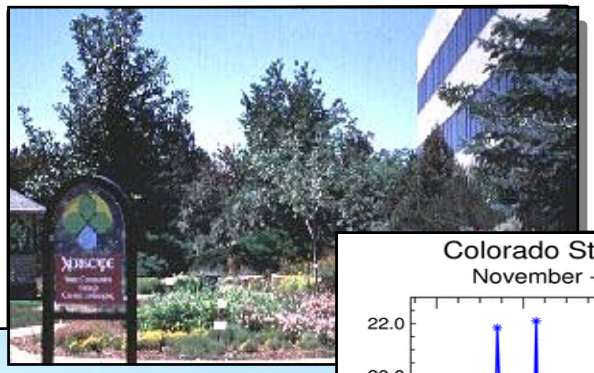
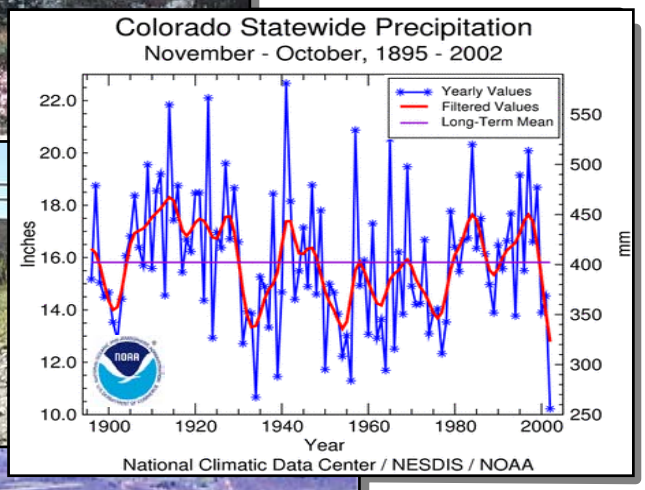
WHAT THE CURRENT DROUGHT MEANS FOR THE FUTURE OF WATER MANAGEMENT IN COLORADO





S Fk S Platte at Arena

Horsetooth Reservoir and Dam

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January 2003

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The opinions expressed in the report are those of the authors. Trout Unlimited and the Colorado Environmental Coalition endorse the principles presented in this report but have not taken positions regarding specific water management and development projects discussed herein.

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TABLE OF CONTENTS

EXECUTIVE SUMMARY iii
I. The Current Drought and the Future of Water Management in Colorado 1
A. Background and Brief Overview 1
B. Water in Colorado 1
C. The Value of Water 2
D. The Status of Colorado's Water Economy and Principles for Future Management 2
E. The Remainder of the Report 3
II. Hydrologic Description of the Drought 5
A. Conditions in the Spring of 2002 5
1. Snowpack 5
2. Reservoir and Streamflow Conditions in the Spring 7
B. Reservoir and Streamflow Conditions in Mid-Summer 8
1. Streamflow 8
2. Reservoir Storage 9
III. Economic Impacts of the Drought 13
A. Background 13
B. Agriculture 13
1. Dry Land and Irrigated Agriculture in Colorado's Economy 13
2. Agricultural Costs of the Drought 14
3. Overall Effect of Agricultural Losses on State's Economy 15
C. Tourism 16
1. Ski Industry 16
2. Water-Dependent Tourism 16
3. Other Tourism Sectors 17
D. Forest Fires 17
E. Urban Landscape and Municipal Water Supply 18
F. Total Cost and Avoidable Cost 19
IV. Drought Responses of Major Water Management Systems 21
A. Background 21
B. An Example of a Municipal Drought Management Plan: Denver Water 21
C. Drought Response of Other Municipal Users 23
D. Irrigated Agriculture 25
E. Recreation 25
F. Effectiveness of Drought Plans 26
V. The Role of New Storage in Managing Colorado Water: A Basin-by-Basin Assessment 31
A. Introduction 31
B. Is Storage the Answer? 33
C. Overview of Current Water Development Projects 34
1. Arkansas Basin 35
2. South Platte Basin 36
3. Colorado River Basin 39

VI. An Integrated Approach to Meet Colorado's Future Water Demands and Drought Management Needs 41
A. Range of Costs for a Variety of Water Management Options 41
B. Conservation and Demand Management 42
C. Municipal-Agricultural Cooperation 43
D. Supply Integration, Management and Development 43
1. Arkansas Basin 44
2. South Platte Basin – Southern Portion 44
3. South Platte Basin – Central Portion 45
4. South Platte Basin – Northern Portion 46
5. Colorado River Basin 47
E. Annual Water Supply Reliability Report 48

LIST OF FIGURES

Figure II.1. April Snowpack in Colorado 6
Figure II.2. Colorado SNOTEL Precipitation 7
Figure II.3. Colorado Aggregate Streamflow Index 9
Figure II.4. Colorado Reservoir Storage by Basin and Month 11
Figure II.5. Average Reservoir Storage by Basin in October 2002 12
Figure V.1: Typical Streamflow Pattern (Cache la Poudre River) 31
Figure V.2: Typical Year-to-Year Variation in Streamflow (Cache la Poudre River) 32
Figure V.3. The Regulation-Flow Ratio in Relation to Usable Capacity 33

LIST OF TABLES

Table II.1. Table of Percent Storage Capacity Filled in July 2002, in July 2001, and Average July Capacity 10
Table III.1. Economic Impact Total Costs and Avoidable Costs of Drought, by Sector 19
Table IV.1. Denver Water Drought Levels and Water Use Reduction Goals 22
Table IV.2. 2002 Municipal Water Restrictions for East Slope Water Providers 27
Table IV.3. 2002 Municipal Water Restrictions for West Slope Water Providers 29
Table V.1: Existing Water Supply Storage in Colorado 32
Table VI.1. The Range of Cost Estimates for a Variety of Water Management Options (from Denver Water IRP) 41

LIST OF REFERENCES AND SOURCES 51

APPENDICES

Appendix A: Drought Conditions in Spring, Summer and Fall, and Forecast for Near Future 57
Appendix B: An Example of Comparative Hydrographs for the Arkansas River 61
Appendix C: Capacity of All Storage Reservoirs in Colorado and Their Primary Use 63

EXECUTIVE SUMMARY

For at least the last three years, Colorado has been in the grip of a serious drought. In the public debate that has emerged from this natural phenomenon, some elected officials and others have called for more large dams. We believe that a review of the hydrology of the state's rivers, the existing water supply infrastructure, and the economic, financial, and environmental consequences of building large new structures suggests that there are more effective and efficient options. In this report, after describing the state of the Colorado water economy and the value of water in various uses, we: 1) identify the principles for assessing future management strategies and projects; 2) review the hydrologic and economic impacts of the drought; 3) appraise the drought response of water managers; and 4) outline the structural and non-structural options for meeting future demands.

Principles for Assessing Water Management Strategies and Projects

Colorado has a surprising abundance of water for a great variety of purposes, despite relatively low and unevenly distributed precipitation and a perception of water scarcity. This abundance is often obscured, however, by the inefficient way in which water is managed and used. Many, if not most, water management utilities are making significant strides toward improving both their efficiency and system reliability. Nonetheless, while individual users may be efficient from their point of view, at higher levels, like watersheds, the potential for improved efficiencies still exists.

Colorado's water economy has passed from its "expansionary phase" into what might be called its "mature phase," in which: 1) water users are linked by elaborate physical systems and are increasingly interdependent economically; 2) new supply options are limited; 3) costs of new supply are rapidly escalating; and 4) federal subsidies have evaporated. Moreover, people now value free flowing streams for their recreational and environmental worth. Applying a widely accepted rule based on the principle that an efficient and fair public policy decision is one that makes no entity worse off for the betterment of another, present day water supply expansion decisions based on large storage projects are almost always wasteful, inefficient, and unfair. Thus, we recommend that, before considering new storage options, we should:

- Invest in conservation;
- Foster cooperation between the two largest user groups – cities and farmers;
- Restore and enlarge existing storage facilities; and
- Use system linkages to distribute existing supplies more efficiently.

We further recommend that future water supply management and development efforts should adhere to five basic principles of what we would characterize as "smart storage":

- Make full and efficient use of existing water supplies and usable return flows;
- Expand water supplies incrementally to utilize existing diversion and storage capacities better;

- Recognizing that market forces now drive water reallocation from agricultural to municipal uses, structure such transfers, where possible, to maintain agriculture, but in all cases, mitigate the adverse impacts to rural communities from these transfers;
- Involve affected publics and fully address the inevitable environmental and socioeconomic impacts of increasing water supplies; and
- Recognize the fundamental political and economic inequities and the adverse environmental consequences of new transbasin diversions and emphasize the most efficient utilization of existing supplies to avoid new transbasin projects.

Hydrological Impacts of the Drought

The current drought, which began in 2000 and has continued to the present, has been the most severe on record by several measures. Streamflows in Colorado in 2002 have generally been the lowest in over 100 years and the tree ring data suggest that flows are probably the lowest in 300 to 500 years. In terms of multiple year streamflow deficits, the current drought is worse than the historic droughts of the 1950s and 1970s. While this drought has not lasted as long as the drought of the 1930s, it is not yet over and it has been more severe than any three-year period of the 1930s.

Economic Impacts of the Drought

The total economic impact of the drought of 2002 is probably in excess of $1 billion dollars, or roughly 0.7% of the state's income, although no one can yet know the precise losses. Losses occurred in several economic sectors, but mostly in agriculture, and water-dependent recreation and tourism. Federal programs and insurance mitigated some losses. Municipal use, including landscaping, is the only sector where more water supply development and/or measures to increase efficiency could have prevented a large fraction of the losses incurred. As a result, the preventable economic losses were about $250 million overall, or 17% of the total loss. Given that even these "avoidable" losses will recur only with another major drought, probably not more than once every half century, programs to prevent these losses should not cost more than $250 million and probably not even half that.

Managers' Responses to the Drought

Water managers' responses, though late in many cases, did have an effect on customer behavior and did achieve some reduction in customer demand. Initial efforts consisted of educational programs to encourage efficiency and voluntary conservation programs, followed by mandatory restrictions on outdoor water usage. Very few water providers adopted pricing surcharges or placed any restrictions on the issuance of new taps. Many providers invoked restrictions as a precautionary response in recognition that the current drought might not be over.

Water savings achieved by municipal providers' drought response measures varied; but, preliminary results suggest that, on average, municipal water users will have reduced their normal demand by about 10% between May 1, 2002 and April 30, 2003. In most communities the public response to efforts to reduce water use was positive.

Some providers also implemented measures to increase their supplies and reduce their draw on storage reservoirs. These measures included cooperative arrangements with farmers, invoking special drought clauses to relax minimum bypass flows, drilling supplemental wells, trading supplies between users, building facilities to allow better use of existing water rights, and sharing the burden of shortages where the State Engineer was willing to relax administration of the priority system.

Agricultural water users employed a wide variety of strategies to cope with the drought and irrigators were generally more adept than cities at anticipating its onset. Responses included reductions in the amount of acreage planted, changes in cropping mix from full season crops (e.g. feed corn) to partial season crops (e.g. 1- or 2-cut hay and corn for silage). Some farmers decided not to farm this year (2002), and to lease their water supplies to cities instead and many livestock owners sold off significant percentages of their herds in expectation of high-priced and reduced feed supply.

Mechanisms to Meet Existing & Future Water Demands

Looking to the future and the assessment of storage augmentation in managing Colorado's water needs, not all basins are created equal. Some can be eliminated from consideration given current conditions either of hydrology, adequacy of existing storage capacity, economics, project proposals that are already well along (e.g., Animas/La Plata), downstream delivery requirements (e.g., Rio Grande Compact), or some combination of the above. The Rio Grande, the San Juan/Dolores, the Yampa/White, and the North Platte fall into this category. In all of these basins at least two of these factors are relevant. For these reasons, the report concentrates on the question of storage in the Colorado/Gunnison, the Arkansas, and the South Platte.

Reservoirs have been part of Colorado's water development strategy since the late 1800s, in response to its highly variable stream flows. Today, Colorado has more than 7.5 million acre-feet of reservoir storage. About 25% of this capacity directly supports municipal water uses and this fraction is steadily growing, mostly as cities acquire agricultural water rights with their associated storage. In addition, there is the natural storage provided by Colorado's principal underground aquifers. The Denver Basin aquifers contain approximately 150 million acre-feet of recoverable groundwater and aquifers elsewhere within the South Platte, Arkansas and Rio Grande basins contain over 15 million acre-feet.

The traditional purpose for building reservoirs has been to capture excess runoff, which usually occurs relatively infrequently and in large volumes. Consequently, traditional reservoirs are fairly large and located directly in a stream channel. Apart from their well-documented environmental impacts, such large on-stream reservoirs have other major limitations. First, they are relatively costly to build and cannot be built incrementally in response to gradually growing demands. Rather, they must be fully paid for and constructed "up front," which increases their financial risk and diminishes their economic viability. Second, as a basin becomes over-appropriated, additional runoff-capture storage produces ever-diminishing returns in terms of water supply yield, because unappropriated runoff occurs less frequently and storage carry-over periods become

longer. Third, evaporation losses compound the diminishing yield problem, becoming a major limiting factor in reservoirs' ability to provide relief both over extended drought conditions and for severe droughts that occur every few decades or less often. Finally, given the diminishing returns for new storage projects that would be fully integrated into existing systems, storage-yield ratios for projects designed to store wet-year water for drought protection are approaching, if not exceeding, 5-to-1. This means that for 100,000 acre-feet of additional firm annual supply, the reservoir would have to store over 500,000 acre-feet and would cost well over one billion dollars.

If reservoirs are built solely for drought protection, providing a full measure of protection requires keeping these reservoirs almost full until severe droughts are obviously underway. They cannot be used to provide water to existing demands during non-drought periods or to meet the demands of new growth. To do so compromises their drought protection capacity.

Another consideration is that building reservoirs for drought protection does not eliminate the need for municipal water restrictions. Virtually all water providers that enacted watering restrictions in 2002 had sufficient storage supplies to meet their normal demands throughout the year. They enacted watering restrictions as a precautionary measure, recognizing that there is no way of knowing how long the current drought may last.

With these limitations in mind, we find that water providers are increasingly developing "smart storage" – smaller reservoirs designed to optimize already-developed supplies rather than capture unappropriated peak season runoff. Smart storage is now commonly developed as a means for capturing and re-regulating reusable return flows, increasing the yields of exchange rights and augmentation plans, re-regulating the yields of changed irrigation rights to meet municipal demand patterns, and increasing yields from existing water rights and transbasin diversions. In some cases, existing traditional storage capacity has been rededicated to smart storage purposes with resulting increases in yields.

While recognizing the progress water providers are making in developing smaller, off-channel projects, enlargements of existing projects and underground aquifer storage, we think that three basic elements constitute Colorado's water future: 1) conservation and demand management; 2) municipal-agricultural cooperation; and 3) supply integration, management, and development. In the three major basins we have looked at carefully – the South Platte, the Arkansas, and the Colorado -- we believe that this combination of measures can meet growing long-term urban demands.

I. The Current Drought and the Future of Water Management in Colorado

A. Background and Brief Overview

For at least the last three years, Colorado has been in the grip of a serious drought. This year, as conditions became extreme, the state's residents have felt its full effect and demanded that public officials and water managers respond. Notwithstanding demand management measures, the most common response has been a call for more dams. Though this reaction may hold some appeal, its efficiency, effectiveness and fairness deserve close examination. In this report, after describing the state of the Colorado water economy and the value of water in various uses, we: 1) identify the principles for assessing future management strategies and projects; 2) review the hydrologic and economic impacts of the drought; 3) appraise the drought response of water managers; and 4) outline the structural and non-structural options for meeting future demands.

B. Water in Colorado

Colorado has a surprising abundance of water for a great variety of purposes, despite relatively low and unevenly distributed rainfall and a perception of water scarcity. This abundance is often obscured, however, by the inefficient way in which water is used. Many, if not most, water management utilities are making significant strides toward improving both their efficiency and system reliability. Nonetheless, while individual users, whether in cities or in rural areas, may be efficient from their point of view, at higher levels, like watersheds, the potential for improved efficiencies still exists.

Viewing water as scarce often propels people to embrace strong opinions on what they see as a clear relationship between water availability and regional economic growth. Most accept the paradigm of the garden – more water means more growth. Government institutions, political leaders, agricultural and business interests, and ordinary citizens all seem to believe deeply in this concept. Investments in water supply systems, whether for irrigation or municipal and industrial purposes, are justified on the basis of their assumed positive impact on economic growth. Even those who challenge the benefits of growth usually do so while conceding that the water-growth relationship is immutable.

