, forecasts of those "last and first" dates would be desirable. This seemed similar to other requests for forecasts oriented to unusual or unexpected events, as opposed to events that are seasonally expected. Concerns are different, depending on location and elevation, in the case of why frost dates are of interest.

8. Fire and burn weather

Fire weather and climate: Timing of controlled or planned burns is clearly a difficult and important application of weather and climate information. While most attention is given to immediate forecasting for the place in question (a task recognized as seriously difficult), there are also questions for the longer-term. Timing of a burn is critical. In regard to higher-fuel load and non-annual burning, perhaps knowledge of a dry next year or multi-year period (or wet) might affect the desirability of doing more or less burning in the present year. In general, field burning is apparently much less dangerous than forest and range burns, and field burns are probably annual without much regard for conditions or forecasts.

Staffing for burns is variable; weather and climate information may help anticipate needs. (To what extent was this useful in 2000? How about in 2002?)

One very sophisticated weather information user, a Fire Management Officer, asked that we mention that he likes the **GRADS 10-day** outlook, but would like it better linked to maps.
The disastrous fire season of 2002 took place after the interviewing on this topic had concluded, and we are pleased that there have been significant increases in weather and climate information support for fire prediction, risk assessment, and event management.

9. Range Grass Growing Conditions

9A. For livestock

Grass growth is the critical variable for cattle operations using range lands. Forecasts available early enough to effectively adjust the stocking rates might benefit operators. The dates would be highly sensitive to location, elevation, and the current weather, but calving limits the time when cow-calf pairs are sent to range. January is probably not too early, and March is getting to be late for usefulness, but it may depend on other factors affecting sale prices, and the structure of local cattle markets. (Feed lots exist, in part, to provide an even flow of stock for slaughter, and this is a complex market with highly uneven power and capitalization.) These forecasts would be similar to the degree day forecasts, but might include further information if there is expectation of unusually early heat, or other differences from normal. This information may be readily convertible from existing forecast information.

The value of hay varies substantially with weather, and **monitoring** of conditions is necessary for best cutting time (after maximum growth as related to amount of water wanted to be applied, and before the hay dries or goes to flower after water stopped or conditions dry up). The difference in grasses is very important for when to graze or not, and when to cut or not, and elevation and temperature are key control on which species dominate.

9B. For wildlife management

Based on interests in Native species and **wildlife management**, we were asked for consideration of climate information that would help there. Forage grasses information might help, as well as information on **stressful conditions** for animals that may not have much impact on vegetation directly (e.g. especially deep snow, long-lasting severe cold or heat, and icing that affects movement or forage). One may also speculate that other conditions such as unusual growing or threat conditions may be useful when more management is applied, as in closure or opening of areas to livestock. Also, long-term forecasts of various conditions may be informative for herd size management. In many places, there is interest in knowing more about the balance of live stock with wildlife, and improved management capability may increase flexibility of response to changes in values.

10. Range cattle watering conditions and small reservoir ET losses

There are critical cost variables in ranching away from river supplies on which the rancher has good water rights. If the cattle are able to get water in only one place, it must have enough, or additional water may have to be trucked to the cattle. This is a serious cost, especially with high gasoline prices. Interestingly, the day after an informant mentioned this, a State Senator called for a special session of the legislature suspend Colorado state gasoline taxes because of high price impacts on the small agricultural operators. News coverage did not mention drought. Illinois and Indiana suspended their state taxes on gasoline in the summer of 2000 (Colorado Daily June 30, 2000). However, perhaps due to the poor financial condition of state governments in 2002, we observed no similar tax suspensions.

The responses to water shortage in small reservoirs is to move the cattle, increase the water supply, or establish different sources; all of these have costs. The most common problem, however, is inability to foresee the limits on a given small reservoir. The **rates of evaporative loss** can be very high, where there are very shallow conditions, and hot and windy days. Can windiness be added to the forecasting for the next few months, to improve ability to predict reservoir status with greater lead time?

Another consideration for cattle watering on the range is whether there will be unappropriated or junior water left in streams to which grazers may have some access after senior rights are satisfied. Knowing there is a good chance may change one's choices about where to have cattle.

11. Cloud seeding forecasts – Colorado

A state agency in Colorado issues permits for weather modification. There were 8 permits on file before the 2002 drought, though some were inactive since the last few years have been quite wet. The majority are efforts to increase snowfall in the very early season for a ski area (Vail, Beaver Creek, Aspen, Telluride). Another effort is to increase snowfall in the catchment for a reservoir from which the Northern Colorado Water Conservancy District draws. These permits disallow cloud seeding whenever snowpack is above a specified threshold. These have all been somewhat intermittent in operations, depending on the year in question.

The permit with most persistent use is actually held by an association of western Kansas counties, which has used cloud seeding in threatening clouds to reduce hail (and hail damage) for 18 counties for roughly 20 years. The seeding takes place in clouds upwind of the areas sought be benefited, so a strip of land on the state border has been included as benefited in order to secure a Colorado permit. Not all of the counties contribute every year to the operation but there is apparently strong belief that this reduces hail size and thus hail damage. They have reported a reduction in the number of claims for hail damage. Utah is believed to be allowing a considerable amount of cloud seeding also.

The permittees and the regulatory agency would benefit from more detailed wind field information with which to judge both the location of seeding efforts, and to evaluate the effectiveness. Currently, some of this is provided to some of the permittees by private consultants, but the State would benefit from better information.

After the interviewing on this topic had been done, to some surprise the Denver Water Department decided to invest approximately $700,000 in cloud seeding and related measurement, in 2002. There was considerable controversy (e.g. at Colorado State University's Drought Seminar, December 4, 2002) over this decision, based on the lack of evidence of success in past efforts. Some meteorologists claim significant advances in the art, but we know of no decisive showing of success. The Southeastern Colorado Water Conservancy District also invested $140,000 in cloud-seeding, with undemonstrated benefit (Water News 2(4), December 2002). However, at least one consulting meteorologist who contracts to provide services in cloud seeding claimed in an informal interview that success rates for those with correct understanding are better than for those without.

Summary of longer-term interests and climate information goals

A. Irrigation season forecasting for water banking

Eventually, there will be a need for sufficiently reliable and sufficiently well-accepted irrigation season forecasting to allow for effective water banking. The Colorado legal situation is described elsewhere in this report, and there are many possible variations on how water markets might operate, but some of the critical elements may include (1) early-enough forecast to minimize wasted investment (e.g. planting wrong or unused seed), and facilitate making alternative management arrangements to minimize soil erosion, provide forage or meet other goals; (2) sufficiently reliable forecast (not necessarily perfect, of course) that all or an adequate number of participants in the market can commit to transactions; the problem is to compromise on all the parties' risk aversion and relative losses from misjudgments or failed forecasts. This would be a sufficiently accurate forecasts of snow water yield, timing, and other precipitation to support adequacy of consensus to "make a market". The transactions must be designed so that the risks of incorrect forecasts are acceptably distributed, and externalities are minimized.

It may be valuable in pursuit of this goal to undertake examine each of those sources, and to inquire on the extent to which available irrigation water comes from snowmelt, monsoonal or seasonal precipitation, and the extent to which needs are sensitive to local drought indices such as soil moisture and other measures. Drought indices for each potential market area may have to be locally specified.

The Arkansas Valley also has complex water trading and transfers, due to the ability to divert flows from trans-mountain diversions into the Valley, and then again over the Front Range into the systems used by Denver, Aurora, Colorado Springs, and others. The trend at present is toward some resolution or legislative action to clarify the State's interest, and perhaps establish some limits on water marketing in Colorado, and perhaps conditions on out-of-basin transfers. This is an area of lengthy and rich literatures, and considerable speculation. It shows a strong interest in forecasts of the water year as a whole.

Charles Howe's article, "Protecting Public Values in a Water Market Setting: Improving Water Markets to Increase Economic Efficiency and Equity", (2000) is a strong and clear summary of many important issues. (See also Howe et al. 1982, discussing usefulness of climate forecasting for similar purposes.)

A variety of additional interests might be served by effective use of climate variation forecasts, in the opinion of one author (other participants in the study may not agree). (A) Soil maintenance is underserved in current economics – partly due to application of the positive discount rate, and for other reasons, but should be recognized as a public interest (e.g., non-point source water pollution and sedimentation warrant treatment as a public good or bad). (B) maintenance of agricultural land in agriculture as re-capitalized and more flexible production units seems desirable at least in principle, as long as people are willing to keep doing small agriculture. (C) The key to intermittent transfers and some reasonable level of equity may be contracts which are essentially long-term sales of options that can be exercised under specified conditions or with agreement, at specified times, or else with penalties. And, (D), side deals such as support for farmers' markets and recreational access should be strongly encouraged and creatively approached – these would be partnerships between areas of origin and new places of use. In each case, more effective allocation of resources and more cost-effective forms of agriculture and combinations of agriculture and subsidy/externality may be amenable to improvement with increased flexibility for any given year's activities and improved capacity to apply climate forecasting.

B. Localization of forecasts ; geographic specificity

There is widespread interest in getting the benefit from larger-scale climate models and understanding of teleconnections, from local governments and water users on up to larger-scale water managers. The request for more effort to tie the big models to the smallest scales was common. The interests were also widespread, from water management per se to snow safety and flash flood conditions, and the surprisingly widespread interest in reservoir loss and evapotranspiration information (from small livestock operators up to the Colorado River system). Given the challenges and expense, however, there was also strong support for the idea of "calibration" and help for local people in making better use of existing forecasts and models, by better relating what happens at the point of interest compared to the point of forecast.

C. Requests and concerns for long-term climatology support for decision-making and risk understanding

There were a variety of requests for long-term forecasting, for a variety of purposes; of course, the underlying concern is usually to maximize the return on infrastructural investment.
There may also be possible relevance of very long-term forecasts for consideration in Colorado River management.

C1. Long-term forecasting for the Colorado River Basin

This is not likely a surprise, given the enormous importance of the River.

C2. Long-term drought prospects

It would be useful to have a clear indication of how reliable the news is about past droughts and the research on extent and severity. New research seems to be appearing often, and it is hard to know how to weigh it. In the 2002 Drought, there was great interest in the "paleo-drought" studies, and Dr. Constance Woodhouse (a NOAA scientist) vaulted to well-deserved fame and frequent citation for her work on dendrochronology and its information for inference of past climate variation.

C3. Long-term climate as driver of water supply

Long-term climate concerns: There may be particularly strong interest in Native American Tribes/Nations and others where long-term climate variation acts to reduce water supply and no feasible alternatives are currently known. The Native American water rights may be qualitatively different from other rights recognized by the State and Federal governments in terms of their transferability (and hence value as an economic asset). They may also be subject to unforeseeable difficulties in substitution or supplementation, for legal or economic reasons. And there may also be concerns not unique to Tribes, such as losses in carriage contracts which are specified not in terms of water "put in" but in water that is "delivered" to another user. Where reservoirs are losing more to evapotranspiration, the distribution of the losses may not be clear. This has become increasingly important in considerations of additional storage facilities for drought mitigation in Colorado, where the legislature enacted a bill calling for a referendum to approve $2 Billion in bonding capacity, with provision that at least one major project at great expense will be selected for construction, if not more. Storage to yield ratios for new reservoirs are an important issue (Luecke et al., 2003).

C4. Long-term forecast for organizational management

Army Corps of Engineers planning and budgeting for maintenance is based on a **three years advance programming** effort. Our informant speculated that long-term maintenance and staffing plans might benefit from consideration of multi-year cycles, if adequate reliability is achieved in forecasting, because work needed in wetter areas may not be as urgent in dryer areas. Funding is always an issue. In the **very long term**, the Corps has some land management responsibilities also, in association with wetlands as well as dams and levees and harbors.