To be sure, in an urban setting water serves a utilitarian purpose and in agriculture it is essential. In cities it goes hand-in-hand with other services and amenities citizens expect; in rural areas it is used in abundance for irrigation. Few would contest the assertion that the availability of natural resources has a role in facilitating regional economic growth.

Time and again, empirical economic studies reach a surprising, but irrefutable conclusion: investments in water supply systems, particularly if locally financed, do not have a noticeable impact on a region's growth. These counter-intuitive results suggest that the process of planning and financing water resources development, particularly in cases where a major share of the project funding will be generated locally, must be rethought. If water is of limited or insignificant value in stimulating growth, public

expenditures for the expansion of water supply infrastructure must be carefully reviewed, particularly given the ever increasing competition for capital funds and the growing public concern for environmental conservation and protection.

C. The Value of Water

A paradox arises in dealing with the value of water. Political and public rhetoric asserts its enormous economic importance. This conventional view, however, contrasts with the reality that the resource exhibits a relatively low economic value. For example, resources devoted to water development, conservation or management for agricultural irrigation can justify a cost of only $25.00 to $75.00 per acre-foot (approximately $.08 to $.24 per 1,000 gallons). Compared with other liquids important in modern economies, the value of water is trivial. Gasoline retails in the U.S. at about $456,000 per acre-foot ($1,400 per 1,000 gallons), implying users are willing to pay 1,700 times more per unit volume than they do for irrigation water. In the municipal sector, although the value of raw water is an order of magnitude greater ($.80 to $2.40 per 1,000 gallons), it seldom compares with the rhetoric surrounding it. What is more, the distribution of water use is exactly the reverse of its value; 80 percent to 90 percent of water diverted from natural systems goes to agriculture, the lower value use.

D. The Status of Colorado's Water Economy and Principles for Future Management

Colorado's water economy has passed from its "expansionary phase" into what might be called its "mature phase." In the former, new supplies were readily available, few interdependencies existed among users, and -- after subtracting taxpayer subsidies from the federal treasury -- projects were relatively inexpensive. In maturity, on the other hand, water users are linked by elaborate physical systems and economic interdependencies. Few new supply options exist and costs of new supplies are rapidly escalating. Also, federal subsidies have evaporated. Moreover, free flowing streams are now valuable for their recreational and environmental worth.

Given the elaborate physical systems the expansionary phase has spawned, the relative value of water in agricultural and municipal applications, and the increasing recognition of instream values, it's only reasonable to ask how efficient and equitable it is to continue allocating the resource and augmenting supplies in the same way we have in the past. Applying a widely-accepted rule based on the principle that an efficient and fair public policy decision is one that makes no entity worse off for the betterment of another, present day water supply <u>expansion</u> decisions that involve major storage projects or diversions are almost always wasteful, inefficient, and unfair. However, the flaws in the expansionary mode of operation can be remedied by recognizing the characteristics of a mature system. Before considering new storage options, we should invest in: 1) conservation; 2) creating opportunities for cooperation between the two largest user groups – cities and farmers; and 3) taking advantage of system enhancements (e.g. reservoir reclamation or enlargement) and linkages to use existing supplies more efficiently.

With this in mind, we recommend that, in Colorado, future water supply management and development efforts should adhere to five basic principles:

- Make full use of existing water supplies and reusable return flows.
- Expand water supplies incrementally to utilize existing diversion and storage capacity better.
- Recognize that market forces drive water reallocation from agricultural to municipal uses. Mitigate the adverse impacts to rural communities of these transfers, whether permanent or temporary.
- Involve affected publics and address the inevitable environmental and socioeconomic impacts of increasing water supplies.
- Recognize the fundamental political and economic inequities and the adverse environmental consequences of new transbasin diversions and emphasize the most efficient utilization of existing transbasin water to avoid the need for new transbasin projects.

Over the past decade, many of Colorado municipal water providers' supply-side strategies have embodied several of these principles. They generally produce the most economical, least risky and disruptive, and most easily implemented courses of action to augment existing supplies.

E. The Remainder of the Report

The remaining five sections of the report deal with: 1) the hydrologic impacts of the drought; 2) an estimate of the economic impacts (total and avoidable); 3) the response by water managers; 4) future plans for supply augmentation; and, 5) an integrated approach that incorporates conservation, cooperation, more efficient use of existing supplies and incremental supply augmentation.

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II. Hydrologic Description of the Drought

The current drought, which began in 2000 and has continued to the present, has been the most severe on record by several measures. Streamflows in Colorado in 2002 have generally been the lowest in over 100 years and the tree ring data suggest that flows are probably the lowest in 300 to 500 years. In terms of multiple year streamflow deficits, the current drought is worse than the historic droughts of the 1950s and 1970s. While this drought has not lasted as long as the drought of the 1930s, it is not yet over and it has been more severe than any three-year period of the 1930s.

A. Conditions in the Spring of 2002

1. Snowpack

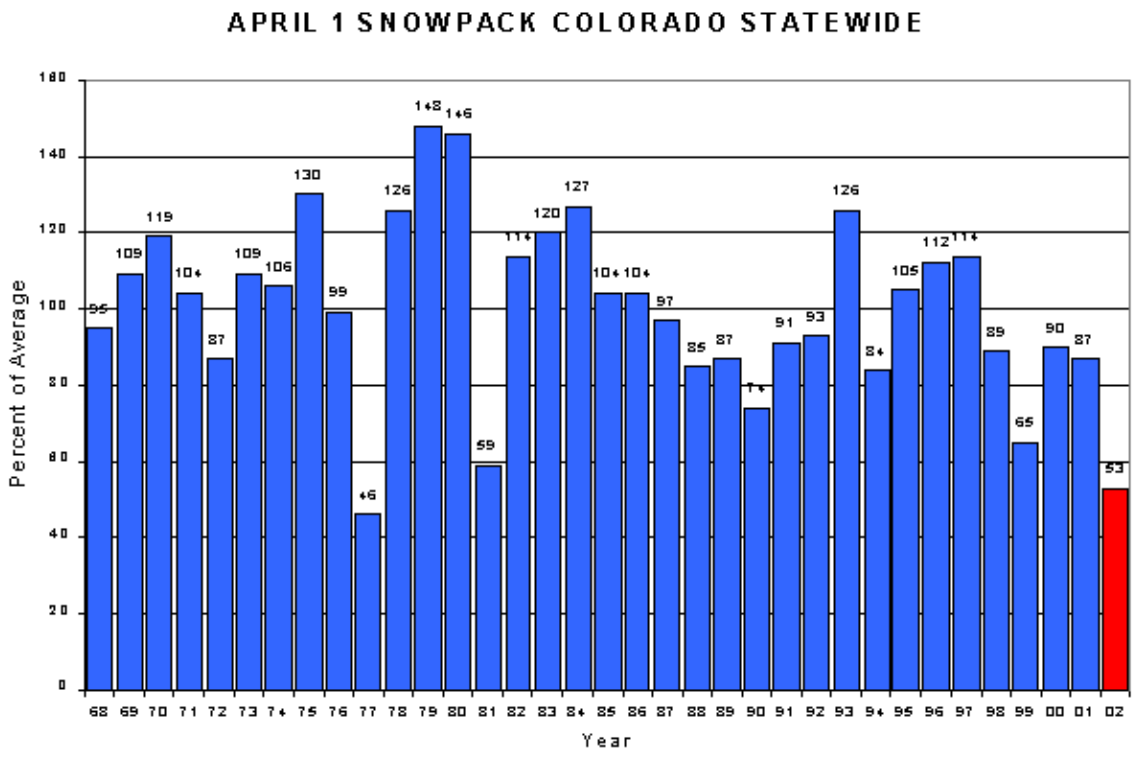
By mid-winter of 2002, Colorado - like most of the interior West - was in its third year of drought. In February snowfall across the state was well below average. It marked the sixth consecutive month with below normal snowfall and resulted in a continued decrease in the state's snowpack. The readings indicated the statewide snowpack was 56% of average, down slightly from January's 58% of average. The lowest percentages (less than 50% of average), occurred in the San Juan, Animas, and Rio Grande basins of southwestern Colorado, and the South Platte headwaters and Saint Vrain basins in northern Colorado. The highest snowpack percentages were measured in two Colorado River tributaries, the Williams Fork and the Blue River, both at 73% of average. Elsewhere across the state, readings ranged from 50% to 70% of average. In 2002 Colorado was in its fifth consecutive year with below average conditions on March 1. In the San Juan, the hardest hit basin, snowpack had dipped to only 28% of the previous year's.

The statewide snowpack percentages continued their steady decline during March. On April 1st, readings were only 53% of average, statewide. Not since the drought year of 1977, when the state had only a 46% of average snowpack, had conditions been this poor. (Figure II.1.) Again, the lowest percentages were found across southern Colorado. The combined San Juan, Animas, Dolores, and San Miguel basins reported the lowest readings, at only 34% of average. The Rio Grande Basin, at only 38% of average closely followed. Also, the Arkansas Basin saw its percentage decrease sharply to 48% of average. Conditions were somewhat better in the north, but remained low. The state's best snowpack occurred across the Colorado and North Platte basins, both reporting 63% of average readings. During late March, warm temperatures induced rapid snowmelt at a number of measuring sites.

Snowfall across Colorado during April, normally the second snowiest month, was unusually low and temperatures unusually high. As a result, snowpack steadily declined throughout the month leaving the state with only 19% of its average on May 1, a record low, dipping 2 percentage points below the previous record measured on May 1, 1981. The lowest percentages in individual basins were again found in southern Colorado, with the Rio Grande and combined San Juan, Animas, Dolores, and San Miguel basins both

reporting only 6% of average. The North Platte Basin was the highest, but still only 44% of average. With the shallow snowpack accumulations and early spring-like temperatures, many sites had completely melted by May 1. Meltout at most sites across the state progressed six to eight weeks earlier than normal.

Figure II.1. April Snowpack in Colorado



Unusually warm and dry weather allowed snowmelt to proceed unabated throughout the month of May. This left the state with a snowpack of only 2% of average and 10% of 2001 totals on this date. Only the Yampa and White, and North and South Platte basins had any snowpack remaining. As a percent of average, they ranged from 15% in the North Platte Basin, to only 1% in the South Platte Basin. By and large, the state's basins had melted out about two months earlier than normal. In many parts of the state this meager snowpack was sitting on very dry soils. As melting began, much of this moisture simply soaked into the ground, never making it to the streams. In addition, windy conditions and low humidity during much of May led to direct sublimation (vaporization of snow surface) of the snow and substantial losses of water.

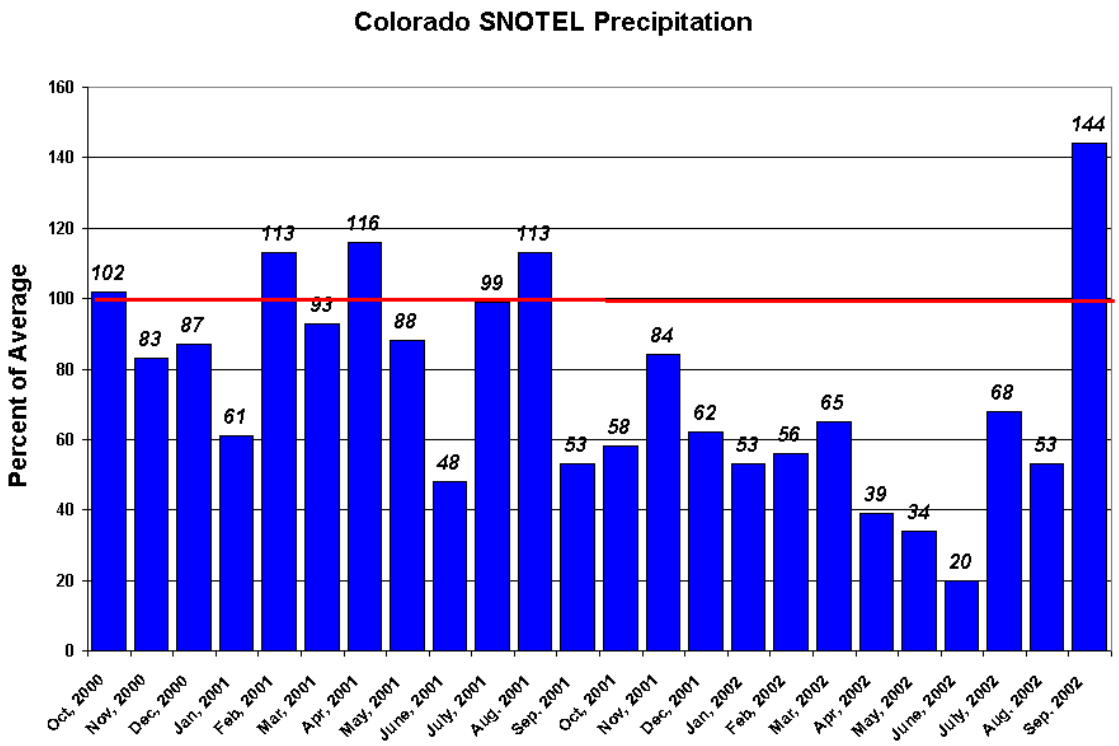
Average statewide precipitation data for the period from October 2000 to September 2002 (Figure II.2) illustrate why runoff this year was so low and also suggest why water managers were, to some extent, caught off guard. Spring precipitation was well below

average and continued to decline into the summer, whereas in 2001, despite "dry conditions," late-winter/spring precipitation was relatively high and midsummer enjoyed average to above-average precipitation.

2. Reservoir and Streamflow Conditions in the Spring

In the Rio Grande, reservoir storage was between 23% and 78% of normal and streamflow barely exceeded 500 cubic feet per second (cfs). A normal peak would have been around 5300 cfs; in 1977, another dry year, the river peaked at 1200 cfs. In the San Juan/Dolores, reservoirs were at 60% to 70% of normal, though some were quite low. By mid-April, most streams had peaked and junior water rights were being called, i.e., being asked to reduce or stop diverting, similar to conditions in 1977.

Figure II.2. Colorado SNOTEL Precipitation



In the Gunnison, the mainstem reservoirs (Blue Mesa, Morrow Point, and Crystal) were releasing from storage rather than filling. In the upper Gunnison, Taylor Park Reservoir was at 62% and received no more storable water. Other reservoirs were in worse condition. The Gunnison flow at Grand Junction was 32% of normal and as of April 15th most of the basin was under a call -- for the first time in 50 years. In the Yampa and White Rivers, none of the reservoirs (with the exception of Stagecoach) were near full nor expected to fill and streamflow conditions were, for the most part, extremely low. In

mid-April, for example, the Yampa flow at Maybell was 1830 cfs, less than 70% of the average. The one anomaly was the White River gage near Meeker, where flow was above average. In the Colorado basin, reservoir storage was generally near 90% of capacity in April. Some were even full. Streamflow, on the other hand was well below average. At several stations, the Colorado, Fryingpan, and Roaring Fork were all between 40% and 50% of the longterm mean.

In the South Platte basin, reservoirs were all below normal and, with rare exceptions, received little additional water. Flow at the Kersey gage, downstream of Denver, was no more than 500 cfs, half the average for mid-April, and the river was already under an 1871 call (i.e., any water right junior to this was out of priority and could not divert). Some of the major reservoirs, like Cheesman and Carter Lake were at less than 50% of full volume. Horsetooth Reservoir was at less than 30%. The North Platte was in slightly better shape, because its snowpack had been consistently above that of the rest of the state.

In the Arkansas basin, the situation was similar. Storage in the basin averaged about 40% of normal and flows in both the upper and lower river were some of the lowest ever recorded. By April 1st the river was under an 1884 call, slightly better than the 1874 call in April 1978, another low water year.

B. Reservoir and Streamflow Conditions in Mid-Summer

1. Streamflow

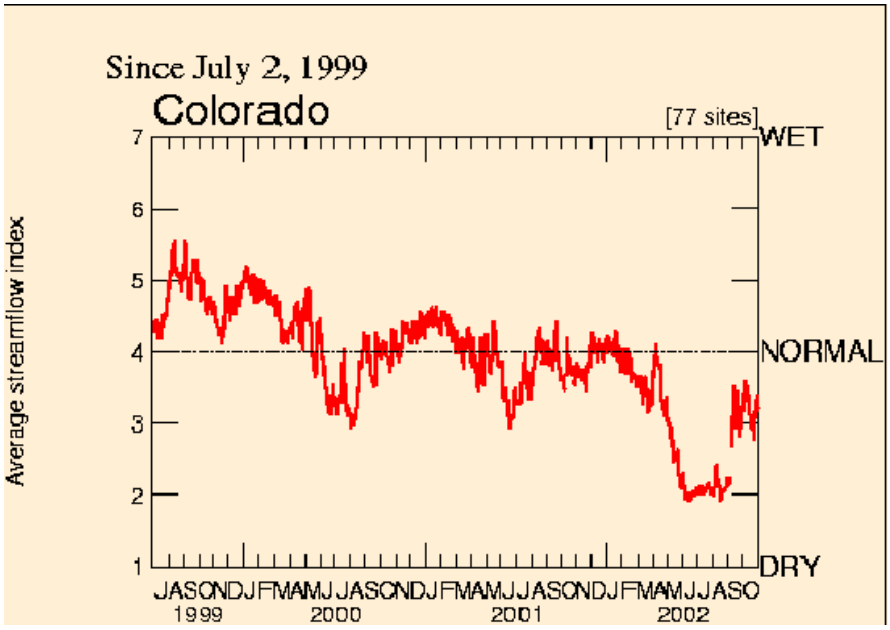
Streamflow conditions in June reflected the combination of low snowpack linked with the dry spring. The worst situation was found throughout the San Juan and was typified by Navajo Reservoir inflow, which was only 9% of normal. In the Dolores, Mancos, Rio Grande and lower Arkansas basins the situation was similar with flows measured as small percentages of normal. The state's “best” conditions, while still quite dismal, were found in the tributaries of the upper Colorado River and the northern tributaries of the South Platte River. Here, flow volumes were 40% to 47% of average.

The streamflow conditions for the entire state are captured in Figure II.3 which traces the Streamflow Index from July 1999 to October 2002. The Colorado index (red line on the graph) is an average of the streamflow indices for all streamgages in the state with 30 or more years of data. The figure shows the low flows of both the summers of 2000 and 2001 and the extremely low flows of 2002. For a specific example of a typical stream, comparing average and low flow hydrographs, see Appendix B.

2. Reservoir Storage

Reservoir storage in July reflects the conditions already described for snowpack and streamflows. Most reservoirs were less than half full in July and many small storage facilities were already empty. Table II.1 gives some examples from around the state, comparing the percentage of filled capacity in July of 2002, in July of 2001, and the average July utilization for the life of the facility. The table includes only two exceptions to the "less than half full" condition: Stagecoach on the Yampa and Elevenmile on the South Platte. Stagecoach is a reservoir in the upper basin with little demand for the water it stores. Elevenmile is the Denver Water Board's drought protection insurance policy.

Figure II.3. Colorado Aggregate Streamflow Index *



*Index values correspond to streamflow percentiles in which 1 represents the 1st percentile [lowest streamflow on record]; 2 is the 2nd to 9th percentiles [much below normal]; 3 is the 10th to 24th [below normal]; 4 is the 25th to 74th [normal]; 5 is the 75th to 89th [above normal]; 6 is the 90th to 99th [much above normal]; and 7 is the 100th percentile [highest streamflow on record].

The table is followed by two figures -- Figure II.4 and Figure II.5 -- that depict statewide summaries of the condition of reservoir storage by basin. In the first figure, the color coded bars represent, for each month of the 2002 water year, the amount of actual storage above or

Table II.1. Table of Percent Storage Capacity Filled in July 2002, in July 2001, and Average July Capacity

Reservoir	Basin	July 2002 Capacity (%)	July 2001 Capacity (%)	Average Capacity (%)
Blue Mesa	Gunnison	45	80	86
Cheesman	South Platte	29	97	88
Green Mountain	Upper Colorado	40	98	99
Stagecoach	Yampa	77	100	89
Vallecito	San Juan	15	82	77
Granby	Upper Colorado	28	73	85
McPhee	Dolores	43	75	82
Pueblo	Arkansas	35	57	63
Elevenmile	South Platte	102	104	101

below average in each basin. The last column is the cumulative total for the state. The second figure shows the basins on a map of the state and storage capacity as a percentage of full utilization by basin for October 1, 2002. By October the amount of water in storage was 48% of average, 56% of what it had been a year earlier when the figure was 86% of average. This amounts to a net withdrawal of approximately 1.2 million acre-feet of water from storage, equivalent to about 20% of Colorado's total usable reservoir capacity, in one year.

Figure II.4. Colorado Reservoir Storage by Basin and Month

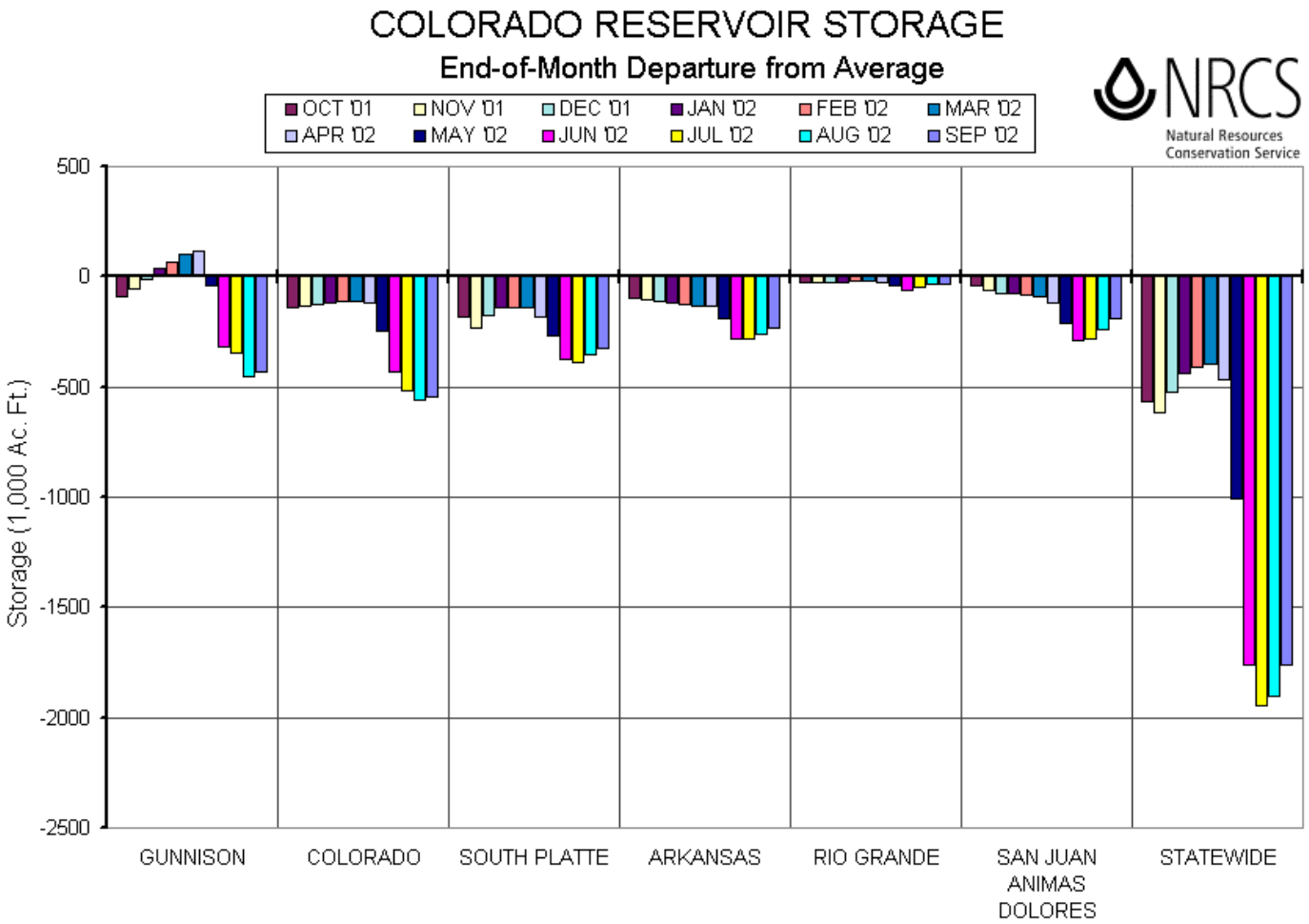
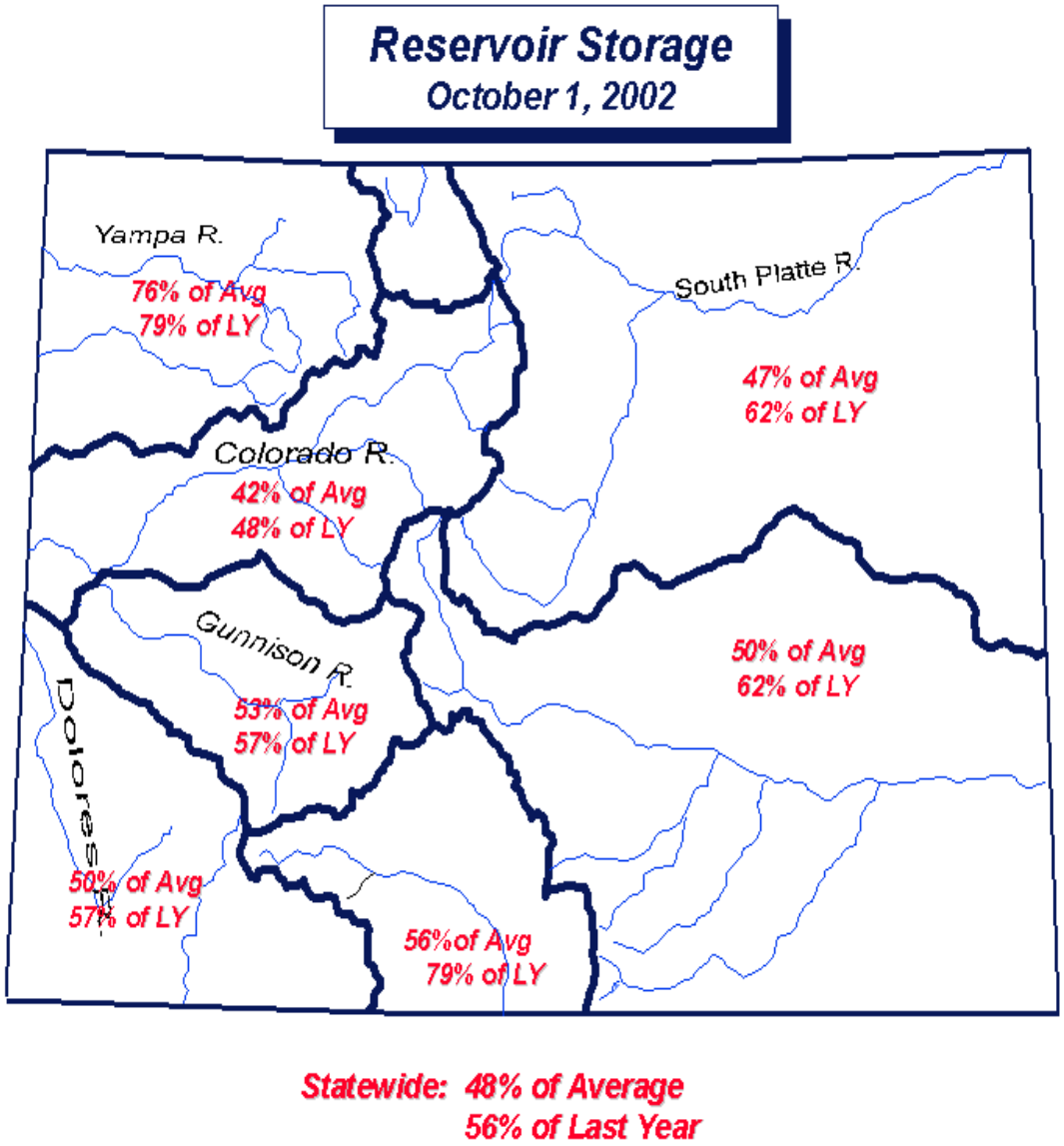


Figure II.5. Average Reservoir Storage by Basin in October 2002



III. Economic Impacts of the Drought

A. Background

Newspaper reports suggest that the economic impact of the drought in 2002 was $1.1 billion. That would be roughly 0.6% of Colorado's gross state product, although a much higher fraction of some agricultural counties' income. The precise source of the estimate is difficult to track down, but appears to come from the Colorado Farm Bureau. The estimate is almost certainly wrong as much of the loss is too difficult to estimate or won't show up until future years. The estimate assumes that water-based tourism and agriculture incurred the most costs, with some additional losses due to forest fires.

However, those sectors were not alone. Some homeowners and businesses have losses due to declining water levels in wells. In extreme cases, some must redrill wells to reach the lower water tables. Owners of landscaped property have costs in replacing landscaping killed or injured by drought if the injury is more than temporary. Landscape providers have at least temporary losses when restrictions are placed on new landscaping or landscape maintenance. On the other hand if they survive, they may recoup those losses later when landowners purchase replacement landscaping after the drought is over. Providers may also come out ahead as people replace present plants with more water efficient ones. Individuals may suffer losses when forced to pay more attention to how they apply their water to their landscape, but these losses are not measurable unless they interfere with the person's market activities.

Some of these losses will not show up in the product accounts for the state. For example, if a person loses $1000 worth of landscaping because of the drought and then replaces it with a similar amount of material next year, the net effect would be somewhere between zero and $1000 gain in state product. It would be zero if the purchase of landscape material comes at the expense of other consumption (e.g. fewer dinners out). It would be $1000 if the expense comes out of savings or working harder to increase income. In each case, the person has a loss of $1000, but the State shows a gain or at least neutrality.

B. Agriculture

1. Dry Land and Irrigated Agriculture in Colorado's Economy

In a normal year, agriculture produces about $4.6 billion in total sales in Colorado, between 2.5% and 3% of the $175 billion gross state product, but net agricultural income is around $700 million, which is only 0.4% of state income. Two-thirds of sales are from livestock and the other third from crops. The major crops are corn, wheat, vegetables and hay. Sod and landscaping plants are another major sector that is sometimes included and sometimes not included in agriculture. In this report, landscaping will be related to municipal water use, not agriculture.

In 2002, the drought seriously injured much of agriculture. The specifics are hard to identify, in part, because the data are still being collected. Basically, irrigated agriculture

had modest losses while dryland agriculture, which depends on natural precipitation, incurred severe damage. About 4 million (12%) of the state's 31 million acres in agriculture are irrigated. Irrigation is used primarily for corn, vegetables, hay, and, in western Colorado, orchards. Higher prices, livestock sales and various insurance programs apparently mitigated the losses and net agricultural income for the first six months of the year was actually higher than in 2001. Data are not yet available for the remainder of the year.

2. Agricultural Costs of the Drought

Raising cattle for meat, Colorado's number one agricultural sector, by far, depends on having adequate pasture and finishing feed sources (corn, hay, alfalfa, etc.). While finishing feed sources are generally produced from irrigated agriculture, pasture grass depends on moisture in the soil from snow and rain during the year. Unlike urban grass, irrigation of cattle pastures is generally not economically feasible. With the drought, ranchers ran short of pasture grass and finishing feed and were forced to sell off some of their herds. Estimates are that the herds in Colorado declined by 50%. Fortunately, there was good pasture in states like Missouri, so that ranchers were able to sell the young cattle to ranchers in those states without severely depressing prices. As a result, livestock income this year will actually increase due to the increased sales. When and if ranchers do rebuild their herds, they will incur additional costs, and next year there will be a loss, as there won't be cattle available to sell. The Colorado Farm Bureau has estimated the direct loss to the livestock sector at $154 million. The multiplier effects are discussed below.

The estimated wheat crop was only 38 million bushels, down from 69 million in 2001 (which was also a dry year), and from an average of 85 million between 1989 and 1997. Wheat was particularly hard hit because most wheat is grown without irrigation. The loss from the drought is between 30 and 45 million bushels with an average price around $4 this year. Estimates of the market value of the loss based on sales have been about $120 million in a crop with a normal year market value of $250-300 million. Net income lost would be more like $25 million.

The corn crop was also substantially damaged. The dry land corn crop was a near total loss from about 20 million bushels. However, recent reports indicate that yields in irrigated cornfields approached normal, although some farmers apparently cut fields early as silage. Thus, total crop yield was down by 30 million bushels, not the 50 million estimate of earlier in the year. At $2.75 per bushel, this is a loss of $82 million. In most recent years, the prices have been nearer $2 per bushel and the typical value of this crop is $300 million. The smaller percentage loss of corn (about 20%) results from corn being largely an irrigated crop. Again net income lost is a small fraction of sales lost.

Vegetables account for about one-third of total crop value in Colorado. They tend to be irrigated and the crop losses appear to be relatively small. Combined value in a normal year appears to be about $500 million and the losses appear to be less than $100 million in sales. Yet, potatoes, the dominant crop in this group, set records in the San Luis Valley and have the ironic problem of being too big to market.