In the **middle range**, specific operations and maintenance activities might be better scheduled if there were good forecasts of wetter or dryer periods. Which actions should or may be postponed, and which must not be postponed or should be moved to earlier timing? One example was maintenance and lubrication of a large kind of gate that is used for rapid (flood-related) releases. Part of the job is easier and faster in dry times with low water, and testing can be done, but the need is to have that accomplished before high water. The Corps does not compromise on safety, but optimal scheduling might reduce costs and staff juggling, as for specialists who serve many facilities.

C5. Very long-term forecasts for irrigation needs

There was also interest in the **longer-term changes** in climate that would affect irrigation needs, and water supplies. Tribal resource managers are interested in what may affect their reservoirs, both in supply and demand, and the other resources which may be critical for subsistence. (See USGCRP Native Homelands report for extended discussion.)

C6. Long-term forecasts for breeding and stock selection

Livestock operators want to breed the most suitable cattle and sheep for the conditions they face. Some choices are quite important, in the value of breeding bulls being bought and sold, and in the outcomes from different breeds in different conditions. There is potential benefit in choice of qualities to seek from knowing more about **next year's conditions**. The need here is really for information about the likelihood of extremes as well as means, since success depends on resisting losses in all conditions, and maximizing gains of weight. The lead time is fairly long; breeding is 9 months ahead of calving, and there is additional lead time for negotiation of stud services or purchase of breeding bulls. And, once the information is public and widely used, there will be secondary effects from competition being at the new level. Now, however, the next step is for increased use of the long-lead forecasts with the "local calibration" mentioned elsewhere, starting about a year ahead. Unfortunately, this does nothing to narrow down the request, but it shows another benefit from the complete forecasting suite of products.

D. The concept and application of probable maximum precipitation

Regulators in two states mentioned a concern related to dam safety programs. Officials are concerned that the PMP idea may apply more accurately, at least in current practice, in the Eastern U.S. than the West. If the PMP application is unnecessarily strict, it may be imposing needlessly high costs on dams. Consequently, not only is expense too high, but these officials fear that small water development may be needlessly inhibited by these high costs. In light of concerns that climate variability may be increasing, the request for some reconsideration of the whole concept and how to achieve optimal dam safety regulation seems important. The fundamental information on which PMP is calculated seems suspect if there is climate variation either greater than previously thought, or under pressure of anthropogenic climate change. There may be substantial inefficiency from mis-specification, such as from over-design of facilities.

E. Reliability standard and measures of confidence:

We asked about the quality of information needed to rely on a forecast, and several agricultural advisors said, as a first estimate, that **80 percent accuracy** would be good enough for them to act on, and they thought it would be good enough for most farmers. The professional agricultural managers and consultants volunteered the 80 percent figure as well. The **usefulness** of information is not limited to forecasts meeting such a standard, however, and as suggested (in accordance with leading literature such as Katz, R. and A. Murphy, Eds., 1997, The Value of Weather and Climate Information, Oxford), less confident information – properly understood as such – could still be very useful. This informant (an agricultural advisor) suggested error bars or some other **measure of confidence** as part of any forecast. We make no representation of any detailed understanding here, because we did not press our informants on their understandings of accuracy or reliability (though in most cases these people are formally highly educated and not likely to have been speaking without a firm grasp on probabilistic information in their own technical fields.)

F. Bureau of Reclamation, River Forecast Centers and climate information

There are important policy issues associated with the Annual Operating Plan for the Colorado River as a whole, and perhaps limits on the authority to include or respond to forecast information in the Annual Plan as a whole. But, there are also Monthly Updates, and Facility Plans which might incorporate forecast information. There seems to be a great potential for integration of the new forecast information with the existing ESP modeling from the River Forecast Centers. (After these interviews were held, we learned informally of various efforts to improve forecasts by the RFCs, and we do not know the current status of this situation.)

The Annual Operating Plan includes some of the factual basis for the determination of whether the Secretary of the Interior may declare that there is "surplus" which may be allocated to California or other Lower Basin claimants, in accord with the Upper Colorado River Basin act of 1968 (see also Pulwarty, R.S. and Melis, T.S., 2001 Climate extremes and adaptive management on the Colorado River: lessons from the 1997-1998 ENSO event. Journal of Environmental Management 63: 307-324).

The Colorado River system as a whole has such large storage capacity for the benefit of the lower basin that management has generally been concerned with very large scale changes in hydrology only. Because there has been a "surplus" in the sense of the "Law of the River", there has been little pressure to accommodate planning situations such as those developed in the "severe sustained drought" study (Powell Consortium 1995). The potential for improved management on smaller scales may not be fully explored yet, and it may benefit from climate forecast information in ways not yet fully considered. The range of choice is not easily specified in general terms because of the varying contracts and obligations to which each facility is subject.

In 2001, we wrote that, "There is also potential for considering very long-term forecasting of general trends such as PDO as well as ENSO influences in river management as a whole, though the reliability of the information would probably have a direct bearing on the extent to which such considerations would be useful outside the Bureau and agencies charged with some foresight as well as operations management. This is probably several big steps ahead, but may be of interest to NOAA's researchers." In 2003, finalizing this report, we are impressed at the remarkable progress made by NOAA scientists in this area.

G. Forthcoming growing season degree-days

Agronomists use degree-days (combination of day length, relative humidity, temperature) for description of crop requirements and optima. The best choice of crop or variety can be identified with standard forms or charts of crop requirements. (This might be expanded in the future to include more easily available information on the sensitivity and vulnerability of crops to climate variations, one suspects.) The modification of the current forecasts to degree day information would therefore have big potential benefits for crop adjustments.

What to do with these requests? Considering the calendar and the "shopping lists"

There are two directions for application. First, the National Weather Service or perhaps Forecast Service Offices in appropriate areas may wish to consider how their current services provide answers, already available, and perhaps consider how other answers might be pursued. The climate programs may find the timing of forecast issuance requests useful, as well. Other NOAA offices and collaborators who work with OGP may find it useful to consider how the requests from this project match with those from others, such as the CLIMAS study on vulnerability to climate variability in the farming sector (Vasquez-Leon et al., Dec. 2002; see CLIMAS Regional Integrated Science Assessment website; reachable through US GCRP website).

A. Everyone wants better weather forecasts – but priorities within this include focusing on threats (see calendar and requests 1, 7)

Most of agriculture revolves around plants and animals that are fairly well adapted to "normal" conditions, but they're often pushed in ways that expose them to earlier or later dates, or unexpected locations and conditions. This puts a premium on knowing about unexpected conditions such as early or late frosts, sudden changes in weather, and so on. The forecast of a surprise event in a shoulder season may be more useful than when seasonal changes have taken place; when to plant is somewhat adjustable, but after planting, as one person said, hail forecasts are a big help if you can get your car in the garage in time to keep the windshield in one piece so you can see the ruined corn.

Structural vulnerability of irrigation systems to flash flood hazards is particularly acute, so severe storm information is important all the time. The coincidence of flash flood hazard with other thunderstorm hazards increases the value of improved forecasting. The tornado forecasting effort has inspired many to hope for better hail and local intense rain forecasts, and ideally, warning about the possibility of microbursts. This may relate to the extent and adequacy or intensity of radar and other remote sensing coverage, which is thought to be poor in rural areas. That in turn adds motivation to the next point. Basic information gaps, such as reductions in SNOTEL funding and stream gauging were frequent complaints.

B. More help in applying available forecasts to local situations ("Calibration" as opposed to downscaling)

One often sees calls for vast increases in modeling capacity and computational speeds, to downscale to smaller and smaller grid sizes, and incorporate more and more detail and achieve better realism. Unfortunately, simpler but perhaps quite cost-effective approaches to improving local information seem to lack appeal to both science funders and researchers. In discussions with our informants and advisors, we have elaborated a notion of "calibration" – working from known weather patterns and local conditions to help people make their own adjustments or applications of forecasts made for different places. This may be too "low-tech" to attract much scientific attention, but that could be a help in working with various partners.

The majority of our advisors have a fairly strong sense of how things usually happen in their place. For example, we often heard such remarks as, "If conditions are such-and-such, then the snow usually gets here about four hours after Pueblo gets it". On probing, this reflects belief in a weather pattern that is thought to be most common. The same person might also say, "Well, if the storm is coming from the Southwest, it can do strange things on the way… sometimes it turns and acts like an upslope…" We think the important point is that regardless of the accuracy of any such characterizations, long experience has suggested that there are some apparently common patterns which are larger than local micro-scale terrain effects. The question then would be, are there? Can the NWS and allies provide more than a windrose for the year, and more than windroses for each month? Not that this would be undesirable, but beyond this, are there figures available such as "For June, 80 percent of the thunderstorms in the blue area on this map take place when there is a cold front coming southward and a warm front moving northwesterly"? Or, "In March, storms which have brought significant amounts of snow and water content are almost always a feature of the jet stream moving in a loop that looks like this…. over the Rockies?"

If general weather patterns are identifiable for areas like the eastern plains of Colorado, that information would be helpful in itself, and also would help with the next step. That is, to provide guidance on applying forecasts for urban foci to the rural areas. There may be, for example, a forecast for Pueblo, and that may be adjusted to provide a forecast for Lamar, but for someone dozens of miles out of town and not between these points, right now there is only experience and hunch about how to use that information. This relates in turn to the preference for certain forms of information, as in (4), below.

It may be possible, at moderate or small expense, to provide two changes. First, educational materials would be helpful, for farmers and ranchers, about weather patterns in areas of concern. this could also include guidance on adjusting for terrain or elevation, and other factors. If this were widely available, with clear explanation and some help-line service, it could also be used by small towns and others looking for more localized information. Second, if forecasters were asked to incorporate relevant information that would help in this, they might habitually include remarks about the directions and speed of fronts, what might change that, and so forth. Television weather often specifies, and shows, fronts moving through urban areas, but there is much less effort (and perhaps less accuracy) for rural areas where few will be affected.

One interesting issue in this approach is how much information forecasters have that is not communicated, due to thinking it has no value. Who cares about the back of beyond? But, what a small extra cost to add a few sentences to a forecast or text discussion. Where there is no apparent pattern in effect, knowing that is also useful.

There is a huge popular interest in weather, especially in the rural and agricultural areas, and it would be very good to undertake partnerships with local media and local schools to develop this "calibration" work. Schools can keep records and see how well the guidance worked for example, and they can work out local tables and charts for "here compared there", and so forth. And that leads to the next point. Note also, however, that this idea of calibration also helps meet the request for more localized packages of information; especially with school partnerships, since these would start with local climatologies and identification of weather patterns. This kind of local partnership could also support requests B and C, for better localization in the long term and for better climatology for decision support. Even request E, for reliability standards and measures would be helped.

C. Support development of partnerships and expert systems to show applications of climate information in the U.S.; start with Agricultural Extension.

Schools are always interested in their own places, and should be invited to help in this. But universities and Agricultural Extension services are apparently underused. There are some exceptions (e.g. Dr. Jean Schneider of USDA was funded by NOAA OGP), but we found that in Colorado there was little capacity available to solicit or undertake new projects. Weather readings are a daily activity for many Experiment Station and Extension staff persons, but long-term research efforts are increasingly hard to fund and staff. So, private sector interests may have to be brought in, with careful limitation on the extent to which they are allowed to monopolize uses or dissemination of public research and information. There is considerable disgust with feeling that cities get great help but in the country you have to pay a lot for the same thing and then you get warmed-over re-hash of airport forecasts. The newer experimental grid-point forecasting by NWS was not available during our interviews, so this may change, but it is not clear in some inquiry we made that people are aware of the new information and formats like the meteorograms. As always, internet-only information provision is prejudicial against the rural areas where old wiring and less internet service can defeat new computers most of the time.