Hay, silage and all other crops including fruit, amount to $300 million in a normal year, but nearly $500 million in 2001. The drought probably hurt hay modestly, but silage may have actually increased as growers cut some corn early and converted it to silage. The fruit crops, with their very senior water rights on the Colorado and Arkansas Rivers, lost only small amounts of yield. No estimate of losses is available. With the high prices for hay during the summer, the hay producers probably gained, but at the expense of hay consumers.

The total losses in livestock and crop value appear to be about $0.5 billion in direct losses from this year's drought. These are sale values. The net income losses within the agriculture industry would be much smaller, perhaps $0.2 billion. Net farm and ranch income in Colorado varies widely from year to year, but has averaged less than $1 billion total per year in recent years (out of total sales over $4 billion). The reduction this year will be substantial and some farmers and ranchers will not survive. For others who did not plant or did not harvest their crops and did not tend as many cattle cost reductions will temper losses. In addition, crop insurance and federal payments from various drought relief and disaster programs, including some not yet passed by Congress, will further mitigate losses.

3. Overall Effect of Agricultural Losses on State's Economy

The impact on the Colorado economy is greater than the net income loss by farmers and ranchers. Some of their costs are wages to farm workers and some are payments to suppliers. The economic impact includes all losses except costs that go out of state for things like tractors and fertilizer. Further, what income the farmers do earn is spent and creates a multiplier effect on the economy as a whole. The multiplier that is usually used is between 2.5 and 3. If that multiplier is correct, the drought's impact is $0.5 to $0.6 billion in agriculture alone.

It is common to add the value created by processing agricultural products to agriculture's economic impact, which roughly doubles the total impact. That calculation also has the interesting effect of making Denver the biggest agribusiness county in the state due to concentration of processors. Since Colorado processors are likely to substitute produce from other states and continue their work with little or no loss of output, they are unlikely to contribute additional economic loss to the state economy as a result of the drought.

While some irrigators made money in 2002 by selling or leasing their water to cities to make up for the cities' shortages, those profits can be regarded as transfers. The irrigators' gains equal the costs to the city who bought the water. Hence there is no net gain or loss from such transactions.

In summary, agricultural losses, primarily from raising cattle, appear to be the major component of drought-related costs in Colorado. Income may have dropped by as much as 30% from an average year. Looking at all state income, this figure represents 0.11%.

C. Tourism

Tourism is estimated to generate $7 or $8 billion annually in Colorado. In April, the Office of State Planning and Budgeting identified several possible impacts that a drought could have on tourism:

- Decline in skier visits due to lack of snow;
- Decline in hunting because of a loss of habitat from wildfires or herd size from lack of precipitation;
- Decline in fishing and rafting because of lower stream levels;
- Decline in outdoor recreation because of fire bans and/or restricted access;
- Decline in resort visits if water restrictions are imposed on golf courses; and
- Decline in touring and parks visits if forest fires impact these areas.

1. Ski Industry

The state's list of potential impacts from the drought started with ski lift ticket sales, based on the fear of a repeat of the almost 40% sales drop in the 1977 drought. Fortunately, that loss did not occur in 2002. In 1977, snowmaking was uncommon and ski areas were dependent on natural snow. Today, most ski areas have water rights that allow at least basic snowmaking even during a major drought. The 2001-2002 ski season did suffer some loss of business, but most of it was early in the season at destination resorts and the standard explanation was fear of flying after the events of September 11, 2001. Late season skiing was nearly as busy as prior years. The concern last spring was about the 2002-2003 ski season and whether drought would affect sales this season. The early snow has been good at most ski areas and all signs are that the 2002 drought will have no effect on the skiing portion of tourism.

2. Water-Dependent Tourism

The drought seriously affected rafting in 2002 as river levels were much lower than average and there just wasn't the water to raft. The total estimated economic impact generated by this industry in 2001 was $125 million, based on direct expenditures of $49 million. That dropped by about 50% in 2002 due to short seasons on most rivers. The economic impact of the loss is about $60 million.

Boating in general was also down. Water-based state parks reported reductions between 20% and 53% in revenues to the state as boat ramps were left high and dry by falling water levels. Average revenues appear to be off by about one-third for boating other than rafting. Boating has been estimated at $550 million per year including rafting, or about $425 million other than rafting. If the boating was down by one third, then this was a loss of about $140 million. The Colorado Division of Parks and Outdoor Recreation (Parks) mentioned that there was one benefit in that the low water levels have allowed them to accelerate some needed maintenance work and to extend ramps in some places to protect from future low water levels.

The Colorado Division of Wildlife estimates fishing (net of boating) at $500 million per year. Fishing licenses appear to be holding fairly steady from 2001 although no final figures are available. Some fisheries, notably Antero Reservoir, were lost as water was drained below the levels necessary to sustain the fish. There were fish kills on rivers (e.g. Dolores), too. There will be future costs to restocking those fisheries after the drought, but the extra cost over routine stocking is unknown. There will also be an offsetting benefit in many cases as new reservoirs are generally better fishing sites than reservoirs that have been filled for a long time. There is a loss here, but it is probably small.

3. Other Tourism Sectors

Other outdoor recreation: hunting and camping were estimated to account for about $500 million in direct spending (this figure includes fishing). The state released 16,000 extra cow elk licenses in September for fear that the elk would die over the winter anyway. The elk herd in Colorado is still almost 50% higher than the Division of Wildlife's estimate of the state's elk carrying capacity, so no loss can be attributed to the extra elk harvest.

State park visits were down by about 5%, but no breakdown is available between recession, fire and drought. As of the early spring, park visits were expected to rise, so there may be a significant loss versus the expectations. The Parks division estimates a total loss against expected visitors of around one million visitors. A study contracted for them estimated local area expenditures of $66 per visitor, suggesting a direct loss of $60-70 million due to fewer visitors to the state parks. Most of this probably overlaps with boating losses so the net might be a direct loss of $20 million and an economic impact after counting multipliers of perhaps $50 million.

Overall lodging for the state is down slightly, but no more than could be expected from the recession plus fear of flying after September 11th. Somewhat surprisingly, lodging appears to be up in Grand Junction, Glenwood Springs and Salida, all areas where drought effects would be expected to appear. There are surely some areas where there is a loss within the state, perhaps the Durango area, but not enough to show up in the statewide figures. Losses may be included in the park visitors and boating losses.

The total loss in tourism appears to have been perhaps $200 million in boating and rafting, plus perhaps $50 million in other parks-related tourism. Many of the feared losses have apparently not materialized. And, while the $250 million represents a 30-50% loss in water-dependent tourism, it is less than 4% of the total tourism sector.

D. Forest Fires

The costs of forest fires include the cost of fighting the fire, the loss of value of the forests and improvements that burn, and the losses in income from inability to use the forest in the future (to the extent that loss of use is not captured by the value of the burned forest). The drought contributed substantially to the record forest fire season in Colorado. About 500,000 acres burned, including many acres in several fires close to towns. The cost of fighting the fires plus immediate restoration has been estimated at

$200 million. Denver Water has budgeted several million dollars to filter out ash and restore reservoir banks after the Hayman fire, costs that may or may not be included in the state's estimate of restoration costs. Some costs would, of course, be incurred in even a wet year and those should be subtracted from 2002 costs to estimate the drought impact. Future restoration costs for the forests should be added, but are unknown.

The value of the burned forests in terms of lumber is close to zero, as lumbering in Colorado has been almost profitless for either the industry or the owners of the trees, for years. However, the value of the homes that were destroyed is significant. Fires burned 384 homes and 624 other structures. The total value of improvements lost may exceed $50 million. The loss of future use of the land for other than lumbering purposes is captured in the losses in the tourism industry, but is likely to be small. Total cost of the forest fires appears to be $200-$300 million plus the nine people who lost their lives fighting the fires.

Fire fighting and rehabilitation costs are mitigated by the fact that a major share of the costs is borne by the federal government, not the state or local governments. To the extent that the fire fighters buy local services, there may even be an economic gain from the presence of federally financed fire fighters. Denver Water has received a federal grant to cover some of its fire-related costs. Losses in buildings are partially offset by insurance, although the insurance benefits are reduced by increases in premiums after the fires. Fire fighting costs are significant even in wet years. The local share of fires including losses in homes and structures, net of insurance and net of normal years costs, is probably between $100 and $150 million.

E. Urban Landscape and Municipal Water Supply

Water districts themselves are incurring some costs in trying to mitigate the effects of the drought. Most water districts in Colorado imposed some form of water restrictions during the summer. There are costs to enforcing the water restrictions. Some districts are using lower quality water supplies that require more treatment. Some are establishing emergency service to nearby residents whose wells have dried up. Denver estimates that its drought related costs, excluding rehabilitation after the Hayman fire, will amount to about $11 million over two years. Lost revenue due to water restrictions is estimated at $22 million for their one million customers. The water that was not used is presumably worth at least as much as it costs to the customer. Hence customers restricted from buying $22 million worth of water (over two years) have a loss of at least $22 million. The real loss is not the revenue lost to Denver Water, but the customers' inability to buy (or even waste) a product that they want. Total loss in the Denver water service area is thus $33 million.

Denver water customers amount to almost one fourth of the state. Some districts have more serious problems and some less. If we assume that Denver is an average district, the projected loss statewide would is $130 million for water users. Such an estimate is, of course subject to a large possible error from districts that do not match Denver and from people served by wells.

The sod industry estimates that at least half of its business was lost for this year due to the restrictions. Some of the loss will be made up after the drought is over. Similar problems affected the whole landscaping industry, although to a somewhat lesser extent. The landscape industry estimates its impact on the Colorado economy at $2.2 billion per year, although that seems high. If business were down in this larger industry by 25%, then the loss would be $500 million. As some of this will be made up after the end of the drought and more business will be generated if people convert to more drought tolerant landscaping, the net loss may be more like $200 million.

Adding the municipal water and landscape costs together suggests a cost in this sector of $330 million. The two main components of this loss are the value of water not used by consumers and the loss of landscaping sales in the landscape industry. These may overlap and are both very uncertain numbers.

F. Total Cost and Avoidable Cost

Some of the estimates for some sectors are only educated guesses. Adding the costs for each of the above sectors: $500-$600 million in agriculture, $250 million in tourism, $100-$150 million in forest fires, and $330 million in municipal and landscaping; gives a total of $1.2-$1.3 billion cost for the drought of 2002. That, of course, assumes that there is no continuation into 2003. That amount is roughly 0.7 percent of our state's income. While this estimate is actually higher than the published estimate of $1.1 billion, the increase stems from a more complete inventory of the damage and is still a very small fraction of state income.

Table III.1. Economic Impact Total Costs and Avoidable Costs of Drought, by Sector

SECTOR	TOTAL COSTS (million)	AVOIDABLE COSTS (million)
Agriculture	$500 -$600	$50
Tourism	$250	$50
Fires	$100-$150	0
Municipal	$330	$150
TOTAL	$1,180-$1,330	$250

In the West, drought is inevitable and some of its costs are too. However, some could be avoided. As one looks through the costs of this drought, it is apparent that most of the costs incurred would be difficult to avoid.

In agriculture, nearly all of the effects come not from lack of water, but from lack of very cheap or free water. Dry land farmers are not going to irrigate their crops unless the water can be delivered to the crop more cheaply than the loss of product. The big agricultural loss is from loss of pasture and that would be almost impossible to irrigate

economically. Only losses because of shortages of irrigation water could be avoided. Those cost avoidances would require cheap additional water in the right places. It seems unlikely that any realistic water storage or flow enhancement will prevent more than ten percent of the losses, or $50 million.

The tourism losses that can be identified could be limited if streamflow were increased, but most of them are similarly inevitable. According to the rafting industry, the need for more water for rafting on the Arkansas was most acute at the end of the season. Programs that increase runoff in the early summer would create high peak flows that make rivers too dangerous for many customers. More water in new reservoirs would not prevent the boating losses on existing reservoirs. If new storage or flow enhancement is trapped in existing reservoirs, then some additional boating is possible. Perhaps one-third of the non-rafting boating losses could be prevented, about $50 million.

The fire fighting losses could be stemmed either by wetting or cutting the forests only. No amount of storage or of water in the streams would have prevented this year's fires.

The municipal costs are the only ones that would yield substantially to additional water supplies in a way that could conceivably pay for the cost of producing some supplies. If municipal suppliers had more water in storage, then they might have set fewer restrictions on use of that water and there would have been less loss in this sector. Still, it is unrealistic to suppose that even a majority of the cost and restrictions could be avoided. Mitigating landscaper losses would have required fewer restrictions. Most of the districts that imposed restrictions in 2002 did have enough water for the year; the restrictions were imposed because they feared that the drought would continue into 2003 and beyond. Having more water in storage would have reduced the restrictions, but not eliminated them. Slightly less than half of the municipal and landscaper costs would be about $150 million.

Adding up the avoidable vs. non-avoidable losses, we find that only $250 million of the economic impact loss could be prevented by water projects that provide reliable yield during droughts as severe as the 2002 drought in Colorado. The remaining $0.9 to $1.1 billion is simply there and not avoidable. Even these figures assume ideal conditions. The new water project would have to produce new water yield in the water short areas, sufficient to eliminate most restrictions. Any new storage reservoirs would have to be full from prior years' precipitation. More likely, the benefits of any water projects would be substantially lower than this estimate for a record setting drought year.

Given that the drought is an infrequent phenomenon, there is a limit to what we should spend to avoid these losses. Expenditures have to be made well in advance of the losses and, therefore, incur an interest cost for making the expenditure. If such a drought can be expected only rarely, then the cost incurred to prevent the avoidable losses should not exceed the $250 million estimated losses and probably should not exceed half that amount. The issue could be phrased as "how much would you spend today to prevent a $250 million loss twenty or forty years from now and once every half century thereafter?" The actual drought evidence suggests that this kind of drought is considerably less frequent than even these numbers suggest.

IV. Drought Responses of Major Water Management Systems

A. Background

Streamflows in Colorado during the year 2002 were the lowest in several centuries. While water supply planners have been aware that extremely dry years like 2002 have occurred in the past and will probably occur again, most major municipal water supply systems are designed to withstand drought conditions that have occurred in recently recorded history. In most parts of Colorado, flow measurements for major streams have been recorded only over the last 50 to 100 years, and precipitation measurements over the last 20 to 60 years. Most water providers have used the historical drought of 1954-1956 as the standard against which to design their systems.

Water supply planners have not adopted a universal definition of drought or common design standards for water supply system reliability. The vulnerability of any particular water supply system to shortages depends on many factors such as natural variations in the geographic patterns of drought conditions, types of water supply sources (e.g. surface water or groundwater), and types of water diversion and storage facilities. In many instances, legal and institutional factors may be the primary determinant of system reliability, whereas in other cases the actual availability of physical supply may be the limiting factor in times of drought.

B. An Example of a Municipal Drought Management Plan: Denver Water

Denver Water operates the largest municipal water supply system in Colorado and has adopted a conservative approach to planning for drought. Denver bases its estimate of the amount of demand that can be reliably met on the *firm yield* of its system. The firm yield is determined using a computer model to calculate the maximum amount of demand that could be met during the driest period in a representative hydrologic study period, 1947 through 1991. Three consecutive dry years within that period, 1954 through 1956, determine the firm yield of the Denver Water system. For the Denver system, water year 1954 yielded the least amount of supply of any year in the hydrologic study period. 1954 was followed by two additional dry years during which the firm yield of the system is limited by natural inflows to the system and the amount of water in storage reservoirs.

Recognizing the potential for droughts more severe than the 1954-56 period and other uncertainties, Denver Water utilizes additional measures to reduce the risk of water supply shortages. In modeling the water supply system, Denver assumes that water demands will be higher than average during periods of drought. The firm yield of Denver's system is thus based upon an unrestricted demand, whereas during an actual drought under Denver's Drought Response Plan (2002) water use restrictions would be imposed to reduce demand. In addition, Denver Water reserves 30,000 acre-feet of its firm yield as a safety factor to help insure the reliability of its system in the event of severe drought and other risk factors.

Denver Water has prepared a Drought Response Plan to be used as a guide for identifying and responding to drought conditions. For purposes of defining drought response triggers, Denver uses projected reservoir storage levels as of July 1st. Denver's drought plan is based upon three levels of drought severity and identifies demand reduction goals associated with each drought level, as summarized below.

Table IV.1. Denver Water Drought Levels and Water Use Reduction Goals

Stage	July 1 Storage	Drought Severity	Water Use Reduction Goal
Stage 1	Less than 80% full	Mild	10%
Stage 2	Less than 60% full	Moderate	30%
Stage 3	Less than 40% full	Severe	50%

Denver's plan includes a "Menu of Possible Board Actions to Cut Water Use" for each of the drought levels. The menu includes measures to temporarily increase water supplies, reduce deliveries of water to contract customers outside the City and County of Denver, education programs to increase public awareness and encourage voluntary conservation, and mandatory water use restrictions. The board may select the combination of measures it determines are necessary and appropriate to meet the applicable water use reduction goal, given the circumstances at the time.

Denver Water initially projected that its reservoirs would reach at least 80% full by July 1st, but subsequently reduced its projections and, in accordance with its drought response plan, began mandatory watering restrictions by mid-summer, in spite of having generally adequate reservoir supplies. Denver did have a problem with its North End system. The North End pulls water from the Fraser and Williams Fork Rivers, both tributary to the Colorado, through the Moffat Tunnel under the Continental Divide, to Gross Reservoir on South Boulder Creek, a South Platte tributary. From the North End, Denver must meet several raw water contract obligations, but there is far less storage than in the remainder of the system.

In the south portion of its system, Denver Water transferred the contents of Antero Reservoir to Cheesman Reservoir in order to reduce evaporation and help mitigate the water quality effects of the Hayman Fire. The water is still there, but is more efficiently used.

Denver Water adopted Stage 1 drought response measures on June 5, 2002 and asked all customers to voluntarily reduce water use enough to achieve a 10% reduction in demand. Due to the rapidly increasing severity of the drought, Denver then declared a Stage 2 drought response on June 26, 2002 and imposed mandatory water use restrictions, effective July 1, designed to achieve a system-wide demand reduction of 30%.

During July and August 2002, the severity of the drought became more apparent, with streams in some areas flowing at 10% of average and 30% to 50% less than the lowest

flows ever recorded. On August 21st, Denver Water staff projected that even with the desired 30% demand reduction, reservoirs would be at only 40% of capacity on April 1, 2003 due to lower than expected inflows. They also reported that the mandatory restrictions adopted by the board on June 26th had not resulted in the desired 30% savings. In response to these concerns, Denver adopted additional restrictions on outdoor water use and rate surcharges to encourage indoor use reductions through the winter.

C. Drought Response of Other Municipal Users

While 2002 has been by far the worst drought year on record in terms of streamflow, most municipal providers generally had sufficient supplies to manage with little disruption to unrestrained demand. Most providers that invoked water restrictions did so as a precautionary response in recognition that the current drought might not be over, not because they would otherwise run out of water in the next 12 months. Providers' real concern is that their storage reserves would not last through another year or two like 2002.

Most water providers focused on implementing drought response measures to reduce demands as well as to increase supplies. The City of Louisville appears to have been the first major water provider to implement mandatory restrictions on May 1. Aurora implemented mandatory restrictions and rate surcharges to encourage conservation on May 15 and Lafayette and Boulder adopted mandatory restrictions in early June. Most other water providers adopted mandatory restrictions, but generally not until mid-July or early August.

Unprecedented low streamflows and rapidly diminishing water levels in storage reservoirs triggered these drought-response measures. During the last major drought in 1977, the extremely low snowpack that was evident from mid-winter onward alerted water users and providers alike to the impending drought. By contrast, in 2002 the snowpack on April 1st in the basins which supply most Front Range and many other Colorado municipalities was about 60% of average, which was not considered to be worse than that of 2000 or 2001. No one anticipated that the cumulative effects of virtually no precipitation in April and May, coupled with unusually warm and windy conditions during those months, would result in the lowest streamflows in recorded history.

Unlike Denver Water, most municipal water providers did not have formally developed drought response plans. Few had procedures in place to closely monitor rapidly evolving drought conditions. When snowpack and streamflow conditions rapidly deteriorated in May and June, most water providers found themselves having to move quickly. Initial efforts consisted of education programs to encourage efficiency and voluntary conservation programs, followed by mandatory restrictions on outdoor water usage. Only Aurora, Berthoud and Denver adopted pricing surcharges. Very few water providers placed any restrictions on the issuance of new taps.

Groundwater-dependent providers in Douglas County were generally unaffected by the drought, although at least one provider enacted watering restrictions in support of metro-

wide restriction efforts. Most of the wells in Douglas County are in the Denver Basin aquifers, which have little or no annual recharge. The future problem of the Denver Basin is that it contains a massive but essentially nonrenewable supply of water and will eventually become prohibitively expensive to pump at current and projected withdrawal levels without artificial recharge. As Douglas County grows, water levels in the aquifers will drop and the number of wells must be continually increased to sustain current pumping levels. This effect is independent of whether or not we have a drought.

Some providers also implemented measures to increase their supplies. Examples included canceling municipal leases of water to farmers, leasing irrigation rights from farmers, reducing minimum streamflow bypasses, utilizing ditch water or treated effluent for irrigating park lands, drilling supplemental wells and, in the case of some small water systems, trucking in emergency water supplies. Lafayette traded Colorado-Big Thompson (CBT) project (Bureau of Reclamation project operated by the Northern Colorado Water Conservation District (NCWCD)) water to Boulder for Boulder's Baseline Reservoir water. This trade allowed each city to give up water that it controlled but could not easily use in exchange for water that was more directly deliverable. In similar fashion, Eldora ski area acquired a lease on CBT water and traded that water to Louisville in exchange for using some of Louisville's Marshall Reservoir water as an exchange supply for increased snowmaking diversions from South Boulder Creek for the upcoming season.

A few utilities began building facilities to allow them to make better use of their existing water rights. Lafayette began building a new diversion from Boulder Creek upstream of Boulder's wastewater discharge in order to maximize use of its Boulder Creek water rights. The Town of Kremmling began construction of a Colorado River pipeline to use its conditional rights from that source. Broomfield continued developing facilities to increase its reuse of treated wastewater effluent for irrigation.

Providers also invoked a variety of drought reservations that allowed them to reduce bypass requirements and to interrupt agricultural leases. Denver Water invoked drought reservations that allowed it to reduce its minimum flow bypasses at its Fraser basin points of diversion and at Strontia Springs Reservoir and to stop others' irrigation diversions temporarily above Williams Fork Reservoir. The U.S. Bureau of Reclamation similarly decreased its minimum flow bypasses below Granby Reservoir in accordance with drought provisions in its agreement with the U.S. Fish and Wildlife Service.

Boulder invoked its drought reservation with the Colorado Water Conservation Board (CWCB) in order to use senior water rights for municipal purposes even though Boulder had previously conveyed these rights to the CWCB for instream flow purposes. In spite of this action, Boulder Creek streamflows remained at average flow levels because of the interplay of extremely low streamflows and water rights: senior rights at the bottom of Boulder Creek called out water rights that normally dried up the creek from upstream locations.

D. Irrigated Agriculture

Agricultural users employed a wide variety of strategies to cope with the drought. The rapid onset of the 2002 drought was less critical to farmers because as a group they were expecting severely reduced supplies even at April 1 snowpack levels. Many farmers planted only half of their usual acreage, in anticipation of reduced direct flow and storage supplies. Some switched their cropping mix from full season crops (e.g. feed corn) to partial season crops (e.g. 1- or 2-cut hay and corn for silage). Even feed corn growers who had not switched to lower water crops before planting cut a higher percent of their crop as silage in response to reduced late season water supply. Livestock owners sold off significant percentages of their herds in expectation of high-priced and reduced feed supply.

In northern Colorado, the NCWCD imposed a 70% CBT quota rather than its usual 100% quota because of reduced water in storage. In spite of this reduced quota, CBT allottees are carrying over a total of 50,000 acre-feet (equivalent to 25% of this year's quota) into next year. Most of the water being carried over belonged to cities that used a less-than-normal amount of CBT because of demand restrictions and reduced exchange potential. Some municipal providers leased CBT water from farmers to augment their supplies.

Along the South Platte, farmers with both surface water rights and alluvial wells relied more heavily on their well supplies and began bidding up the price of augmentation supplies in anticipation of upcoming augmentation requirements. Cities like Aurora and Denver with excess reusable return flow credits (primarily return flows from imported water) generally leased all their available credits to alluvial well users. Additional water was released from Cherry Creek Reservoir in late August for emergency augmentation of South Platte alluvial wells. Some farmers decided not to farm for this year, and to lease their water supplies to cities instead.

E. Recreation

Each sector of the recreation industry faced its own problems and met them with differing solutions. Fishing opportunities and guided fishing shifted from rivers to lakes and from spring and late summer to the runoff season (which is normally not a prime stream fishing period). Fishing pressure increased on reservoir-controlled stream segments. The Colorado Division of Wildlife captured and relocated some critically vulnerable populations of native trout species to lakes, reservoir and isolated sections of hatcheries. Rafting companies increased their trips during the peak flow season (which is normally a relatively difficult boating season) and offered trips on rivers that are normally too difficult for commercial rafting during peak flows. Companies also offered more trips on reservoir-controlled river reaches. Golf courses restricted their irrigation to critical areas and allowed some brownout of fringe areas.

The 2002 drought generally did not affect Colorado's ski areas because of reasonably good early season snow in 2001 and sufficient reservoir and contract supplies to allow for normal snowmaking in 2002-2003. In addition, the early snow in the fall of 2002 has made even this supply less critical.

F. Effectiveness of Drought Plans

Water savings achieved by municipal providers' drought response measures varied from basically zero effects to reductions of up to 75% of normal summer demand in the case of Lafayette. Preliminary results from ongoing efforts to quantify actual demand reductions suggest that municipal water providers will have reduced their normal demand by about 10% between May 1, 2002 and April 30, 2003. In most communities the public response to efforts to reduce water use was widespread and positive. The following tables offer, for both Front Range and West Slope municipalities, demand reduction targets and, where available, estimates of actual reductions.

The results reported in the tables are in line with the findings of two University of Colorado researchers who compared water consumption in Aurora, Boulder, the Denver Water area, Fort Collins, Lafayette, Louisville, Superior, Thornton, and Westminster, from May 1 to August 31, 2002 to consumption over the same time period in 2000 and 2001. Six of the providers studied (Boulder, Denver Water, Fort Collins, Superior, Thornton, and Westminster) implemented voluntary restrictions on outdoor use, with five (all but Thornton) eventually shifting to mandatory restrictions; the remaining three cities used mandatory restrictions exclusively. Though their results are preliminary, they found, as one might expect, the strictest regulations generally produced the greatest savings; similarly, mandatory programs fared better than voluntary approaches.

Table IV.2. 2002 Municipal Water Restrictions for East Slope Water Providers

City	Restrictions		Rate Surcharge	Demand Reduction Goal	Actual Demand Reduction	Comments
	Voluntary	Mandatory				
Arvada		7/1		30%		Raw water contract with Denver
Aurora		5/15	31-75%	20%	24% outdoor 7% overall	No lawn watering after 10/15
Berthoud		8/20	Yes			
Beulah						No restrictions necessary, ran out of water
Boulder		6/10	No	25%	28-30%	
Broomfield	Until 7/16	7/16	No	30%	27% (July)	
Brush	Yes		No			July use up 40% over previous 3 Julys
Colorado Springs		6/11	No	20% outdoor	18% outdoor 9.5% overall	Tightened restriction in mid-August
Dacono		Yes	No	10%		
Denver		7/1	Yes	30%	27%	May demand up 19% over 2001
Eaton		Yes	No			
Erie		Yes	No	10%	10%	
Evans		Yes	No			
Evergreen		July	No			Banned outdoor use in July, then backed off to every third day on 7/25
Fort Collins	7/1	7/16	No	10%	9.5%	In early June said restrictions not needed
Fort Morgan		9/1	No	10%		Golf course usage cut 25%

City	Restrictions		Rate Surcharge	Demand Reduction Goal	Actual Demand Reduction	Comments
	Voluntary	Mandatory				
Greeley		7/2	No	10%	13%	
Lafayette		6/1	No	75% outdoor 35% overall		Most severe restrictions of all cities
Longmont		8/5	No	10%	June 13% July 7% Aug 19%	
Louisville		5/1	Considering	50%	July 42%	
Loveland		6/6	No	20%	13-24%	Used state's emergency water law to acquire water, rented 1,100 AF from Ag
Mead		Yes	9/1	20%		Same as Little Thompson Water District
Morrison		7/17	No			
Northglenn		7/25	No	30%		Voluntary did not work
Platteville		7/15	No			Looking for temporary supplies
Pueblo		7/29	No	30%		
Sterling	Yes	8/7	No			Water use up 16% through June
Superior		Early Aug	No		10-16%	
Thornton	Yes	8/13	No	15% of Sept. 2001	23.7%	Received emergency authorization from state to use gravel pit storage
Walsenburg		Yes	No			Banned all lawn watering
Westminster		8/1	No	20%	25%	
Windsor		8/1	No	30%	13%	

Table IV.3. 2002 Municipal Water Restrictions for West Slope Water Providers

City	Restrictions		Rate Surcharge	Demand Reduction Goal	Actual Demand Reduction	Comments
	Voluntary	Mandatory				
Durango	Yes		No	20%		Animas River 30% below worst ever flow
Frisco		8/15	No	15-20%		
Kremmling	Yes		No			1.5 million gal less in July than July 2001
Montezuma		Yes	No			
New Castle	Yes		No			
Rifle	Yes		No			
Carbondale		Yes	No			
Glenwood Spgs		Yes	No			
Telluride		7/10	No			
Vail	6/1	8/1	No			

Sources: Northern Colorado Water Conservation District and the City of Fort Collins

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V. The Role of New Storage in Managing Colorado Water: A Basin-by-Basin Assessment

A. Introduction

Reservoirs have been part of Colorado's water development strategy since the late 1800s, in response to its highly variable streamflows. Streamflow patterns in Colorado are dominated by snowpack accumulation and melting. In a typical year, about 65% of streamflow occurs in May through July, while less than 20% occurs during late summer and less than 5% occurs during winter months, as shown in Figure V.1. Streamflow also varies considerably from year to year as shown in Figure V.2, with drought periods frequently extending over several years.

By the 1870s, demands for summer irrigation water began to exceed the reliable streamflow and irrigation companies began building reservoirs to capture excess spring runoff for release later in the irrigation season. By the early 1900s, cities also turned to reservoir development to provide reliable winter season supplies and for drought protection.

From the 1880s through the 1920s, most reservoirs built in Colorado, with the exception of Cheesman Reservoir on the South Platte, were modest projects – small off-channel structures filled via feeder ditches – that reflected the engineering and financial limitations of local water users. Construction of Colorado's major on-stream reservoirs in the 1940s through the 1960s was made possible by a combination of the United States' deliberate investment policies in western water development projects, the technical expertise of the Bureau of Reclamation and the growing financial capabilities and political influence of Colorado's larger cities.