Beyond the forecasts, there appear to be important opportunities for development of expert systems which can link existing information and forecasts to locally-obtainable information, such as one's own soils' qualities, and existing models and tools such as the "Cropflex" irrigation scheduler that can be downloaded from Colorado State University (there are similar programs from Kansas State and Nebraska, also; CPIA 2002, 2003; see website of Central Plains Irrigation Association for information on presentations and see Colorado State University for the model itself.) Presently, we are informed by the Cropflex principal author, Dr. Israel Broner, that one can easily use this tool to see some outcomes from inputting different sequences of weather and irrigation, made up or "true"; so, it can be used to see effects from synthesized or predicted conditions. The next step will be adding range forage species and more soil conditions and qualities, to extend use for non-farming applications.

Modest funding with considerable educational benefits for graduate students from several disciplines could support demonstration programs for linking and elaborating some of these tools and basic measurements for a variety of test sites. With reasonably good localization (and guidance on how others would calibrate the results for their own locations, as above), this might produce low-cost helpful improvements in seasonal interpretations of available climate forecasts.

D. Develop the new climate divisions for more useful applications

The Arkansas Basin is within one climate division in the current mapping, and this may be misleading when climate forecasts are combined with new applications for improved soil moisture and agricultural forecasting. The work by Dr. Klaus Wolter of the Climate Diagnostics Center which has been informally presented seems to be an excellent means of increasing the value of existing data and increasing the usefulness of future forecasting efforts. We understand that further work refining these new climate divisions is in progress. It will be very welcome on the West Slope and in the South of Colorado.

E. Additional forecast timing, effort allocation and similar issues

1. Soil moisture over the winter

October and November, depending on elevation, are the times after harvest and before hard freeze when land treatments may be undertaken, and these could be informed by forecasts for the winter season's weather conditions and moisture conditions. Soil moisture is always critical information for farming and range, and it is increasingly important (e.g. in recommended "best management practices" -- BMPs) to manage to retain stubble and roughness for moisture retention. In some areas, the BMP will probably not change, but before the hard freeze it may be quite helpful to know if there is an unusual chance of especially dry or wet or warm or windy conditions over the coming winter season.

2. Extreme weather probabilities over the winter and coming year

Livestock sales are extremely complicated by the price effects of many sellers and buyers reacting to the same news at the same time, which can be commodity prices that affect feed prices and thus expected profitability to feedlots and others. On the whole, more information seems to be desirable, though we are not making this assertion with confidence. We suggest further elaboration of livestock management issues in regard to forecasting. It is fairly clear that the very large firms that make up an oligopoly in commercial meat processing are in full possession of state of the art climatology, and that small firms cannot afford this. This informational asymmetry creates advantage for those already advantaged by size and sheer capitalization, which unfortunately raises issues of public policy about who benefits or does not benefit from public science which is not directly useful without expensive interpretation. This issue has been raised elsewhere, but not resolved to our knowledge (e.g. in discussion in Stern and Easterling, 1999). Other National Academy and National Research Council deliberations also relate to this (e.g. "A climate services vision"), but optimal allocation of efforts can only be judged by some position on this. Given the extent of expense in agricultural policy and the public interest in land management on the majority of the surface of the country, there is certainly grounds for pursuing the issues.

3. The early December forecasts for the coming year

As discussed in the Calendar, allocation of expenses to one year or the next is an important December decision which might benefit from forecasts at this time. One point we raise without any recommendation is that timing of decisions on county options in crop insurance may also warrant an effort while the forecast can influence date setting and considerations of prevented planting to the extent that these are or can be made regionally flexible.

4. February forecasts may become more valuable

Although these mechanisms are just getting started, dry-year options or interruptible supply contracts may create interest in forecasts at this time, when many farming operations can either do the best thing for a year of normal operations or a year when much of the water will be transferred elsewhere.

5. Hydrology and flow forecasting for Bureau of Reclamation projects

The West is served by critically important big water projects, which typically allocate water based on shares of the estimated amount available. We appreciate that there many research efforts in progress to improve the forecasting of available water supply, but despite this there were some very unpleasant surprises in 2002 (post-mortems are beginning to appear, but already see Luecke et al. 2003 ("What the current drought means for the future of water management in Colorado", 66 p., from <www.cotrout.org>) noting that municipal expectations were under-informed on soil moisture in watersheds and other factors. Just so, other major water managers were unpleasantly surprised, and so were their users. We think this suggests that more monitoring is certainly indicated, and also that more forecasting support could help. The techniques used are already under revision, but the techniques coming into use might not yet be extended to local applications. Without adequate background in this area, our recommendation is only that NOAA might want to be assured that this is being considered.

6. After-April updates – especially for more sensitive areas

April 1 is the traditional date for assigning volume to shares of "project water", but as climate variability may increase, there may be increasing value in updates that would help with in-season reallocation of resources. Should water banking and other management flexibility increase, the ability to respond will increase the value of information. Schneekloth (2002, 2003, Central Plains Irrigation Association presentations) and others are offering increasingly popular guidance on water-stress management, and highly responsive agriculture will surely become more common. In regard to allocation of effort, areas which rely on ground-water (e.g. the Sulphur Springs Valley examined in the CLIMAS report) are much less sensitive to short-term fluctuations than those dependent on surface water, and in turn, it is usually thought that greater storage in proportion to demand reduces sensitivity (see review in IPCC 2001). Linking forecast effort to well-understood engineering principles like these could be helpful guidance. This responds, incidentally, to requests 2, 5, 9, 10, and A, B and C.

F. A variety of other recommendations, described in detail in section so named

In this section, a variety of other recommendations are summarized. These arose from the interactions with our informants and advisors. Some came more or less directly from them. Some resulted from reflection on the issues raised.

1. Range management and climate forecast applications workshop.

There is insufficient clearly-organized and accessible information on the relationships between climate variation and growth of major forage grasses. The information desired would be easily available on internet, but also disseminated through newsletters, local news media, and however appropriate. It should be presented in fashion intended to make its use as easy as possible. The relationship between climate and growth should be described in terms of normal, last year, and this year's progress so far and projections based on current forecasting. The growth of the grasses should be described as above-ground and below-ground, to inform users of root development and capacity to recover from grazing. For each location, the major forage grasses should be identified, with links to information on their grazing values, times of growth, and information about altitude variation. Although this extended abstract does not include the informants identification, note that this suggestion came from elaboration of an idea from Co-operative Agricultural Extension agents.

The lack of this information complicates management for both livestock and wildlife, and beneficiaries would include small acreage, larger livestock operators, and wildlife managers. A workshop could be designed to cover some relevant climatology, some of the agronomy of the forage grasses, and how these relate, to identify gaps in knowledge and gaps in knowledge about how to apply what is known to particular places, with use of moisture and other factors. It would also be useful to consider estimates of the value of improved information, for livestock production, range management for wildlife and management for environmental concerns. A research agenda should be developed to help coordinate and cumulate research.

2. Long-term observation proposals

The Ute Mountain Utes have equipped their Farm and Ranch Enterprise with state-of-the-art weather monitoring, and precision agriculture equipment. Much of this could be used for other purposes, if there were suitable partnerships developed. The West Slope is not apparently well studied in most ways, and this set of expertise, instrumentation and environmental interests should be of value to most land and water management agencies. Comparison of local weather observations and their relation to other observations could be useful, and the level of monitoring already present could be useful to compare with other study sites. The Tribe should be respectfully approached with ideas that reflect the need for long-term ecological monitoring and range management studies, as well as greater understanding of irrigation and salinity in this climate. The Tribe has for some years offered an educational program on soil and water management, and has several partnerships in progress with the Bureau of Reclamation. This recommendation is based on observing the potential for mutual benefit.

In the Arkansas Valley, there are long records from the Agricultural Experiment Station near Rocky Ford, and there is acute local interest in the Valley in improved resource management, for reasons relating to revegetation and alternative land uses, to irrigation improvement and more efficient traditional commodity production, and many goals between these.

3. Spot weather forecasting applications

The National Weather Service provides "spot weather forecasts" for some agencies which are planning controlled or prescribed burns. The means by which these forecasts are prepared might be considered for more general use or perhaps for modification as help for local forecast applications.

4. Agricultural efficiency improvements – see appendix: agricultural efficiency proposal

There is growing interest in improving agricultural irrigation efficiency, as a way of increasing overall system efficiency, and increasing farm returns on assets. The rationale is described in an appendix on this topic.

5. Rural internet access and communication problems – a note to website designers and managers

Several of our advisors and informants urged us to report that older telephone lines may have so much static that access to any source is difficult, regardless of the quality of service available. The more modern the source (e.g. satellite images or loops) and the denser the images and pages, the more difficult it is to get this information to come across adequately. In weather emergency conditions, high wind, rain or snow may aggravate this difficulty and make the sources useless. This is particularly important where people at home cannot access information about conditions. The Corps of Engineers at John Martin Dam has a high quality line, but others cannot get that service in emergency management situations. Reliance on the internet can be a problem. During good weather, service can be poor or blocked as well.

Interoperability and communications problems are serious for both forecast and emergency information communications in multi-jurisdictional areas with many small groups in large spaces without funding for new equipment. Progress on emergency coordination might come from solving the problem in general. The 911 phone system, for instance, suffers from the multiplicity of telephone and cell phone service providers, whose operators must attempt coordination of the responses, often from far away and perhaps with little or no knowledge of current emergency service provision – for example, ambulances may be dispatched from volunteer fire departments, fire districts, cities or hospitals, some of which maintain ambulance districts. The service areas are not matched to zip codes, telephone exchange prefixes, or even county boundaries in some cases. Half of Bent county, at the time of one interview (April 2000) was in no fire district. Further complicating this situation is the problem of very low levels of paid staffing and equipment availability. To the extent that NOAA weather radio can serve as a backstop or common denominator for emergency communications, it could be a life-saver. Mention of improved and increased services was well-received, but there was skepticism about reception and funding for better coverage.

6. The role and goals of crop insurance, and its relation to climate forecasting.

There are a variety of potential applications of climate forecasting in crop insurance applications, including some which may alter the balance of interests presently served. For instance, if the Risk Management Agency were operating as a private insurer seeking profits, it might apply forecasts of a dry year to disqualify those who apply for insurance, on the ground that there is likely to be prevented planting so the insurance is unavailable. Or, it might disqualify applicants or areas on the grounds that the forecast establishes that there is no reasonable expectation of adequate water supply. Insured farmers, on the other hand, might find it especially useful to apply for insurance at high levels of coverage when they have forecasts predicting that yields will be low, and apply for insurance at only catastrophic levels of coverage (highly subsidized, does not pay a high percentage of expected yield) if they expect a good year. Careful use of the forecasts, assuming adequate skill, would increase the net benefits to farmers and decrease the net economic well-being of the insurer; in effect, risk management would be improved for the farmers at public expense. That might be a good thing and also perhaps an economically good thing, if it were cost-effective in place of other subsidies or supports for various policy reasons. Because crop insurance is county-specific, in some dates and in calculations of expected yields or estimates of losses, there is a great deal of localization built into the current plans. This might be considerably impacted by application of forecasts, and it would seem valuable for USDA and NOAA to consider some effort to develop understanding of the potential consequences from either USDA Risk Management using forecasts, or farmers using forecasts, or both. These might be considerably different.

It may be valuable to investigate using the crop insurance tool to influence water management. This clearly is a major policy choice. One can imagine requiring combinations of dry-year options, reserve programs, and insurance plans to smooth and distribute risks, possibly with premia paid by all parties to an arrangement (e.g. urban transferees as well as agricultural transferors).