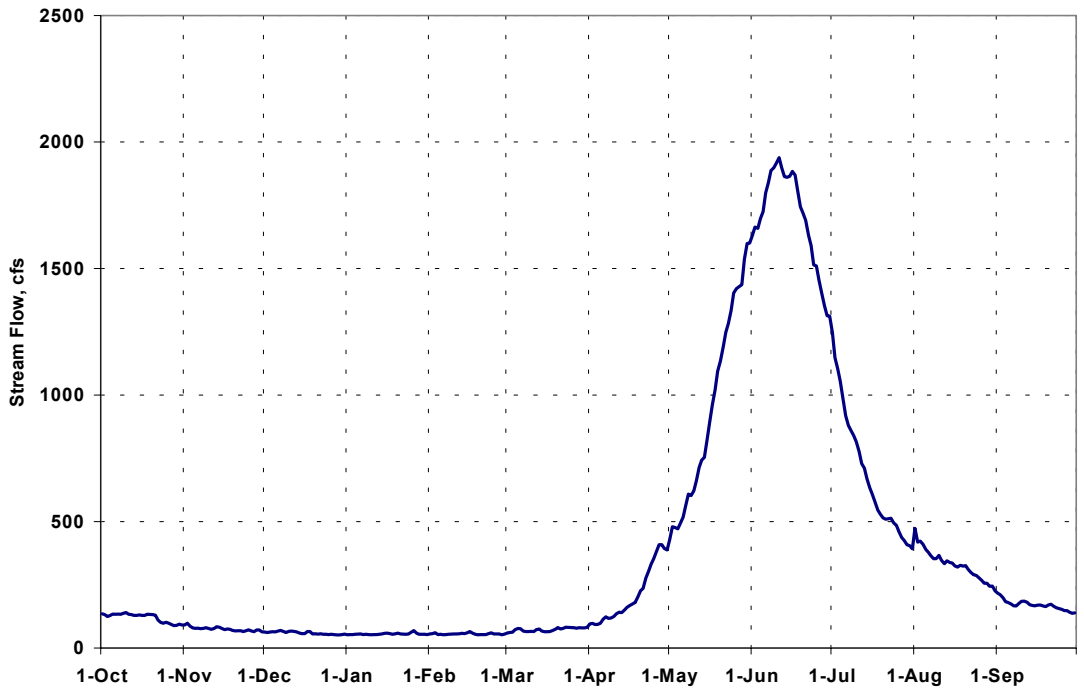

Figure V.1: Typical Streamflow Pattern (Cache la Poudre River)

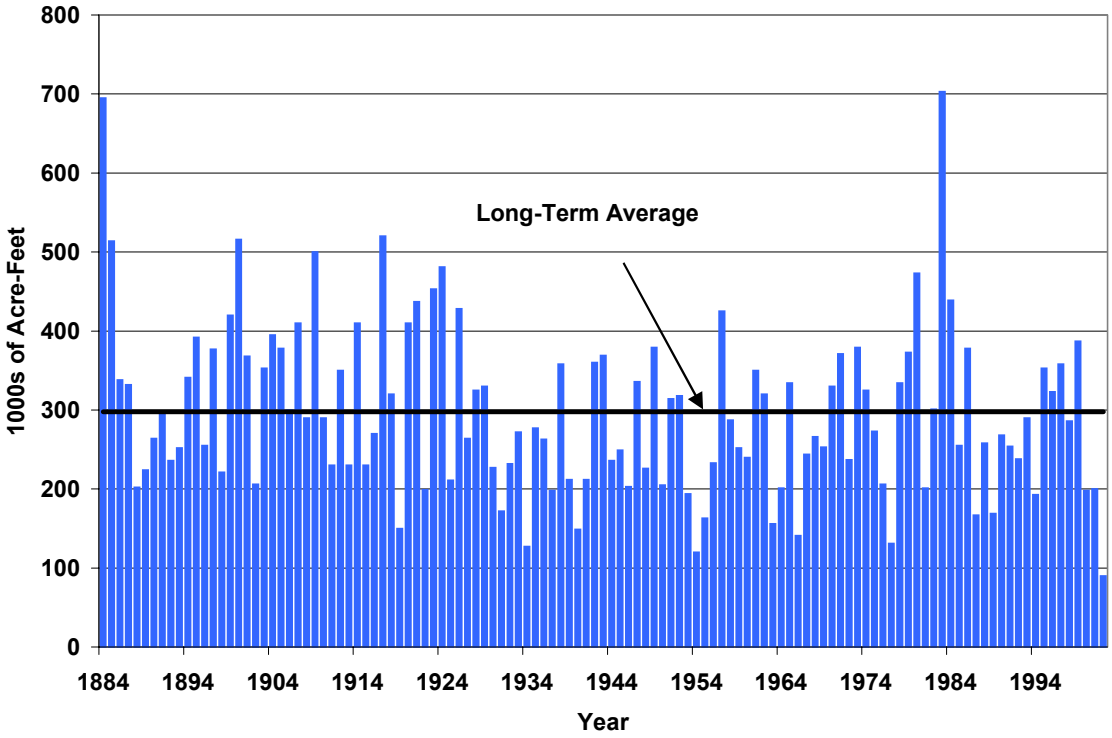

Figure V.2: Typical Year-to-Year Variation in Streamflow (Cache la Poudre River)

Today, more than 7.5 million acre-feet of reservoir storage has been built or is under construction in Colorado as summarized in Table V.1. About 25% of this capacity directly supports municipal and industrial (M&I) water uses and this fraction is steadily growing as cities continue to acquire agricultural water rights and their associated storage interests. Appendix C lists all of Colorado's reservoirs.

Table V.1: Existing Water Supply Storage in Colorado

Basin	Total Storage Capacity	M&I Portion
Arkansas	1,870,000	275,000
South Platte	1,710,000	750,000
Gunnison	1,360,000	10,000
Colorado Mainstem	1,340,000	850,000
San Juan/Dolores	761,000	130,000
Rio Grande	350,000	15,000
Yampa/White River	110,000	10,000
North Platte	35,000	1,000
Totals	**7,536,000**	**2,041,000**

While this amount of storage may seem large, it is dwarfed by the natural storage provided by Colorado's principal underground aquifers. The Denver Basin aquifers contain approximately 150 million acre-feet of recoverable groundwater beneath the six-county metro Denver area and the alluvial and deep aquifers elsewhere within the South Platte and Arkansas Basins contain over 15 million acre-feet. Cities and farms throughout Colorado have recognized the value of groundwater and aquifer storage and have developed strategies to utilize these resources.

B. Is Storage the Answer?

The traditional purpose for building reservoirs has been to capture excess unappropriated runoff, which usually occurs relatively infrequently and in large volumes. Consequently, traditional reservoirs have had to be fairly large and located directly in a stream channel to be of much value. Apart from their well-documented environmental impacts, such large on-stream reservoirs have other major limitations from a water supply perspective. They are relatively costly to build and cannot be built incrementally in response to gradually growing demands. Rather, they must be fully paid for and constructed "up front," which increases their financial risk and diminishes their economic viability. As a basin becomes over-appropriated, additional storage designed to capture runoff produces ever-diminishing returns in terms of water supply yield, because unappropriated runoff occurs less frequently and storage carry-over periods become longer. This phenomenon is illustrated in Figure V.3 (a graph, based on work by the U.S. Geological Survey, of the storage-annual flow ratio to the yield-annual flow ratio). For example, when storage is equal to average annual flow (1 on the horizontal axis) a little less than 40% of the average flow is available for use (0.36 on the vertical axis), whereas doubling the storage (2 on the horizontal axis) only increases availability by about 10% (0.46 on the vertical axis). Evaporation losses compound this problem, becoming a major limiting factor in reservoirs' ability to provide relief over extended drought conditions. Finally, given the

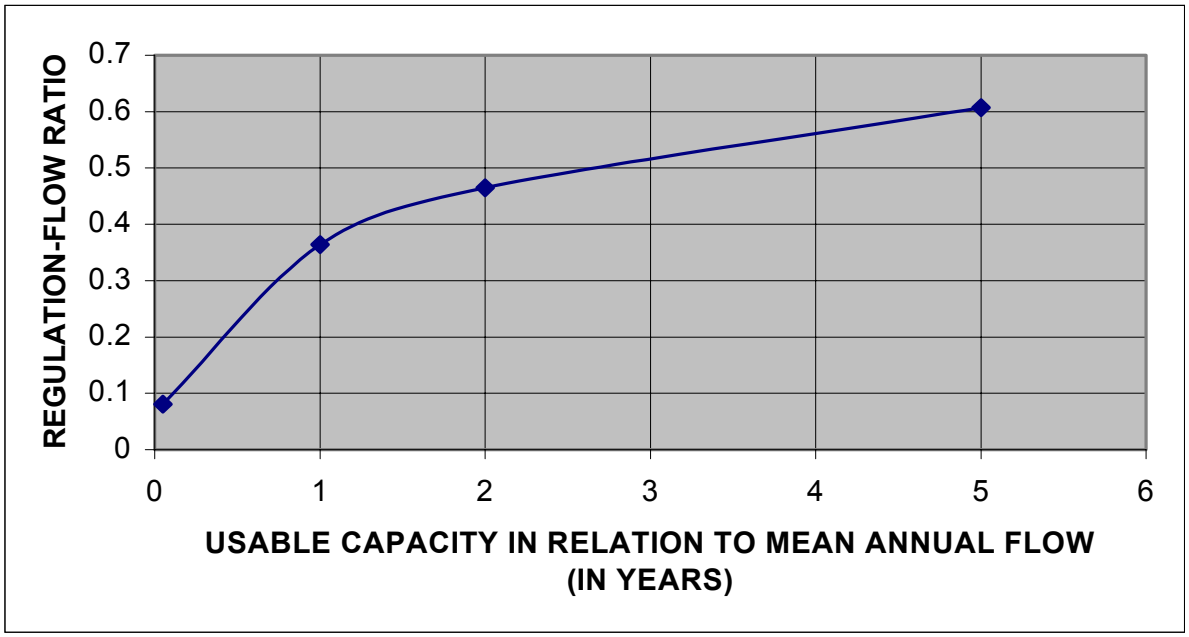

Figure V.3. The Regulation-Flow Ratio in Relation to Usable Capacity

diminishing returns for large, new storage projects, storage-yield ratios are approaching, if not exceeding, 5-to-1, which means that for 100,000 acre-feet of additional supply during drought conditions even less severe than those of 2002, a water utility would have to build 500,000 acre-feet of storage at a cost well over one billion dollars.

Alternatively, reservoirs can be constructed exclusively for drought protection. If this were done, a much smaller reservoir would be needed than in the example above. One major problem associated with building reservoirs solely for this purpose is that, in order to provide a full measure of protection, such reservoirs must be kept full until severe droughts are obviously underway. They cannot be used to provide water to existing demands during non-drought periods or to meet the demands of new growth; otherwise they would be significantly drawn down before a major drought occurs. Dillon Reservoir was built in response to the severe drought of the 1950s, but because Denver uses it to meet day-to-day demands, it entered the spring of 2002 less than 75% full.

Another problem is that building reservoirs for drought protection does not eliminate the need for water restrictions. Virtually all water providers that enacted watering restrictions in 2002 had sufficient storage supplies to meet their normal demands throughout the year. They enacted watering restrictions as a precautionary measure, recognizing that there is no way of knowing how long the current drought may last. Tree ring evidence suggests that there have been several droughts in Colorado over the past 400 years that have persisted for more than 10 years.

Because of these limitations, water providers are increasingly developing "smart storage" – reservoirs designed to optimize already-developed supplies rather than capture unappropriated peak season runoff. Providers now commonly develop smart storage as a means for capturing and re-regulating reusable return flows, increasing the yields of exchange rights and augmentation plans, re-regulating the yields of changed irrigation rights to meet municipal demand patterns, and increasing yields from existing water rights and transbasin diversions. Smart storage tends to take the form of smaller, off-channel projects, enlargements of existing projects and underground aquifer storage. In some cases, existing traditional storage capacity has been rededicated to smart storage purposes with resulting increases in yields.

C. Overview of Current Water Development Projects

In assessing the role of storage augmentation in managing Colorado's future water needs, not all basins are created equal. Some can be eliminated from consideration given current conditions either of hydrology, adequacy of existing storage capacity, economics, project proposals that are already well along (e.g., Animas/La Plata), downstream delivery requirements (e.g., Rio Grande Compact), or some combination of the above. The Rio Grande, the San Juan/Dolores, the Yampa/White, and the North Platte fall into this category. In each of these basins at least two of these factors are relevant. Furthermore, in each of these basins the primary use of water is for irrigated agriculture. In none does municipal or domestic use exceed 3.5% of the total and only in the San Juan/Dolores is it expected to reach 6% over the next 30 years. There are no economic conditions conceivable under which agricultural interests in these basins could pay for new storage. In any farm budget, water rarely has a value of more than $100/acre-foot and the cost of new storage, on an annual basis, is at least an order of magnitude greater. For these

reasons, we will concentrate our attention on the question of storage in the Colorado/Gunnison, the Arkansas, and the South Platte.

In recent decades, reservoir storage has been only part of the answer to water supply development. Water users also rely on direct flow diversions, transbasin imports, acquisition of irrigation rights, groundwater development, water reuse and coordinated operations with other providers as major components of their water supplies. Most of the water development projects currently being contemplated or underway involve combinations of these strategies. Basin level activities are described below, but the inclusion of specific projects should not be interpreted as endorsements.

1. Arkansas Basin

In the Arkansas Basin, the Southeastern Colorado Water Conservancy District, Colorado Springs, a number of other in-basin municipal water providers and the City of Aurora are all examining a range of new storage projects, reservoir enlargements, re-operations of existing reservoirs and new raw water pipelines for water supply development purposes.

The Southeastern District has sponsored a cooperative planning process for in-basin water users (the Preferred Storage Options Plan, or PSOP) to examine potential storage projects that could help meet municipal in-basin water supply needs and facilitate cooperative water-sharing arrangements between in-basin cities and farms. Options preliminarily selected in the PSOP include enlargements of Pueblo and Turquoise Reservoirs and re-operation of existing storage capacity in Pueblo Reservoir.

In addition to participating in the PSOP, Colorado Springs is examining a range of water supply options of its own. Over 80% of Colorado Springs' water supply comes from transbasin sources and is therefore reusable. Most of Colorado Springs' reusable return flows accrue to Fountain Creek, which joins the Arkansas River within the City of Pueblo, downstream of Pueblo Reservoir. In addition, Colorado Springs has acquired a significant amount of irrigation rights from the lower Arkansas River. Colorado Springs is examining several storage and pipeline options for regulating and delivering its reusable return flows and irrigation rights to its service area for municipal use, either by exchange to its existing points of diversion in the upper Arkansas or by direct pipeline delivery. In addition to the storage options preliminarily selected in the PSOP, Colorado Springs is considering a new water delivery pipeline from Pueblo Reservoir to its service area, as well as new on-stream storage reservoirs in the Upper Arkansas basin. In the long term, a pump-back facility from Ruedi Reservoir into the upper Arkansas River may be considered.

The City of Aurora has acquired major portions of the irrigation rights associated with the Rocky Ford Ditch and Colorado Canal. Aurora is examining several storage and pipeline options for maximizing the delivery of that water to its service area, either by upstream exchange to its existing point of diversion at the Otero Pump Station or by direct pipeline delivery. Aurora is considering new gravel pit storage below Fountain Creek, new reservoirs in the lower and upper Arkansas, and new pipelines directly from the Arkansas River to Aurora. So far, Aurora's water supply needs and planning efforts have not been included in or coordinated with the Southeastern

District's Preferred Storage Options Plan process, because Aurora has been considered an "outside" from in-basin water users' perspectives.

2. South Platte Basin

Water providers in the South Platte basin are currently pursuing a wide range of water supply development options that reflect the varying circumstances in each portion of the basin. To simplify the description of these options we have divided the basin into southern, central and northern portions.

a) South Platte Basin - Southern Portion

In the southern metro Denver area, Douglas County water providers are working with Denver Water and the Colorado River Water Conservation District to develop a regional conjunctive use project. The project would incorporate new storage (aquifer recharge and off-channel reservoirs), water reuse, and water conservation into a sustainable water supply future for Douglas County and a back-up drought year groundwater supply for Denver Water. The project would recharge Denver Basin aquifers beneath Douglas County with unappropriated water from the South Platte and Blue River basins. It would include a system of alluvial wells, small regulating reservoirs and enhanced treatment facilities to reuse fully Douglas County providers' reusable return flows. It would also feature enhanced water conservation measures designed to reduce the consumptive use of municipal water in Douglas County, thereby decreasing the region's depletion of groundwater. Capture of unappropriated South Platte and Blue River waters would be accomplished by more intensive operation of Denver's existing reservoirs coupled with back-up groundwater supply for Denver.

Individual providers in the south metro Denver area are also pursuing a variety of storage and pipeline projects. Parker Water & Sanitation District is planning to build Rueter Hess Reservoir, a 15,000 acre-foot off channel reservoir on Newlin Gulch, located southwest of Parker. The Rueter Hess project would be used to capture and blend Parker's reusable return flows with storable flows from Cherry Creek for potable use within Parker. The East Cherry Creek Water & Sanitation District is planning to build two raw water pipelines to deliver recently acquired groundwater rights and contract rights from Denver Water. Other nearby providers may join in this pipeline. East Cherry Creek is also working with Aurora, Cottonwood Water & Sanitation District and Arapahoe County Water & Wastewater Authority to implement the Upper Cherry Creek Water Management Project, a regional augmentation plan designed to increase the yield and reliability of the participants' alluvial wells in Cherry Creek upstream of Cherry Creek Reservoir. Centennial Water & Sanitation District is finishing the construction of its 6,000 acre-foot South Platte Reservoir, a gravel pit storage facility that will optimize the district's reuse and exchange rights and allow for capture of South Platte runoff. Several other Douglas County providers are pursuing similar small-scale projects.

A few providers and political interests in Douglas and Arapahoe Counties are actively pursuing a new transbasin diversion project from the Gunnison River basin, although no specific projects are currently being proposed.

b) South Platte Basin – Central Portion

Projects currently under development in the central portion of the basin include a wide range of facilities and operating agreements centered around water reuse and exchanges, alternate points of diversion and coordinated facilities operations. Denver Water and Aurora are examining the synergistic potential of a joint use project involving Antero Reservoir. Denver's water supply yield from Antero is relatively small because of the reservoir's small physical supply and its junior water rights. However, Aurora's imports from the Colorado and Arkansas Rivers, which are potentially quite large and vary considerably from year to year, can be delivered into Antero Reservoir and storage there would significantly enhance their yields. Aurora is also actively pursuing a conjunctive use storage project involving surface storage and aquifer storage in the upper South Platte basin.