In 2003, we investigated crop insurance in the Arkansas Valley, but were unable to learn much due to pressure on the Farm Service Agency staffs who were faced with severe challenges in implementation of the 2002 Farm Bill, the new programs being implemented by the end of the fiscal year, and the continuing stress of low water availability and poor soil moisture carrying over from 2002, which was a very difficult year. This topic will be further investigated in the future, but so far there seems little doubt that the county-specific and crop-specific localization of each insurance program (there are therefore more than 600 in Colorado alone), and the boggling differences and occasional inconsistencies between programs (particularly in issues such as prevented planting which does or does not qualify for coverage, and the notion or evidence of reasonable expectations of adequate water and the timing questions on that) seem calculated to provide sleepless nights or perhaps madness for a dedicated staff, and frustration for everyone. Officials in other agencies were also concerned with the difficulty of advising farmers about programs and reported that they try hard to avoid misinforming their clientele and sometimes can offer little specific information.

Potential applications of climate and weather information with a "water bank" mechanism in place: Three ways to apply climate information

A. Dry year options:

These are long-term contracts intended to be used in place of permanent "sell-out" and loss of irrigation use ever after for the lands from which water rights are sold. Permanent transfers have different effects from those which will take effect only in dry years, but so far the legal and engineering costs of "interruptible supply contracts" or "dry-year options" have been so high that cities considering them have just gone ahead with permanent sales of water rights, and leased water back to agriculture as convenient (interviews with Broomfield, Boulder, Thornton, Westminster officials, 2002). The Northern Colorado Water Conservancy District has also considered the problem (interview, 2002). No one is against the idea, and everyone appreciates the value to agriculture of retaining the property right, even subject to loss of use in some years. But, the legal threshold of being first to do it is likely to be a high expense, high-effort trip to the Colorado Supreme Court, and it would be essentially a gift of that expense to the agricultural community from the citizens of whatever municipality decided to make it. Instead, cities just buy the water rights, and lease the water back to agriculture when it is not needed. This involves the same transactions costs, and more advantages in the additional flexibility for the city. There are also some other options for "emergency" temporary water supply plans (recently enacted HB02-1414, and HB03-1008 with forthcoming rules).

There is a new law (HB03-1334) authorizing these contracts, so we expect developments soon, but it is not clear how useful this will be, because of the limitation that they can operate only in a year when the Governor has declared a state of drought, or the year following a declaration. This is considerable progress, since the duration of these contracts does not seem to be limited. The question is whether the drought declaration will constrain operations to too few years for this to meet many uses. The Drought Mitigation Plan does not answer this question, since there appears to be considerable discretion.

But, where drought increases the need for municipal water supply, as it did rather dramatically in 2002, there may be more will to make unusual deals. At the time of writing, there is little formal information available about the ways cities acquired more water; anecdotally, it has been a time of serious pursuit of agricultural water as leases for this year, and apparently, for 2003 as well.

The long-term climatology surely will help inform people considering dry-year options, since the municipalities want very long-term commitments. The reasoning is that the cities "sell a tap forever" – so they need supply commitments for a long term. But they are also interested in the potential cost-savings from increasing supply in dry years only, when there is by definition very little need for additional infrastructure. No new storage is needed, only some new connections in some cases. The benefits in theory would be the savings from avoiding the next-cheapest source of supply.

B. Pre-season planning and crop-switching: easier said than done?

There are substantial opportunities for benefits for agriculture from pre-season planning. For any given year, if institutions allowed, it would be ideal to be able to lease water, and to reasonably well estimate the demand compared to the supply. With some degree of knowledge of the likely supply, it becomes more attractive to invest in water-intensive crops, anticipating larger supply, or perhaps to plan low-water crops and transfer some water for a guaranteed return no matter what else happens. One can easily imagine the range of possibilities, and how they can incorporate improved knowledge of one's own growing season, that of the likely competitors, and one's own farming or ranching conditions. In regard to knowledge of competitor conditions, for example, several farmers mentioned that if other places with lower costs of production were going to have a good year, they wouldn't compete in onions. On the other side with widespread drought there has been very high demand for alfalfa and hay and prices have been much higher than normal this year. The producer must match the uncertainties of the yield with the uncertainties of the financial and price outcomes from the larger markets.

Two agronomy considerations make the use of pre-season planning attractive. One is the availability to select different cultivars; corn (maize) can be had with 80 to 150 day growth periods. For instance, for the sweet table corn market, there are much better prices for the earliest and the latest fresh corn. For the feed corn markets, timing is much less important. The other is the difference in when crops need water is also important; spreading out the critical growth stages by different choices may mean the difference between success and failure with the same water supply. Current research in agricultural extension in Colorado and Nebraska includes efforts to identify and teach the differences between providing less-than-ideal water supply during vegetative growth stages versus reproductive growth stages, and relating yield differences to finances (Schneekloth

2002, 2003, Central Plains Irrigation Association 2002).

So far, there is little interest in crop-switching as a response to drought, according to our advisory group's observations over the 2002 year. This is also supported by the preliminary report from the Colorado State University annual survey of agriculture (Schuck et al. 2003, see Colorado Water, on-line from Colorado Water Resources Research Institute, Colorado State University). The survey did not consider cultivar versus crop switching, so it is possible that changes in the kind of corn were not reported. It is also possible that many farmers were committed to their plans for reasons related to crop insurance contracts, and maintaining base acreage for various federal programs. It would be valuable to inquire further. It may be possible to achieve greater flexibility in the future if other elements (including financial and risk management) are also adjusted to harmonize with more responsive decision-making.

Flexibility to switch among crops is limited in important ways by the timing of water availability. What water you have controls your choices. One ditch, for example, was said to be unable to plan on winter wheat because it didn't have the early and late season water needed. In general, the senior priorities can much more easily respond to the market, and therefore have more ability to farm the high-value crops. Juniors, on the other hand, must rely more on safer crops, and will plant more alfalfa since it can use a great amount of water or get by with lower production if the water is short.

Each ditch must make its own decisions, based on water rights and ability to get more, and within the ditch soils may make a difference sometimes. We were advised that if you locate the CRP (Conservation Reserve Program) lands, those maps will identify the worst soils for you. No other limits on crop-switching were mentioned; we asked specifically, and were told that there was no problem with herbicide carry-overs or such things. But, those who did not feel the need would not take a chance. Rocky Ford, in particular, would always have the water, and so did not need to worry about switching away from the traditional uses for that farm.

1978 was the last year for any beets in the lower Arkansas – transport to mills just got too expensive. The tomato business declined a lot in the early and mid 1980s, and the last contract was in 1995, California competition just got too hard to beat. And, local buyers in the past couldn't actually take very much at a time; one plant in La Junta long ago could contract for 100 acres, but the last one could only take 10 acres or so.

There is still one vegetable buyer in the Valley, in La Junta, but it is held now by the last of a series of owners. There were informal statements that these owners are now buying cucumbers from Mexico in semi-trailer truck loads, because the previous owners engaged in business practices and suffered reverses of fortune such that farmers would not sign any further contracts with them, before they sold out. The ill will was said to have persisted.

Our advisors all agreed that labor prices had become a big problem with vegetables in the Valley. Even the melon growers were having troubles. The Rocky Ford growers had the late and early water that is needed for vegetables and fruit, but were moving away from vegetables regardless of local buyers. Milo, also known as grain sorghum, sweet sorghum, and rarely "cane", is an important cattle fodder crop, which is baled and fed. Unlike Alfalfa, it is harvested only once, but it is very flexible compared to most crops. It can be planted in early Spring, and harvested in mid summer. It can also be planted as late as June 1, and then harvested as late as October 1. This makes it possible to use milo as a cheap substitute for a corn crop that failed early in the year (as can happen most often from hail on young plants).

An important implication from water timing acting to limit ability to switch is that it provides additional incentive to switch from surface water to groundwater use if possible. This is a serious conflict with the added complexities of keeping track of ground water and timely submission and required approval of plans for augmentation of river flow so that downstream and down-flow water rights holders (including the State of Kansas, under the Arkansas River Compact) are not injured by depletions from the alluvium out of water rights priorities. It is hoped that improved technical management capacity will allow improved ability to respond to climate and other information in conjunctively using surface water supplies, reservoir storage, and alluvial aquifers.

C. In-season re-allocations:

Another set of possibilities comes from the increasing ease of use of irrigation scheduling computer models. Hanley et al. 2002 provided a good review of some fairly high-end modeling work, at the 2002 AMS meeting, and this suggestion is pitched at a somewhat different target. One of the problems faced by downscaling efforts is the problem of localizing the results for terrain and the hydrologic responses of different soils. And, the time scales involved are important. One way to partially "end-run" some of the problems is to work with localized (farm-specific or even field-specific conditions) inputs, and shorter time-scales. Using models now available that run very quickly on desk-top computers, (Cropflex, KanSched), one can input continuous updates of precipitation received, and even (soon, perhaps) adjustments for evapotranspiration losses. These are distillations available for free on internet from sources such as the Cooperative Agricultural Extension Service of Colorado State University and USDA (Central Plains Irrigation Association 2002 and see <http://ccc.atmos.colostate.edu/~crop/>). This means that the rest of the season can be reasonably modeled. It will be possible to use this kind of tool to input forecasted conditions, to see how things would play out, as well, with translations from climate forecasts to hydrology that are becoming more feasible, as other papers in this symposium are showing.

It will soon be considerably easier to compare expectations based on current conditions and current prices for future crops, and prices for water, to consider in-season reallocations. Here, quick and low-cost water transfers are especially important. Farmers with low-value crops may realize higher returns from transfers to those with high-value crops in need of additional water, if weather changes adversely impact supply or soil moisture. Ability to use the increased evaluation capacity, however, depends on being able to make the transfer. Currently, there may be high flexibility on a very local scale, such as on the same lateral or nearby on the ditch, but larger areas within which trades can occur would include larger variations in productivity and probably potential gains from trade.

D. Increased incremental flexibility – useful to have

The current lack of flexibility in whether or not to use all available water, and difficulty of changing the rate of return or productivity from use, may thus be eased by the combination of new information and the ability to respond to it. Presently, there is limited ability to incrementally adjust operations, before or during the year, because of the fear that declining use of water rights risks losing them, and the lack of useable temporary transfers for many potential participants. Municipal buyers or lessors can easily accommodate additional shares of a ditch company's supply, for example, where the effect is to increase the city supply back upward to where it had previously been, so new connections or conveyance are not required. Where there is no new plumbing needed, things are faster. But even here, many of the transfers that interviewees mentioned were possible with little new information needed simply because there had already been substantial investment in quantifying the transferable amounts for similar transfers. These conditions do not often apply to agriculture-agriculture transfers.

E. Salinity reduction and the public interest – an additional motivation for transfers

There have been substantial improvements in water and salt transport and flow modeling from the Colorado State University Water Resources Research Institute and Department of Civil Engineering. In particular, see Gates et al. 2002, showing highly localized salt source identification and salinity in studies of an area roughly 80 km along the river and major canals; this is complementary to on-going work at field-scale in several locations, with very localized mapping of the height of water tables and salinity changes over time (presentations have been made regularly by Dr. Luis Garcia, e.g. at Colorado Water Congress, January 2003).

See Gates, T. K., Burkhalter, J. P., Labadie, J. W., Valliant, J. C., and Broner, I. 2002, Monitoring and modeling flow and salt transport in a salinity-threatened irrigated valley. *Journal of Irrigation and Drainage Engineering*, ASCE, 128(2), 87 - 99. (This is available on internet by download; browse to the journal name.) There is also a powerful demonstration of the CSU capacities at < http://www.ids.colostate.edu/projects/spmap_hide/>; the user manual does not require GIS capacity to illustrate the usefulness of the package.