Over 90% of Aurora's existing water supply is reusable because it comes from transbasin or nontributary groundwater sources or has been changed from in-basin irrigation use on a fully consumable basis. Most of Aurora's return flows accrue to the South Platte River at the Metro Wastewater Plant downstream of Denver and the exchange potential available to Aurora from this location to Aurora's existing upstream points of diversion is very limited. Aurora is therefore examining options for capturing and re-regulating its reusable return flows downstream of Denver and delivering these supplies to its service area for nonpotable and potable uses. Some of these options may involve water trades with Burlington Ditch and Barr Lake shareholders.

Aurora is also moving toward development of the Denver Basin groundwater resources located beneath its service area. While the natural recharge of this groundwater source is limited, it is unimpaired by surface water droughts and therefore represents excellent drought year insurance.

Denver Water is actively pursuing several projects within the South Platte basin including its nonpotable reuse project, its "North End" project, a Chatfield delivery project and development of Denver Basin groundwater. Denver's nonpotable reuse project will utilize over 17,000 acre-feet of Denver's reusable return flows to provide a nonpotable water supply to industrial, commercial and municipal irrigation uses in the northeast portion of Denver's service area, including the Cherokee power plant and water uses associated with DIA development and Stapleton redevelopment. Denver is also in the process of adjudicating the reusable portion of its lawn irrigation return flows to increase its legally reusable supplies. Over the longer term, Denver is considering several potable water supply projects that would more fully utilize Denver's reusable return flows. This would probably involve a regional advanced water treatment facility that would serve the combined needs of several northeast metro Denver area providers.

Denver's "North End" project is designed to address raw water delivery needs associated with its Moffat collection system. Denver currently has raw water delivery obligations associated with its Moffat facilities that exceed Denver's divertible North End supply in severe drought periods. It is considering an enlargement of Gross Reservoir and/or a new reservoir at Leyden Gulch to address this problem. This additional storage capacity would allow Denver to increase its Moffat collection system diversions in wet years. Other options under consideration include an indirect potable water supply from Metro to Denver's Ralston Reservoir that would utilize some of

Denver's excess reusable return flows, and treated water or raw water pipelines from Denver's southern system. Denver may allow participation by other East and West Slope providers in its North End project in order to address water supply and instream flow deficiencies in the Fraser River and Boulder Creek basins.

Denver is also planning to develop a pump and pipeline facility from Chatfield Reservoir to its existing raw water conduits. This project would allow Denver to make better use of its existing water rights and storage pool in Chatfield. The Corps of Engineers and the CWCB are also completing a study that could allocate as much as 20,600 acre-feet of existing Chatfield flood control storage to municipal water supply purposes. (Currently, Denver Water has 10,785 acre-feet of water supply storage in Chatfield.) Denver is also doing a feasibility study of developing the Denver Basin groundwater beneath its service area as a back-up drought year supply. Other providers in the central South Platte region are actively pursuing a range of storage projects and reuse projects including Consolidated Mutual's Fortune Reservoir, enlargement of Standley Lake, Clear Creek and South Platte gravel pit storage, and nonpotable reuse projects in the Big Dry Creek basin.

c) South Platte Basin – Northern Portion

A wide range of major storage development efforts are being considered in the Northern Front Range, centered around five goals: firming up the yield of the Windy Gap transbasin diversion project, capturing excess return flows in the South Platte below Greeley, regulating acquired irrigation rights for year-round municipal use, facilitating exchanges and capturing unappropriated peak flows.

Potential projects under consideration for these purposes include enlargements of Halligan and Seaman Reservoirs on the North Fork of the Poudre; new off-channel reservoirs adjacent to Carter Lake (Chimney Hollow), south of Livermore (Glade Reservoir), north of Greeley (Lonetree Creek), and between Granby and Willow Creek Reservoirs on the West Slope (Jasper North); new mainstem dams on the Poudre and the Little Thompson Rivers; and new gravel pit reservoirs along the Poudre. Most of these projects are being considered in various combinations as part of the Northern Colorado Water Conservancy District's Windy Gap Firming Project, its Northern Integrated Supply Project and its South Platte Water Conservation Project. Some options are being pursued by individual providers.

In addition to developing new storage, northern Front Range providers continue to acquire South Platte irrigation rights and CBT shares, develop water exchange and reuse projects, and construct new raw water delivery pipelines to assure year-round water availability from CBT reservoirs and to protect source water quality. Examples include the proposed Pleasant Valley Pipeline which would run between Horsetooth Reservoir and the Munroe Canal, Lafayette's 75th Street delivery pipeline from Boulder Creek, Broomfield's development of nonpotable reuse capabilities in its developing service area, and a potential new pipeline from Carter Lake to Boulder Reservoir designed to avoid potential water quality problems at the Boulder Reservoir water treatment plant.

3. Colorado River Basin

a) Colorado River Mainstem

There has been a range of modest water supply development activities, including reservoir development, ongoing in the Colorado River mainstem basin. The water rights and augmentation aspects of in-basin water supply needs for Summit and Grand Counties have been largely addressed by the Summit County and the Clinton Gulch Reservoir Agreements and the Green Mountain Reservoir Operating Policy and contracting agreements. Remaining problems in the basin are primarily related to physical flow shortages during critical fall and winter season low flow periods. The Upper Colorado River Basin study has identified remaining needs in the two counties related to in-basin water supply, instream flow deficits and desired recreational reservoir levels along with conceptual solutions for each of these issues.

In Summit County, physical shortages in the Snake River basin can be addressed by pumping water from the Montezuma drop shaft of the Roberts Tunnel. Physical shortages in the Blue River basin can be addressed through water rights administration agreements between Denver Water and Colorado Springs. Physical shortages in the Ten Mile Creek basin can be addressed through additional acquisition and redevelopment of water rights and facilities related to the Climax Mine.

In Grand County, physical shortages can be addressed by Grand County participation in Denver's North End project, which would allow Denver to increase water deliveries from its Moffat Tunnel collection system to the Fraser River basin without loss of yield to its system. The Town of Kremmling is addressing its water supply problems by developing its conditional water rights for diverting water directly from the Colorado River. Related to the CBT system, Windy Gap participants are investigating reservoir options for firming the yield of the Windy Gap project. One of the options being considered is a proposed off-stream Jasper North Reservoir, which would be located north of Willow Creek between Willow Creek Reservoir and Granby Reservoir.

In-basin water users in Eagle County are actively planning to address their future water supply and instream flow needs through a combination of small scale upper system reservoir development, consolidation of water supply systems and purchase of augmentation supplies from Green Mountain Reservoir. Any remaining in-basin supply needs are likely to be addressed through development of a cooperative project with the City of Aurora and the Climax Mine, which has been the principal focus of the Eagle River Assembly (an ad hoc group of water interests from the Eagle River Valley and the cities of Aurora and Colorado Springs).

Other water development activities in the Colorado River mainstem basin have been primarily focused on augmenting the flow of the Colorado River through the 15-mile reach of critical habitat for endangered fish species near Grand Junction.

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VI. An Integrated Approach to Meet Colorado's Future Water Demands and Drought Management Needs

This section outlines our view of the three elements of Colorado's water future: 1) conservation and demand management; 2) municipal-agricultural cooperation; and 3) supply integration, management, and development. However, we first discuss the cost range estimates for a variety of water management options. We conclude this section by presenting the concept of an annual water supply reliability report, an accounting to customers on the status of utilities' systems current and expected future performance.

A. Range of Costs for a Variety of Water Management Options

Cost effectiveness, defined in terms of dollars per acre-foot of reliable yield, is an important consideration in water supply development and water demand management. The costs associated with various water supply development options and water conservation measures can range from less than $1,000 to over $20,000 per acre-foot of yield. While the cost effectiveness of a given supply project or demand management strategy will be influenced by project-specific and utility-specific factors, some general observations can be made regarding the relative cost effectiveness of different types of options. Denver Water, as part of its Integrated Resource Planning process, developed preliminary cost estimates for a wide range of demand management and supply development options that it is considering (see Table VI.1). These estimates may or may not be representative of these options in other settings, but they are illustrative of costs that water users face. The costs do not incorporate all mitigation and they do not reflect the financial benefits of phasing that are associated with small projects. For the most part, the low end of the range in each category represents the costs associated with the proposals we advance below.

Table VI.1. The Range of Cost Estimates for a Variety of Water Management Options (from Denver Water IRP)

Type of Project	Cost Range, $ per Acre-Foot of Yield
Water Conservation	$4 to $8,000
Acquisition/Change of Irrigation Rights	$700 to $12,000
System Refinements	$700 to $16,000
Reservoir Enlargement	$1,400 to $10,000
Exchange/Augmentation	$4,600 to $10,200
Conjunctive Use	$7,400
Nonpotable Reuse	$8,000
New Transbasin Diversions	$4,300 to $11,700
New Reservoirs	$5,300 to $19,500
Indirect Potable Reuse	$14,000 to $16,000

B. Conservation and Demand Management

Water users have increasingly incorporated demand management into their water supply strategies. Nearly all cities now require the use of water meters and most large and medium-sized cities have adopted water conservation-based water rate structures, promote the installation of water-efficient appliances, fixtures and landscaping, and provide a wide range of education and guidance on efficient water use to their customers. Farmers increasingly employ a range of more efficient irrigation techniques such as surge valves and low-pressure sprinklers and benefit from irrigation scheduling information programs provided by conservancy districts and agricultural extension services.

Demand management is undoubtedly the best strategy for responding to drought. With proper planning, municipal water demands can be reduced quickly, flexibly and with relatively low cost in response to drought through the use of watering restriction programs and appropriate water rate structures coupled with focused public information programs. In 2002, Colorado cities and towns reduced their normal water demand by an average of about 10% or 100,000 acre-feet. Municipal demand reduction responses in 2002 allowed cities to cope with an extraordinary drought while sustaining only relatively minor, temporary damages and without having to invest billions of dollars in new supply projects.

Despite the commitment that some Colorado municipalities have made to increase end-use efficiency, there is still a great potential for doing more. For example, the Metropolitan Water Supply Investigation (Final Report) contains population projections ("build-out" or 2040) and water demand estimates that imply per capita use along the Front Range of 235 gallons per capita per day (gcd). A reduction of this figure to 200 gcd or even 190 gcd (still very reasonable and achievable, see Smart Water report) translates into between 168,000 acre-feet and 215,000 acre-feet of demand reduction. Applied to the state as a whole, municipal demand reduction alone could exceed 250,000 acre-feet.

Any reasonable conservation program should contain three primary features: 1) a multi-tiered price structure [at least three tiers that account for indoor, outdoor, and excessive outdoor levels]; 2) water use education; 3) incentives to purchase and replace inefficient water use devices [see AWWA article on indoor water use savings potential] and to invest in lower water use landscaping. In Colorado, this translates into programs of:

- The thorough integration of demand management into future planning and supply development;
- Universal ascending three-tiered pricing structures;
- Point-of-sale and point-of-rental-license-renewal requirements (with appropriate monetary incentives) for installation and inspection of ULV toilets, faucets, showerheads, washing machines and dishwashers; inspection and correction of leaks between meter and building;
- Minimum topsoil and organic matter content requirements for lawn installation or renewal, moisture sensor overrides on automatic sprinklers;
- Provision of real-time meter reading capability for individual customers;

- Treated water distribution system standard of no more than 5% leaks/unaccounted losses between the treatment plan and the faucet (inclusive of customers' laterals); 15-year timeline for achievement, supported by CWCB loan money, for small systems;
- Maximum irrigated lawn sizes or a tap fee surcharge for larger lawns; and
- Xeriscape promotion programs (e.g., tap fee rebate for Xeriscape).

C. Municipal-Agricultural Cooperation

Given the existing physical links between municipal and agricultural water supply systems, the potential for enhancing those links, and the relative value of water in municipal and agricultural uses, some movement of water from irrigation to households and industries is inevitable. The challenge is one of protecting agricultural interests and rural economies while at the same time making it possible for those who own agricultural water rights to enjoy some of the benefits of allowing their water to be used, from time to time, in higher value applications.

Resistance to agricultural-municipal transfers is usually based on the conventional view (that water is the *sine qua non* of a region's economy) and, thus, that removing water from agriculture would have significant negative economic effects. In fact, there is little evidence to support this hypothesis. In the sectors losing water (generally forage, and food and feed grain production), the net economic value foregone for a 10 to 20 percent supply reduction will usually fall in the range of $5 to $30 per acre-foot. On the other hand, the gain in net value of product or in a municipality's willingness to pay is likely to be at least five to ten times as high. Indirect impacts, measured by income from primary regional resources ("value added") and by employment per unit of water (including multiplier effects), indicate that these secondary losses associated with transferring water from agriculture, while not insignificant in terms of either income flows or employment, are dwarfed by the gains in nonagricultural sectors. In particular, the sectors most likely to be affected (again, forage, and food and feed grains) yield relatively small indirect employment and income effects (per dollar of income) when compared to those for emerging urban sectors.

The economic interests of farmers whose water is transferred to urban uses are generally protected by existing state institutions, but transaction costs may be high and decisions binary, i.e., water is sold or not sold. More flexible and imaginative alternatives are needed, including agricultural-municipal drought insurance (an annual premium payment by cities to farmers for the right to call out the irrigators in very dry years) or the right to move conserved irrigation water to municipal uses. Given the relative amounts of water allocated to irrigation and municipal use, making 10% of agricultural supplies available to urban users (at fair prices) under drought leasing arrangements could increase firm urban supplies by as much as 25% or more.

D. Supply Integration, Management and Development

All supply options should honor the five basic principles identified in Section I.D. Many of the ongoing development activities described below (and some described in Section V as well) do. They are organized by sub-basin and include observations, recommendations and caveats associated with their relative merits.

It should be noted that the following discussion addresses the merits of projects on a conceptual level only. Virtually all new water supply development projects will have some level of project-specific environmental and recreational impacts. Identification or discussion of such project-specific impacts is beyond the scope of this document, but we assume that all projects will meet the conditions of the Platte River Cooperative Agreement and the Colorado River Recovery Implementation Program.

1. Arkansas Basin

There are several commendable aspects to the Preferred Storage Options Plan (PSOP) process in the Arkansas basin, as conducted by the Southeastern Colorado Water Conservancy District and water users within the District. From an in-basin perspective, the process has been open and inclusive, it has taken into account the effects of some level of water conservation, and its analysis of structural alternatives has generally been sensitive to environmental, recreational and agricultural values. The storage options that have emerged from the process are focused on re-operation of existing Frying Pan-Arkansas project reservoirs and enlargement of Pueblo Reservoir rather than construction of new reservoirs.

However, the total identified storage need of 122,000 acre-feet appears to be significantly overstated for several reasons. First and foremost, this amount of storage need is based on growth projections and associated water demands that were described in the PSOP itself as "high" and "optimistic" even in the context of the late 1990's economic boom when they were made. No analysis was made of storage need based on more realistic projections, and it is likely that a realistic storage need would be much smaller. Second, 15,000 acre-feet of this total 122,000 acre-foot amount is earmarked for meeting a mixture of agricultural needs and facilitating interruptible supply arrangements between farmers and cities. The agricultural need-based portion of this 15,000 acre-feet storage volume is questionable on economic grounds, while the municipal portion appears to be duplicative of cities' individual storage needs, which comprise the remaining 97,000 acre-feet. Third, the PSOP modeling analysis did not justify 29,000 acre-feet of the 97,000 acre-feet of the new storage individual cities claim to need. Thus, almost one quarter of the 'need' warrants further scrutiny. Finally, the PSOP should be expanded to incorporate Aurora's need to maximize the delivery of its already acquired Arkansas basin irrigation rights to its service area. While Aurora may be seen as an "outsider" from the Arkansas basin's internal perspective, this view does not justify the risk of increased expenditure of public resources to build duplicative facilities.

Additional transfers of water from agriculture to cities are likely to continue given the large disparity between the values of water for agricultural versus M&I use, and the increased financial pressures placed upon both sectors. However, additional transfers should focus on cooperative arrangements with farmers and farming communities that reasonably mitigate local economic impacts, even in the case of outright acquisitions.

2. South Platte Basin – Southern Portion

It is clear that the southern portion of the metro Denver area should not grow in population from 200,000 to over 600,000 while continuing to rely almost exclusively on groundwater pumped

locally from the Denver Basin aquifers. This future scenario is ultimately unsustainable, only the date of its economic demise is uncertain.