The water bank may offer the capacity to re-allocate land and water for a wide variety of purposes, if the institution can be established. This would include important opportunities for public interest, recreational and amenity value improvement, and the capacity to increase economic efficiency for all water and land uses. It depends on adequate engineering support and adequate legal capacity to allow low-cost changes in use and place of use.

F. The Engineering Needs – a non-trivial investment

The lack of transactions in water in many places means that there may be very little existing information on the return flows, suitable for quantification of the transferable fraction of a water right. This is critical for defense of the pattern of return flows required to maintain legally vested water rights. When a transfer is sought, the water court will normally hear testimony based on local investigations as well as review of adjudicated water rights, and other change applications; in fact, one of the objections raised to the Water Bank Pilot Project was that it takes so much work to do this that some objectors believed it impossible for the State Engineer's office to quickly review proposed transactions. The counter-argument, however, was that there had to be some level of adequate engineering estimation to make this work, even if there was some error, and that this was on offer. The reversibility of changes is an additional persuasive factor.
(The rules are available at <http://water.state.co.us/pubs/rule_reg/arkpilotrules052302.pdf>, and see <http://water.state.co.us/pubs/rule_reg/arkriverbasis.pdf>.)

The core issue was whether the "acceptable factors" for calculation of transferable consumptive use would be acceptable. Legally, these are rebuttable presumptions, and the question is who bears the cost of proving them wrong (an objector) or right (a party seeking the change). The expense of making a proof either way could be substantial, so the lack of protest or litigation is an important accomplishment, which reflects the potential benefits if this can be made to work. Another way to consider this is a new agreement that the risks are worth the experiments with temporary transfers.

Although not explicitly relevant, there is also important new engineering technology and modeling being developed, and this very likely affected the outcome. Oddly, this comes in part from the litigation by Kansas versus Colorado, over claimed failure to meet the interstate compact obligations. This has resulted in an extremely high level of monitoring on the Arkansas River. The social acceptance of the adequacy of engineering "off the shelf" is likely to be higher than previously, but it is not clear that there is adequate acceptance yet. and the expectation that mistakes causing injury will be caught is reasonably high, as well.

There is a memorandum on the irrigation efficiency problem attached to this extended abstract, with further discussion of the issues and potential benefits from improved engineering. It will further be argued elsewhere that this may be a cost-effective public investment, based on the high values now and in the future of environmental buffers and quality assurances from better water management, as well as provision of amenity, recreational, and tourism values (see McGranahan 1999, Feather et al. 1999, Heimlich and Anderson 2001, and Hellerstein et al. 2002, cited in references to the irrigation efficiency memorandum below; these are USDA ERA Agricultural Economics Reports, available on-line).

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The Irrigation Efficiency Problem For Water Banking, other Agriculture to Municipality Transfers and "Saved or Salvaged Water" Legislation

The problem: Moving water between agriculture and other uses – in a hurry

Current drought conditions along with the rapid growth of Colorado cities have led to unprecedented levels of temporary transfers of agricultural water to municipal use (<u>Rocky Mountain News</u> January 11, 2003, and see appended items). This is occurring in addition to the steadier permanent sales of water to cities, and it is taking place as those sales have aroused concern for lost agricultural activity, declining numbers of small farms and ranches, and secondary economic impacts on rural economies. The technical support needed to facilitate these temporary transfers while protecting other water rights holders from injury is not well developed. This is because such past transfers have been very largely confined to permanent water rights sales and then some temporary lease-backs to agriculture of water purchased by municipalities in anticipation of future need. Those permanent transfers from agricultural to municipal ownership involved full engineering analyses to determine the transferable quantities of water, so all rights were protected in the process. Now, the new transfers from agriculture to temporary municipal use call for technical support that is qualitatively different from the normal. Further, the litigation over State Engineer administration of well-user augmentation or replacement flows, to preserve water rights in the South Platte basin, has shown the central importance of credibility for such transfers (see on this, H. Pankratz, "High court weighs well dispute", Denver Post p 3B, 20 Feb 03; AP story 20 Feb 03 Boulder Daily Camera p. 2B). Litigants and others have insisted that only the water court adjudication process can provide adequately reliable protection of existing water rights (See M. Hammond editorial comment "Colorado's water court system still best option", as well as positions on water transfers and agricultural efficiency by M. Kassen (Trout Unlimited), P. Binney (City of Aurora) and G. Walcher (Director, CO Dept. of Natural Resources), 09Mar03, Denver Post pp 1E and 4E.)

Most of the current explosion in transfers will be legal under some form of authority for temporary substitute water supply plans or drought arrangements, subject to short-term approval by the State Engineer, and limited in duration. But, the true costs and impacts are not known with sufficient certainty yet, and injury to others would result in rapid reversals of plans. In fact, as of the end of January there was discussion in the legislature of both expanding and limiting this authority, and litigation currently before the Colorado Supreme Court concerns the legality of similar authorizations by the State Engineer. The interests are extensive, and the politics are complicated. See legislative surveys on current bills, most recently 11 Mar 03, Denver Post, on HB 1001; see also, especially, HB 1318, but there are many other relevant pending bills; a short survey appeared on p 10A, Rocky Mountain News, of bills supported by the Governor, including state-wide water banking, interruptible supply contracts, and "conserved water rights" – "allows cities to work with farmers and ranchers to use water conserved on farms through more efficient irrigation practices". In the end, there was legislation on the South Platte situation (SB03-73), providing a compromise to allow out-of-priority well-users some additional time to file plans for augmentation of flow to avoid injury to water rights; as of October, the results are complicated and some well users are effectively looking at another year of shut down, according to informal sources of information; others are said to be facing permanent closure of their wells.

So, as 2003 wears on with only partial easing of the drought, what can the technical communities offer in support of the new transfers, to avoid injury to others, and allow flexibility in water use?

Different kinds of water – the easy stuff has been done

There are two kinds of water in Colorado (and some other states) that can be easily transferred without improved technical support, but they are limited in quantity. These are some of the water which is in storage in a reservoir, and water which is imported by a trans-basin diversion. Stored water has been the subject of an experiment in the Arkansas River Water Bank Pilot Program, in which the transferable amount has so far been agreed to be adequately estimable from previous engineering studies. But, to realize the full potential value of the water, and maximize efficiency of use, another set of estimations is needed, as described below. In the case of imported, or "foreign" water, no legal appropriation can be made of the return flows from its use, so the water is entirely transferable and thus easily-moved.

Right now, this easily-moved water has been moved. The Arkansas River Water

Bank Pilot Program is getting under way, with application only to stored water. But the volumes and water rights involved in the current and foreseeable drought-responsive; similar limited-scope water transfer brokerage "water banks" are now authorized state-wide (HB03-1318). Future potential and seemingly inevitable transfers are much greater, and we are in new territory. The "low-hanging fruit" has been picked. The new transfers will be more complicated and potentially subject to high unnecessary losses and even frustration or prohibition, perhaps inspiring dramatic counter-responses.

An undesirable answer: Dry-up

When non-imported water is transferred, the traditional way to assure that other water rights are protected has been to require "dry-up" of the lands from which the water was transferred. Otherwise, if these lands were still in use, the return flows from the water applied would be wrongfully diminished, injuring others. But dry-up reduces the value of the land, the total productivity of the farm, and the local economy. There is also considerable expense and effort involved in revegetation, though this appears to depend in part on the weather, the standards and qualities to which the land is revegetated, and perhaps soil and water quality. Dry-up is a clear and easily administered solution, but it is crude and costly. If we can do better than dry-up and still defend the rights in return flows, everyone is better off. This requires quick and low-cost technically adequate estimations of the adjustments needed in irrigation water available after a transfer of some of a farm's water.

Although the desire to make these types of quick estimates is new, we may already possess much of the capability. Some of the necessary knowledge is in the private sector, some in academia and government, and some are working on related problems such as the identification of best management practices for irrigators. Can we assemble expertise, build appropriate tools and assess in a timely manner?

Can we do better?

The pressure for innovative flexibility in water use is very strong. The time to act is now, if there is to be technical support for the Colorado lawmakers who feel compelled to increase water use flexibility. The short term approach proposed here is a workshop to consider the current ability to work out some practical answers for the coming few years. This workshop should also help define an agenda for creation of expert systems which can help water users and water rights owners make better decisions within the frameworks of water law, engineering on a cost-effective basis, climate and weather forecasts, and the applications of this information to opportunities for farmers and municipal water suppliers. The best parties to pursue this now include the State Engineer, the Colorado Water Conservation Board, Colorado Department of Agriculture, Colorado State University's Water Resources Research Institute, Cooperative Agricultural Extension, and Civil Engineering Departments, the Research Applications Program at the National Center for Atmospheric Research, the NOAA Climate Diagnostics Center and others, and participants and organizers from the USDA Natural Resources Conservation Service, the University of Colorado, and the private sector. Support from the Bureau of Reclamation and the Department of the Interior may also be critical in bringing to bear the necessary resources.

In the short-term, there should be a short technical workshop, two days in duration, in order to assess the current ability to make adequate estimations of irrigation adjustments needed to protect return flow and also avoid dry-up and its attendant costs to soils and farming. This should take place quite soon, perhaps to provide guidance to the legislature as well as possible, and inform the rule-making which the State Engineer may be called upon to provide.

Desired outcomes include: (1) A statement of which circumstances, if any, allow adequate estimations in a transparent fashion, to support short-term transfers of water from agriculture to municipalities. (2)

A statement of research gaps and needs for the different categories of participants, including the possibilities for creation of a prototype expert system for making estimations, and a plan for local involvement and social acceptance. (3) A longer-term agenda for research and support in combining the expert system for return flow adjustments and water transfers with other systems such as those for irrigation scheduling and water valuation, for integrated regional water modeling and management.

The workshop assessing the state of knowledge should bring together key participants in water administration, research, and irrigation and conveyance technology providers.

What should we do? How can we best do it?

So far, inquiry with researchers and private sector people individually has shown strong concern for the problem, but also concern for the relationship such an effort would have to other long-term research agendas, inter-institutional contexts, and concern that a "top-down" approach might be seen as efforts to promote the interests of municipal transferees at the expense of agricultural transferors. One question is, "who should ask for this?" And then, how does this relate to the agenda and issues raised in the Statewide Water Supply Initiative in Colorado, and Interior's Water 2025 Initiative?

In 1996, the Colorado Water Resources Research Institute convened a panel which reported on <u>Irrigation Water Conservation: Opportunities and Limitations in Colorado</u>, A report of the Agricultural Water Conservation Task Force, by D. H. Smith, K. Klein, R. Bartholomay, I. Broner, G.E. Cardon, and W.M. Frasier, with contributions from D.F. Champion, R. Curtis, R. Kuharich, D.C. Lile, M. Gross, D. Parker, H. Simpson, and E. Wilkinson (CWRRI Completion Report No. 190.) The results are clearly presented, and in short, they are that there is no avoiding sufficient place-specific information and engineering to support findings. When can we get that?

Further details and context for the problem

What's new? Why undertake a fast response?

From the many news stories on the 2003 Colorado General Assembly's expected flood of water and drought-related bills, a quotation from a highly-respected legislator, Senator Jim Dyer, clearly reflects a sense of urgency. "*We don't care what the project is*," Dyer said. "*We just want to show leadership that we're responding to the drought*." (<u>Denver Post</u>, 25 Dec. 02, p. 4B). Senator Dyer represents a constituency hit very hard in 2002, expecting perhaps an even more financially damaging year in 2003. Many bills will address "conservation", interests in acquiring or defending agricultural water, and encouraging leasing to municipal uses. The pressure to move water away from irrigation has built dramatically in the last decades of enormous growth in urban populations (Nichols et al. 2001, Western Water Policy Review Commission, 1998), all over the West, and already Colorado has enacted a Water Bank Pilot Program on the Arkansas River. Now, in response to the severe 2002 drought, the sense of urgency may be stronger than ever. "*It is frequently argued that a reallocation of just 10 percent of agricultural water to municipal uses could augment municipal supplies West-wide by 50 percent.*" (Nichols et al. 2001: xii-xiii). Over 90 percent of consumptive use of Colorado water is in agriculture, in a normal year.

> "*Irrigation agriculture continues to be the focal point of discussion on sources of water to meet growing demands. Calls for conservation have come from several sources, apparently prompted by assumptions that the magnitude of agricultural water use is associated with inherent inefficiencies in current use and that minimal efforts toward conservation could yield the water required for alternative uses.*" (Smith et al, 1996.)

January 2003, news reports indicated unprecedented levels of leasing from agriculture to municipalities, on a short-term basis, at very high rates paid for the water (Rocky Mtn News, Jan 11, 2003; and see appended stories). Among the many bills in the legislature, HB03-1318 extended water banking statewide; other bills allowed easier (though still seriously limited) agriculture-to-municipal leasing, and increased administrative authority for temporary substitute water supply plans. These changes could dramatically increase the transfers of this type for the coming years.

What's wanted?

The social goals include minimizing disruption of agriculture and the local economies that depend on it, while meeting the needs of municipalities. Increased flexibility in water transfers is desired to reduce local impacts on areas of origin, and increase ability of agricultural users to retain title to water rights while making occasional transfers of water (Governor's Commission on Saving Open Spaces, Farms and Ranches, 2000). Agriculture, however, is an important source of state income overall, and often locally critical. Also, agricultural landscapes and land uses are a very important amenity and source of environmental qualities highly valued in Colorado and elsewhere (e.g. Walsh et al. 1994; Feather et al. 1999; McGranahan, 1999; Fix et al. 2001; Heimlich and Anderson 2001). While there has been serious impact on agricultural areas from transfers, water availability and cost have not affected urban growth (Nichols et al. 2001), and are not expected to constrain or channel growth. Ideally, changes would be promoted by economic incentives to achieve more yield from water use, through increased efficiency.

What's in the way of transfers?

There are two kinds of problems which normally slow the flow of changes of water from one use to another, at present. First, in terms of the legal institutions, "…Colorado law generally does not provide an incentive for conservation." (Nichols et al. 2001: 140). Water not used is not the property of the conserver. In fact, the farm's water rights may be the most valuable asset, so there are strong incentives to avoid risking it by reducing water use. Under prior appropriation law, the extent of a water right is the extent of beneficial use, which excludes waste and means that excess is legally taken out of the right. There is no incentive for "saving" water, except where the water in question is "foreign" water imported from another basin, with the legal condition that no water rights in return flows from that water may be established. This allows trans-basin water, such as Colorado-Big Thompson Project water, and Frying Pan-Arkansas Project water, to be freely moved and traded. This water is considerably more valuable in the market (see Nichols et al. 2001 for recent review; the 2000 prices they report were likely considerably exceeded in 2002). But in the case of "native" water, water "saved" is legally lost, hurting the irrigator as well as failing to finance increased efficiency of application. Eventually, efforts to change this will probably be made law; Colorado bills failed for reasons likely to be fixed, in 1992, 1993, and 2001, 2002 and 2003 (see Nichols et al. 2001: 140-141). Senator Dyer seems to suggest the change may be soon. Meanwhile, the trans-basin water held by to cities now is insufficient to comfortably meet municipal demands, especially in drought years, so there is still strong pressure to move water from irrigation to urban uses; this will almost surely increase with the growth rates forecast to continue (Luecke et al 2003).

Second, in terms of the engineering and evidence needed for legal proceedings, there are enormous transactions costs in making changes (Nichols et al. 2001 provide recent review; 143-149), including both the costs of legally securing changes, through the Water Court in Colorado, and the costs of hydrologic evidence and argument supporting a claim of fact about the water which is legally transferable. These claims will include argument about the historic consumptive use, which is the transferable fraction of the water right, and the remainder of the water which is diverted but returns to the stream. The return flow is not legally owned by the diverter and is not transferable.

Some ideas to reduce the first set of transactions costs that have been suggested for years are rapid, low-cost water transfer mechanisms, sometimes called "water banks", and various ways to facilitate temporary transfers from farm to city during dry years, either as long-term option or interruptible supply contracts, or in spot markets (e.g. Nichols et al. 2001, Western Water Policy Review Commission, 1998; National Research Council 1992). These are institutional answers to institutional problems,.

The other set of costs, however, cannot be underestimated. This proposal is a response to the need to match rapid and low-cost scientific support to the parallel institutional changes so often recommended. In Colorado, the need has been shown in the case of the Arkansas River Water Bank Pilot Program, as will be described below. In Oregon, there is an example from legal establishment of a "salvage law", following the general recommendations. "Salvaged water" is water "reclaimed from a non-beneficial use, after diversion", such as water prevented from seeping out of a ditch. (In contrast, "saved" water is conserved by more efficient application of water; these are the Colorado definitions; other states vary due to statute and case law differences; Smith et al. 1996 and see Corbridge and Rice 1999.) The Oregon law allows the actor to keep or sell up to 75 percent of the conserved water, but there has been very little use because the costs of proving the quantities are so high (Nichols et al. 2001; see also Neuman 1998). This approach does not use an adequate estimation approach, perhaps because it contemplates permanent changes in water rights, rather than temporary changes in water use. In general, the number of changes in water use which would tend to increase efficiency of use is probably very high, but foregone because the immediate institutional and the scientific costs are so high when thorough "proof" is demanded to support a change.

The legislature can act quickly to make legal changes, as it did in the case of the Arkansas River Water Bank Pilot Program, and the statewide authorization, but it may not make the best possible changes if it is uninformed concerning the existing and potential scientific support for making changes. If a change in the use of water injures another water right, it will be prevented unless the injured parties agree, and even establishing who is injured before negotiations are begun can be very expensive. And, uncertainty effectively means delay, which defeats many purposes and opportunities.

Among the calls for change and "conservation", the lack of technical support for some theoretically attractive measures may be overlooked. This proposal responds to the opportunity to inform legislators about the present ability to support some kinds of transfers, and to define research and applications questions that should be pursued in the near and middle term.

The larger context:

In the semi-arid West, the ability to shift existing water supplies from one use to another is crucial, given the high economic and environmental costs of new supplies. World-wide, there is increasing concern with water management and the attraction of reallocation as a demand-side options in response to scarcity, rather than increased supply, because "they are regarded as being more environmentally sustainable, cost-effective, and flexible…" (IPCC 2001: 219; citations omitted.) Adaptation to climate variability, presently and in the future, is affected by the legal framework of water management, the complexity of management arrangements, and the ability to "assess current resources and project future resources. This requires continuing collection of data and the ability to use scenarios with hydrological models to estimate possible future conditions." (IPCC 2001: 223). The assessment of management techniques is more of a challenge than the assessment of supply-side technical options (IPCC 2001: 219); little is known about how water transfer mechanisms which may be superimposed on existing regimes. Every study of potential impacts of climate variability and change has recommended serious inquiry into the management institutions and laws governing water allocation and re-allocation, as far as I know (e.g. USGCRP regional and sector studies, available on-line from US Global Change Research Program website).

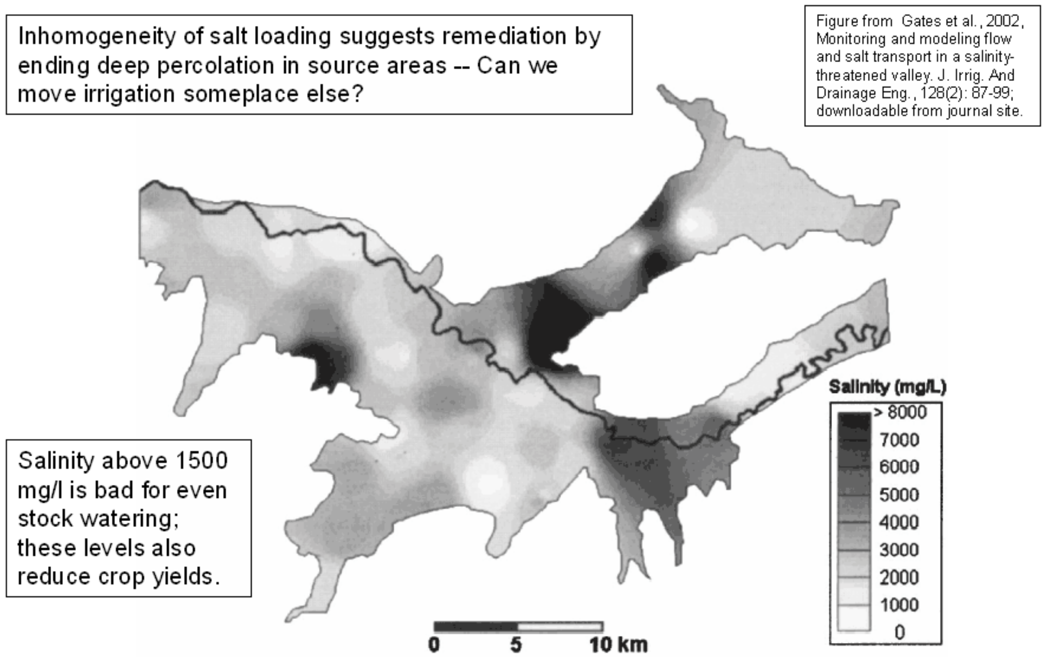
In the western U.S., there is a long tradition of recommending remedies for the high costs of transactions in water (WWPRAC 1998, NRC 1992), believed to constrain transfers, but few "real-life" experiments. While water banks are theoretically desirable, there is little experience with truly market-driven efforts. The famous California drought water bank, a leading example of a transfer mechanism superimposed on a complex historical system of administration, was very effective as a quick response to a crisis situation but experienced large inefficiencies due to a rigid price structure (Archibald and Renwick 1998, Howitt 1998, Jercich 1997). The long standing Idaho water banks have had some beneficial effects but of a very restricted value due to inappropriate pricing structure and priority rules. Additional experience is found in the Arizona ground-water exchange areas where trading is limited in scope (MacDonnell, Howe and Miller 1994, NRC 1992, Saliba and Bush 1987).

It is important that the high transactions costs, in money as well as time, have almost certainly been a significant drag on agriculture's ability to adjust to changing opportunities. Because the high cost of changes would have to be financed (by self with opportunity cost, or with credit and obvious costs), the changes would have to "pay off" quickly. Long-term benefits from perhaps a huge number of small adjustments are probably being lost because they would take too long to pay off, or because they are too small to provide benefits big enough to cover the costs of change. Small changes are, apparently, limited to those "under the radar" within a lateral, for example; this inefficiency could be eased.

There has been public concern in Colorado over large water sales out of the Arkansas Valley to growing Front Range cities (e.g. Governor's Commission, 2000). These transfers have resulted in substantial negative local impacts because of the Valley's high dependence on irrigated agriculture and the absence of alternative investments (Howe, Lazo and Weber 1990; Howe 1997; Howe 2000; Howe and Goemans, forthcoming, and see Colorado Water December 2002 issue). The strong cultural and symbolic importance attached to "our water" in the West has inhibited public acceptance and water market development (Ingram 1990, Thompson 1997). Further, there is very serious concern that municipal buyers can pay so much more than agriculture that any reduction of the frictions will only increase the speed with which irrigation water is drained away (see news item appendix 1 for a statement January 15, 2003). At the South Platte Forum in October 2003, Peter Binney, utilities manager for Aurora, Colorado, noted that his water customers were paying more than $3000 per acre-foot under drought emergency pricing in 2002, (at the highest tier rates, one presumes), and other sources commonly mention figures in the high hundreds of dollars per acre-foot, not to mention tap fees for hooking up new homes.

The question is whether or not policies and institutions that increase the efficiency of water allocation and the efficiency of irrigation would reduce the motivation of farmers to permanently sell water out of the basin. The Arkansas River Basin Water Bank Pilot Program was an innovative legislative effort to help agriculture realize the highest value of water without permanent severance from the land (37-80.5-103, C.R.S.) by facilitating temporary transfers. It was attempted at such an unfortunate time, due to the Drought of 2002 and local political controversies, out-of-basin water transfers (see Howe, C.W. and C. Goemans, December 2002 Colorado Water, available on-line through Colorado Water Resources Research Institute, (http: www.cwrri.colostate.edu>) and "water raids" by speculators who have purchased options on a large portion of the shares of the Fort Lyon Canal, by far the largest in the Arkansas Valley.

Among numerous environmental issues, salinity in Western rivers is an increasing problem as the water becomes more heavily utilized. The Arkansas River reaches 4,500 mg/l of total dissolved solids at the Kansas line (for comparison, Colorado River salinity at the border with Mexico is about 1,500 mg/l and has resulted in millions of dollars in salinity reduction efforts). Thousands of acres in the Arkansas Valley are severely impacted by salinization with yield losses from 10 to 25 percent or more causing yield and profit losses of tens of millions annually (Gates et al. 2002). A water bank can help by facilitating transfers of water off the heavily salt-generating lands. The engineering modeling needed to support these uses of the WBPP for water quality improvement will be available from Colorado State University for our use in this part of the proposed work program (see Gates et al. 2002; more work is scheduled).



Estimated contours of water table salinity based upon specific conductance readings in observation wells for July 14±17, 1999

The Arkansas River WBPP is the first water bank with the potential to incorporate and utilize climate information in design and operation. The current "Three States" project (Howe, P.I.; see Wiener 2000, 2002, 2003) has provided inputs to the Office of the State Engineer that have clarified and broadened the rules for the WBPP so that it will be possible to experiment with a range of designs and transactions with inputs of long-lead seasonal forecasts.

Use it or Lose it and all that…

Legally, however, agricultural water rights have been defined by the amount of water diverted a beneficial use, and by place of use as well as priority for the diversion. If a farmer has a water right to divert 100 units, but had only diverted 75 units, there would have been beneficial use of only 75 units, and the water right would legally be redefined as 75. This is popularly called the "use it lose it" problem. It makes no difference if the reduction in diversion is due to lining the ditch or using a pipe, switching to a more efficient technology, or just not using some land; if the reduction continues long enough, it can be an abandonment of part of the water right. This means that there is not only no incentive to "save" water; there is also a strong incentive to continue using it in ways that could now be superseded by more efficient methods. So, change is not easily rewarded and may be penalized, in terms of the individual. In terms of the river, the inefficiency of the past has been appropriated and is now someone else's water right. If the return flow of water, or water not consumed) is reduced, other water rights are injured.

But, if a farmer cannot benefit from a change, and may in fact be injured by making it, the goals of helping agriculture realize more benefit from water rights, and increasing productivity of water, are defeated.

How could increased agricultural efficiency be pursued?

Colorado now has a "water bank pilot program" in progress on the Arkansas River. Under current rules, this may include small changes which currently cost too much, temporary changes, and interruptible supply or dry-year option contracts. The latter are desirable (Wiener, 2002 and on-going research; Nichols et al. 2001), but have been said to be too experimental for parties to undertake the expense of litigation to achieve formal acceptance.

Also often mentioned are (1) ideas centered on decreasing losses in transit or carriage of water, such as by lining ditches, (2) increasing efficiency of application to crops, such as by changing from furrow irrigation to gated pipes and surge valves, or sprinkler or drag hose systems, and (3) decreasing the amount water lost to phreatophyte plants which may consume and transpire a great deal. Reducing phreatophyte consumption could increase water available for the State to meet interstate compact obligations, or for environmental purposes. For the farmer, the main advantage of "salvage" bills is provision of an incentive for water users to increase efficiency, by providing some reward for the investment needed. The usual idea is that water which is not used in the conduct of an activity by improved means is "saved" and should be available for other uses. For the municipalities, the main advantage would be getting water without ending agricultural activity and with reduced secondary local economic impacts in areas from which water is moved. But, things are not quite that simple.

Why is a change in irrigation efficiency a problem?

There are two elements to consider. First, the idea of beneficial use as the limit on the size of a water right, and second, the rights of others in return flows of native water.

If an agricultural water rights holder "saves" water, the amount not consumed is widely thought to be lost, because the "saved" water is not beneficially used and so not part of a legal appropriation; "use it or lose it" from the water right is the idea. Thus, there is no reason for a farmer to invest in better water management, since what is "saved" in water quantity terms benefits only others on a fully or over-appropriated stream. The public may wish to invest in reduced non-point pollution from run-off, but there is no direct financial benefit to the public, although water treatment costs and environmental impacts are reduced. So, the farmer investing in efficiency must do so in expectation of sufficiently increased yields to compensate for the expense of the improvement and the risk of loss of the conserved water. Irrigation improvements so far, therefore, have more or less closely matched changes in efficiency of delivery and use to changes in cropping and other features so that the same amount of water is beneficially used on the farm.

The idea of what is and is not a beneficial use can be changed by the legislature, as it has been in the cases of in-stream flow and recreational water rights. This is a conceptual challenge, but not a soils, hydrology, agronomy, climatology and engineering challenge. Now, the new interest in leasing from agriculture to others makes it useful to be able to conserve on the farm and transfer some water.

A second part of the problem, however, is harder: the underlying purpose of much of water law, in prior appropriation and the limitation of a water right to beneficial use, is protection of subsequent uses of the return flow of water from an application back to the river where it can be held in another water right. This allows reuse in a fashion which was compatible with 19th Century capacity for engineering and measurement in a cost-effective fashion, to maximize uses of water. Over time, the adaptation needed to allow permanent changes of use involved establishment of ways of determination of the historic consumptive use of the water right, and other determinations of transit loss and seepage, as needed, so that the part of the water on which others could not reasonably lay claim could be sold and moved, and the remaining part left in the river. These determinations are very expensive, and subject to intricate proof and challenge, at substantial expense. Now, we must accelerate the process and reduce its expense in order to achieve contemporary goals of increasing flexibility of use, allowing temporary transfers, and accommodating the needs in dry years, as well as helping water stay in agricultural use when desirable.

The following description is an effort to identify this problem for "salvage" water legislation, and increased "water banking" operations, and an approach to solving the problem on a practical basis. As pressure for new management increases, we may benefit from more clearly understanding the limitations and potential of management options. Economic theory has supported management changes for decades, but there is an important gap between the theory and the practice. Note also that since 80 percent or more consumptive use of Western water is by agriculture, as often noted it would only take a fraction of that to be a significant increase in urban supply. One of the goals of taking this seriously is learn how a few percent here and there from many farms could be aggregated effectively to make that supply, without creating sudden and injurious changes in conditions dependent on the status quo.

Step 1 of The Irrigation Efficiency Problem: Simplest possible case.

Consider 100 acres being irrigated with 100 units of water. The technique is furrow irrigation with open ditch and the return flow from the diversion and application of 100 units of water is 50 units (50% efficiency of use, or "field efficiency".) The Arkansas River Water Bank Pilot Program (WBPP) allows transfer only of stored water, so the example will start with that.

Suppose for simplicity that this field is getting 75 units of direct flow, and 25 units of stored water. The 25 are eligible for the WBPP. Because the return flow has been established for this purpose to be 50 percent, by the State Engineer, 12.5 units can be transferred "away", and 12.5 are administered to maintain the pattern of volume and timing of return flow. The 75 units of direct flow can be applied to 75 acres, in the same way as before, and there will be 37.5 units consumptively used, and 37.5 will be return flow.

So far: the farmer has presumably received money from transfer of 12.5, and return flow is still 50. (For simplicity, please overlook the internal workings of ditch and canal companies right now.) This is least controversial if the acreage irrigated is reduced; "dry-up" of 25 acres is required. So far, in the Arkansas, one of the objections to the WBPP is that there is no funding for enforcement of "dry-up", and some farmers think this is the only fair way to operate the program. The statute establishing the pilot program does no require dry-up, but many leading farmers think it should. Without the requirement, the farmer could spread the remaining 75 units of water on the 100 units of land, and the return flow would be less than it "should" be, since more of the 75 units of water would evaporate or be consumed by the crop. The farmer's efficiency of use would be greater, but the downstream would lose water.

"Dry-up", the requirement of non-use of a proportional area of farm land, is the simplest way to assure that there is no increase in consumptive use. Unfortunately, requiring dry-up requires losing all production from 25 acres, losing or affecting some soil fertility characteristics, affecting use or demand for farm labor, and affecting weed control and erosion. Also, the 75 acres is not giving a higher yield, since management has not changed. The local economy is affected by reduced production.

Enforcement of dry-up also requires some effort by someone at some expense; can this be avoided? Many farmers feel that self-enforcement is not credible, given the strength of incentives to cheat.

A note: if the land taken out of production was not yielding enough to at least "break even", it would be taken out in any case. So, without some other change, this reduces production. If the dry-up requirement is imposed, it would seem also to require taking fairly observable areas out of production, in contiguous pieces. If the amount taken out of production was in corner areas not reached by center pivots, this might have less negative effect than if the dry-up area was more arbitrarily specified. But if the lowest-yielding soils were taken out of production, the shapes and pieces of land might reflect contours or underlying soils and subsoils. That might be most beneficial for the farmer, but hardest to monitor. (You would also see farmers designating some of their best producing soils, especially alfalfa fields that are drinking from the groundwater. We have many fields that, once established, require no irrigation – although they have a water right and are considered to be irrigated. Designation of those fields as “temporary dry up” would not reduce yield nor consumptive use, thereby injuring downstream users.) So, the way "dry up" is operated is itself a question that may lead one to want a self-enforcing solution so that farmers themselves can make the best allocation of remaining water to the land available.

As with the Conservation Reserve Program (CRP), one would expect the least productive soils to be taken out of production. The effect would likely be less return flow because the better soils (perhaps also better drained, less saline, etc.) produce better yields and thus have higher consumptive use to some degree. So the strict area proportions are not likely to be completely accurate. On a large enough scale, that could affect the river, and again, one would prefer some sort of self-enforced solution to the problem of guaranteeing "correct" return flows or water left in the river.

Another note: taking land out of irrigation for one year may have different costs than taking it out for several years in a row, in fertility, salinity, and other farm management issues such as labor. Are there other issues of interest to the farmer or to the community? Salinity and saline return flows, and weed problems are important to the community, for instance.

Step 2 of the Irrigation Efficiency problem:

In a perfect world, the farmer would change the technology of irrigation to increase efficiency of water use. So far, the farmer has transferred 12.5 units of the stored water, 12.5 are "back to the river", and 75 units of direct flow are still available, but 37.5 are "due" as return flow, owned by others.

Suppose that a technology with nearly perfect efficiency is brought in. That would provide no return flow, which is legally not allowed. So, the State Engineer would require return flow to be made up so 37.5 units are "returned". That might mean leaving the water in the river, or it might require some arrangement with the ditch or canal to provide sufficient hydraulic head to continue using existing systems, and in turn, perhaps some assurance that others are not going to use that water. In the super-efficient case, the 37.5 left might be enough to irrigate the whole 100 acres. If so, everyone wins.

Suppose a less-than-perfect technology is installed, but using it with the 37.5 units and some number of acres (less than 100) still provides an increase in yields. (People often mention increasing melons from 450 boxes per acre to 1000; onions may also be substantially increased per acre. To stay with the water issues, we will not consider markets and competition and so on, and leave that to the farmer.) If there is a net gain, after all costs are considered, would this be another case of '"everyone wins"?

The needed administrative step is an agreed-upon way to settle return flow "due" from the direct flow, and dedication of that much (during use of the new system) to the river. Could that be done? Surely, given the usual determinations in water sale proceedings. But for our present purposes, including "water banking" and "salvage" can it be done cost-effectively and rapidly, "close enough" to be an adequate estimation for public support?

Please consider a more likely possibility: the farmer with money from a transfer of some water can now afford some increase in efficiency, say surge valves and gated pipe, or maybe some leveling, and she applies the whole 75 units. Because of the increased efficiency (say 66% for simplicity), only 25 is return flow, now. The consumptive use has increased to 50, and return flow is decreased by 12.5, and that is injury to others. Again, can there be agreement, using some reasonably cheap methods, to allow the farmer to use the new technique on whatever acres she wants, and dedicate the 12.5 "due"? This looks like a problem of whether the estimations can be acceptably done. (By "acceptable", we must mean acceptable to the State Engineer and also to the rest of the water-using community of interest.) This looks like one of the common "salvage" ideas, too, in "saving" water with better technology. The problem is that there is this second step required to account for the efficiency change.

Does this example define the problem? If not, can it be corrected or repaired? If it does, then the approach which seems most useful right now is a meeting of the right people, to work on how and under what circumstances the kind of "close enough" estimations described can be produced. For example, are there geological limitations, such that Plains alluvial river valleys could use an approach that would not work well enough in montane environments, or vice versa? Are soil conditions critical, or simply a factor that has to be taken into account? And can NRCS maps suffice, or should there be some program for competent engineers to make measures which would suffice? And so on… I envision this, if it can be done, to be a sort of very transparent expert system applying the necessary terms and information to make useable estimations to begin experiments with new management techniques.

Additional features of the problem: What are the variables?

Fortunately, there are a small number of changes in technology that may be sufficiently common to warrant consideration. But, are there a relatively small number of other important features to make this feasible? Can the slope, soil, depth of horizons, and other factors be treated in simple enough form to make adequate estimations achievable with the needed speed and low cost? Or, are there some conditions in which these estimations can be made, and others in which they should not be used?

From a different perspective, there are various conditions identified in materials such as those from the Cooperative Extension Service, on how to identify best management practices (BMPs) for irrigation for a given field (e.g. Waskom 1994). These variables may be important for the problem at hand.

They include:

Soil and crop properties:

1. Water holding capacity of different soil textures (sometimes called field capacity; measure usually by inches of water per foot of soil); additionally, depth to different soil horizons may be important.

2. Maximum rooting depths of different crops.

3. Approximate efficiency of the various irrigation application methods (for BMP considerations, mean percentages of technologies have been described as:
   - furrow – 40%
   - surge – 60%
   - sprinkler – 75%
   - drip – 90%

   These are means for rough guidance, subject to site and particular technology features.

4. The total seasonal crop water use is also important for selection of irrigation technology, and should be relevant to estimation of the consumptive use from a given combination of choices and place.

There are also relatively few changes in irrigation technology that make sense and increase water delivery efficiency (Smith et al 1996; CPIA, various). They include:

Structural changes to irrigation technology:

1. ditch to pipe
1. ditch to lined pipe (significantly different from pipe?)
2. ditch to gated pipe
3. pipe to gated pipe
4. pipe to surge valve
5. furrow to sprinkler
6. furrow to drip

7. furrow to subsurface drip
8. sprinkler to better sprinkler (e.g. low pressure or drag hose)
9. sprinkler to drip
10. sprinkler to subsurface drip
11. better sprinkler to drip
12. better sprinkler to subsurface drip
13. drip to subsurface drip

Structural changes to land:

14. terracing, contouring
15. leveling
16. altered tillage or conservation tillage.

Information management

17. Irrigation scheduling to meet needs by soil moisture
18. deficit irrigation (strategic deficits; timing shortages)
19. fertilizer timing

Crop changes

20. change crops, crop mix, or rotation

Although the permutations of these factors would be intractable, farming does not apply all of them, and the scope of practical inquiry is considerably smaller.

What to do? An approach to the problem of estimating irrigation efficiency and return flow obligations:

A. To the extent possible, a first step would be to narrow the range of crops and thus agronomic factors which may be relevant. Perhaps only a few need be considered, such as fodder corn, table or sweet corn, alfalfa, a hay crop, a small grain (oats?), and a representative vegetable.

B. Second, the set of 20 changes noted could be narrowed as well, using expert opinion and experience to select the most likely or most common changes for a given basin or agricultural region.

C. Third, the soil and sub-soil properties could be considered, and representative types could be identified if there is sufficient representativeness in a given region. The Arkansas Valley, for example, has underlying geologic and geomorphic uniformity, but ditches have different areas of soil types and soil processes which may be important variables (e.g. the different salinity conditions mapped by Gates et al., as well as different soils).

D. The integration of the first three steps would be identification of the range of cases which can be reasonably expected to cover a useful portion of current water use and potential transfers. Although daunting in prospect, the extent of local knowledge from agricultural extension and USDA and other experts, as well as the private sector, will quickly provide much of this.

E. Taking the selected set of representative cases, the final question may be asked: can the relevant irrigation and return flow conditions be adequately estimated, given the current state of knowledge?

And, based on that assessment, what is the relevant research agenda for development of the expert systems which are most likely to support public use and acceptance of the increased opportunities for flexibility in water management?

A final note: future values

One need not accept climate modeling or claims of any particular change either forecast or used for study purposes to find valuable reviews of current agricultural trends in the reports commissioned for the US Global Change Research Program. Those for the Great Plains and for the Rocky Mountain—Great Basin Regions, and the Agriculture and Water Sectors include careful reviews of trends in the area which are often driven by forces not much related to climate, including the national agricultural situation and agricultural policies. With those trends in mind, and the changes in land use already under way, it is almost certain that the value of water for purposes such as maintenance of environmental qualities and buffers will increase in the near future. The suite of changes already underway presents a threatening prospect for all water users, under current policy and shifts in public preferences (see Feather et al. 1999, McGranahan 1999, and Heimlich and Anderson 2001; and see also Kansas City Federal Reserve Bank, 2001 symposium on forces shaping the heartland;

available on-line). Low-yielding agriculture may have water to transfer for other purposes not yet being funded as much as in the future. Also in the wind is increased recognition of the environmental amenity and benefits in urban as well as rural areas from the so-called "inefficiencies" of traditional water use which supports habitat and wetlands throughout the areas served by the water distribution system (see Heimlich 1998).

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Appendix 1: A news story from the Pueblo Chieftain which appeared during drafting of this proposal:

The Pueblo Chieftain Online Publish Date Wednesday January 15th, 2003

Water banking could hurt farms [Photo of Terry Scanga, Upper Arkansas Water Conservancy District]

By MARGIE WOOD
The Pueblo Chieftain

The pilot water bank that is expected to begin operating this month in the Arkansas River basin has been promoted as a way for farmers and ranchers to stay alive in hard times like the current drought.

But leaders of the Upper Arkansas Water Conservancy District believe the water bank holds peril for the ag economy, because the law will allow water to be leased outside the Arkansas basin.

Terry Scanga, manager of the district, said he has some concerns about the legal process of the water bank operation, but his principal concern is the prospect of out-of-basin leasing.

Last year, the Legislature adopted a measure that authorizes the state Water Resources engineer to approve temporary supply plans enabling cities to use water they're in the process of buying.

This year, there's another bill in the Legislature to extend those supply plans to water banking transactions, Scanga said, and he thinks that's a deadly combination.

"If they can lease water and move it out of the basin without any judicial review, why would they ever buy water and have to go to court?" he asked.

It's not just an academic question. Aurora's water utility is seeking permission to lease water from the Rocky Ford Ditch while its purchase is still in water court, and to use it for 90 days this summer. (That plan is not involved in the water bank project, because the bank is restricted to stored water in the Arkansas system and the ditch water is a direct-flow right.)

"I would be the first one to support a market system for water," he said. "But we cannot allow the water to move out of this basin. We are an overappropriated system,and we're in a drought."

Scanga said, "When we challenged the water banking rules, we argued that because of the higher value given municipal use, leasing would move water out of our basin to the northern Front Range cities. The advocates asserted that the banked water actually would be leased by agricultural well associations."

But cities are willing to pay $1,500 to $2,000 per acre-foot of water, while agricultural users are hard-pressed to to pay 10 percent of that price, he said.

If cities are allowed to lease water and take it out of the Arkansas Valley, Scanga said, "The agricultural economy of the valley will suffer a horrible loss. I feel split, too, when I think about the farmer or rancher who has an opportunity to lease his water and maybe save himself for a year. But the trouble is when that farmer's gone and his water is gone, then the bank will be gone, too, and the whole ag economy."

Rather than amplifying on water leasing programs, Scanga said the state needs to build more water storage vessels and adopt strong mitigation laws "so that when some city wants to buy water they have to show they're making full reuse of the water they have and they have made maximum effort to buy water within their own basin first."

"We have to work on the supply end as well as the demand end - but to make it easier for a large municipality to buy water from outside its basin is not the way to go," he said.

Appendix 2: Another story which mentions the fears of the new leasing:

Denver Post "Eco-groups: Conservation, not dams, can supply water," By Theo Stein, Denver Post Environment Writer

Wednesday, January 15, 2003 - The Front Range can weather future droughts without big new dams by leasing water from farmers, dredging and enlarging existing reservoirs, and reducing demand, according to a new report from two environmental groups.

Hydrologist Dan Luecke, one of the report's primary authors, suggested that cities should enter into long-term agreements with farmers to let fields lie fallow during dry spells, which would save more water for cities.

"The cost of buying insurance this way is a lot cheaper and quicker than buying concrete for new dams," said Luecke, the former regional director of Environmental Defense.

In fact, many Front Range communities, faced with potential shortages, are scrambling to do just that. Aurora, Broomfield and Thornton are already working on deals with farmers that could dry up as much as 10,000 acres this year to keep city taps flowing.

Farmers and rural legislators worry that temporary leases of agricultural water will become permanent, drying up the farm economy.

The report, commissioned by Trout Unlimited and the Colorado Environmental Coalition, suggests that market-driven leases of agricultural water, in conjunction with other measures, can address drought-driven shortfalls.

It also recommends drawing water from the deep aquifers under the Denver basin in dry times and recharging them during wet years, and using the existing network of pipelines and channels to shift water around the region more efficiently.

"Big new storage as drought insurance is not the answer," said Trout Unlimited water attorney Melinda Kassen. "We believe the principles outlined in this report are a faster, better, cheaper and more environmentally friendly way to ensure sustainable water supplies in the future."

Kassen said the report was designed to help inform debate at the statehouse, where bills calling for new reservoirs and expensive pump-back projects have garnered all the headlines.

But Aurora water manager Peter Binney, who is counting on leased agricultural water to help get his city through the year, says the report's proposals will fall short.

"I don't think there's any question this drought has exposed the vulnerabilities of our water supply systems," he said. "And I think we are in a period of tradeoffs where traditional uses may be limited until better weather comes back.

"There aren't too many degrees of freedom in the equation any more," Binney added. "Some of the ideas in this report are good ones, but the solution is not as simple as they suggest."

Binney is helping Aurora draft legislation that would allow senior water rights holders, mainly farmers, to lease a portion of their supplies to cities, something that's not allowed under current water law.

"We recognize water projects take eight to 12 years to build," he said. "We need to start recovering our reservoirs faster than that."

State agriculture officials also say no workable solution can dismiss new storage proposals out of hand.
[end]