The regional conjunctive use water supply plan currently being considered in the South Metro Water Supply Study as described in Section V is a conceptually sound and sustainable option that should be pursued aggressively. It combines the components of renewable surface water supply, aquifer recharge and recovery, a reduced level of groundwater pumping, complete reuse of legally reusable return flows, and water conservation to develop a sustainable water future for the region. New surface water developed by such a project should be captured using existing on-stream reservoirs, with small amounts of additional off-channel surface storage development to help regulate return flows. A key feature of this plan will be the capture of unappropriated surface water using Denver's existing reservoirs (Dillon and Cheesman). This aspect of the project should be developed with sensitivity to in-stream environmental and recreational values and reservoir recreational levels.

The conceptual basis of the project should be expanded to feature Denver Basin groundwater as a dry-year supply not just for Douglas County but for Denver Water and the West Slope as well. With respect to this latter feature, in dry years groundwater could be delivered to Denver in trade for Denver increasing its bypasses at critical West Slope locations or decreasing its draw-down of Dillon Reservoir.

Maximizing the region's reuse potential will require continued efforts in protecting the water quality of Cherry Creek and Plum Creek and their alluvial aquifers, as alluvial well development within these surface water sources will play a prominent role in achieving full reuse. A relatively small amount of new surface water storage may be needed for seasonal re-regulation of return flows, along with regional advanced water treatment and distribution facilities. The water conservation component of the project should focus on reducing outdoor demands. This will increase the overall yield of the project by reducing municipal consumptive use and thus increasing the supply of reusable return flows. All of the small-scale projects currently being pursued by individual providers in the region, as described in Section IV, appear to be worthwhile and consistent with the regional conjunctive use water supply plan being developed by the South Metro Water Supply Study.

3. South Platte Basin – Central Portion

Most of the projects currently being pursued in the central portion of the South Platte basin, as described in Section IV, appear to be sound and worthwhile ideas. Denver and Aurora's cooperative use of Antero Reservoir makes sense given Aurora's relatively more plentiful wet year supplies from the Colorado and Arkansas basins that could be stored in Antero. Denver and Aurora's interests in developing the Denver Basin groundwater underlying their respective service areas as an infrequently pumped drought year supply, rather than as a base supply, represents a wise approach to utilizing this groundwater source. Aquifer recharge should probably be incorporated into these plans.

If the Corps of Engineers can allocate some of Chatfield Reservoir's existing flood control pool to water supply purposes without significantly increasing the flood risks, it could provide a major water supply benefit to several water providers in the region. Construction of additional

diversion capability from Chatfield directly into local water supply systems would also be beneficial. However, the potential impacts of increased water supply use of Chatfield upon wetlands, recreation and fisheries in the reservoir could be very significant. Any storage reallocation or new diversion facilities should occur only if Denver and the Corps can protect these values.

With regard to Denver's North End system improvements to increase dry year supply, Denver is examining storage and nonstorage options and intends to begin the permitting process without specifying a preferred option. Ultimately Denver should proceed in a manner that addresses Fraser River basin water supply and instream flow problems as well as Front Range instream flow problems in cooperation with local water users in each of these basins.

Possibly the region's largest untapped long-term water supply source is water reuse. By the year 2040, water providers in the central South Platte region are projected to generate over 120,000 acre-feet per year of reusable return flows in excess of current reuse plans. This represents an enormous water supply source, given its potential to be reused up to three times. Full use of this water supply source (as required in Denver's case by the Blue River Decrees) will eventually require additional storage below the Metro wastewater plant and expensive water treatment requirements. Opportunities exist to realize both of these goals in cooperation with agricultural interests in the Barr Lake and Beebe Draw areas north of Denver.

4. South Platte Basin – Northern Portion

One must preface any discussion of water development in the northern Front Range by noting that over 800,000 acres of irrigated agriculture currently remain in this region. While urban populations see irrigated agriculture as an open space amenity, it appears to have equal or greater value as a relatively inexpensive water supply source to water providers. Consequently, while water providers have proposed a variety of water storage projects in the region, large acquisitions and transfers of irrigation water supplies to municipal use are actually occurring.

Nonetheless, there are reasons that justify some new projects. For example, firming up the yield of the recently constructed Windy Gap project would realize the value of the original investments made by Windy Gap project participants. Windy Gap water is also legally reusable on the East Slope, which can effectively double or triple its yield via exchange and reuse plans. Finally, firming up Windy Gap's yield would ease the pressure for further acquisition of South Platte irrigation rights.

The South Platte Conservation Project has the important advantage of being able to be developed in incremental fashion, which would minimize the financial risks of overbuilding ahead of growth in M&I demands. It would also help develop Colorado's South Platte compact entitlement without causing major problems for Platte River endangered species. In the context of firming senior irrigation water rights for year-round municipal use it may prove to be a reasonable investment, unlike storage designed to capture unappropriated water, the result of which is very high storage to yield ratios and enormous costs.

Regarding the specific storage options being considered for these purposes, the enlargement of Halligan Reservoir and new off-channel storage proposed at Chimney Rock and at Jasper North

seem to have the fewest adverse impacts. Seaman Reservoir enlargement would likely encounter problems with the endangered Preble's mouse, as would Glade Park, which would also require the relocation of U.S. Highway 287. Most of the pipeline projects being proposed in the Northern region are conceptually valid mechanisms for better integrating the operations of existing water supply systems.

While most of these structural projects have some merit, their ultimate implementation will be continually tempered by the ever-present alternative of acquiring irrigation supplies, many of which include already-developed storage and provide substantial "up-front' yield without building additional storage. As noted above, continued transfer of irrigation water to M&I uses should be done in an orderly and sensitive manner.

5. Colorado River Basin

a) Upper Colorado River Mainstem and Fraser River

In the Upper Colorado River basin, most of the growth in water demand is expected to occur in the Fraser River basin and in areas around Grand Lake. Water supply augmentation sources for water users in Grand County include Clinton Gulch Reservoir, Green Mountain Reservoir, Muddy Creek Reservoir and Windy Gap exchange water. Remaining water supply problems in the basin are primarily related to physical flow shortages during critical fall and winter season low flow periods in the Upper Fraser River basin and low flows on the Colorado mainstem below Windy Gap.

Physical shortages in the Fraser River basin can be addressed by Grand County participation in Denver's North End project, which would allow Denver to increase water deliveries from its Moffat Tunnel collection system to the Fraser River basin without loss of yield to its system. The Town of Kremmling is addressing its water supply problems by developing its conditional water rights for diverting water directly from the Colorado River.

b) Blue River Basin

In the Blue River Basin, the largest growth in water demands is expected to occur in population centers associated with the Summit County ski areas and in communities around Dillon Reservoir. Most of these communities have water rights and augmentation plans that are sufficient to meet projected build-out. However, potential shortages have been identified for several areas in the Snake River, Upper Blue River and Tenmile Creek drainages, primarily during the fall and winter months, due to insufficient physical supply.

In the Snake River basin, it is possible to meet most of the shortfall by pumping water from the Montezuma drop shaft of the Roberts Tunnel. Water rights administration agreements between Denver Water and Colorado Springs be able to address the physical shortages in the Upper Blue River basin. Additional acquisition and redevelopment of water rights and facilities related to the Climax Mine can address physical shortages in the Ten Mile Creek basin. None of these cooperative projects requires significant construction outlays.

c) Eagle River Basin

Through a Memorandum of Understanding (MOU) with Colorado Springs, Aurora, the Vail Consortium, Climax Mine and the Colorado River Water Conservation District, the Eagle River Assembly is exploring cooperative projects that could serve in-basin and out-of-basin needs. The MOU establishes a 20,000 acre-feet cap on the amount of water that Aurora and Colorado Springs can divert out of the basin in exchange for those cities' agreement to abandon the Homestake II Project. The MOU also provides for an additional 10,000 acre-feet of water, which should be sufficient to meet in-basin buildout water supply and environmental needs.

The most promising water development options for the Eagle River basin involve the possible enlargement of Eagle Park Reservoir, water rights available from the Climax Mine, and a conjunctive use project at Camp Hale with a pumpback system to Eagle Park Reservoir.

Denver Water has been exploring options for participation in the Eagle River Assembly and possible modification of the MOU to address Denver's conditional water rights for the Eagle-Piney and Eagle-Colorado Projects. One of the options under discussion would allow Denver Water to receive a firm yield of 5,000 acre-feet delivered to Dillon Reservoir from the Climax Mine via Tenmile Creek.

E. Annual Water Supply Reliability Report

One beneficial aspect of the 2002 drought was that it heightened public awareness about the importance of water resources in this semi-arid region and our potential vulnerability to drought. Unfortunately, many water consumers were caught by surprise when their providers imposed outdoor water use restrictions and surcharges to conserve water resources. Drought-related impacts on consumers were much more severe in some communities than others. For example, the water supply system for the Town of Beulah failed completely and its residents were forced to truck in all of the water necessary to meet their needs, while in other communities water providers imposed no water use restrictions.

Water utilities need to have a great deal of flexibility in determining how to meet their current and future water demands because of the wide variety of growth pressures and circumstances that affect the availability of water between different locations around the state. It is thus reasonable to expect that drought will affect some water systems and their customers more severely than others. Given these uncertainties, it seems appropriate that water consumers have good information about the reliability of the water supply systems on which their homes and businesses depend. It is also important that water consumers be informed about the risks of drought-related water use restrictions and increased costs of service that may result from service of new growth by their water utilities and the actions for which existing consumers will be responsible when droughts occur.

Whatever course of action water utilities choose in making future management decisions, they should all be required to report to their customers on the reliability of their systems with respect to drought. Under the requirements of the Safe Drinking Water Act, communities are required to provide a Consumer Confidence Report annually to their customers with information about drinking water quality. The Colorado legislature should require that water providers issue a

similar type of annual report to inform citizens about the reliability of their water supply systems, the drought and growth-related risk factors that may affect the reliability their water supplies, and the measures that would be implemented in response to drought. Such a report should provide the following types of information:

- A summary description of the existing water supply system including water supply sources; diversion, collection, storage and treatment facilities; water rights and water supplies secured by contracts or leases.
- An assessment of the long-term sustainability of the existing water supply system (water supply sources and facilities) and the risk factors that could impact sustainability and the cost of service.
- The utility's drought response plan, including circumstances under which water use restrictions could be imposed, the specific types of water use restrictions, and the likely magnitude and recurrence interval of such restrictions given the existing water supply system and existing water demands (including water service contract obligations).
- The status of planning efforts to provide for growth including proposed new water supply sources, water conservation and efficiency measures.
- An assessment of the frequency and extent of drought-related water restrictions that would occur considering planned-for growth in water demand, proposed demand management measures and reasonably certain future water supplies.
- A disclosure of who makes land use and annexation decisions for the utility's water supply service area.

The availability of this information to water consumers would serve to educate the public about importance of water and circumstances that could impact the reliability of their water supply.

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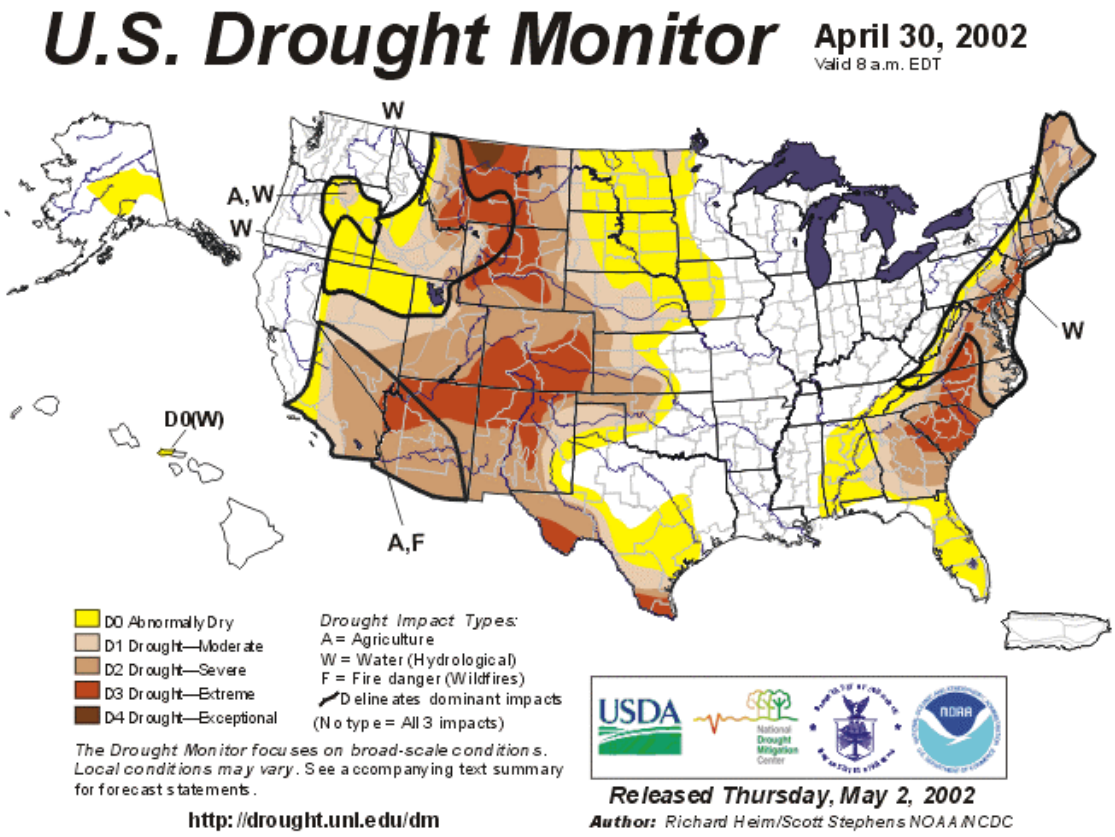
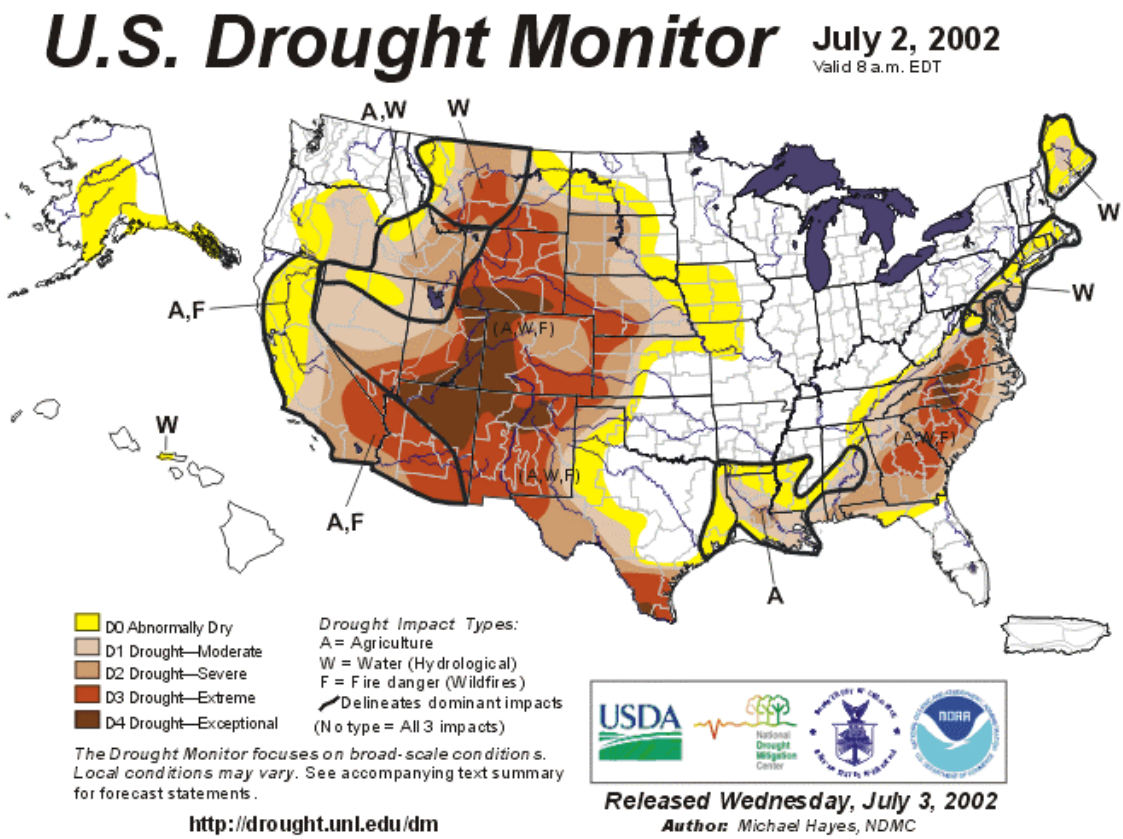
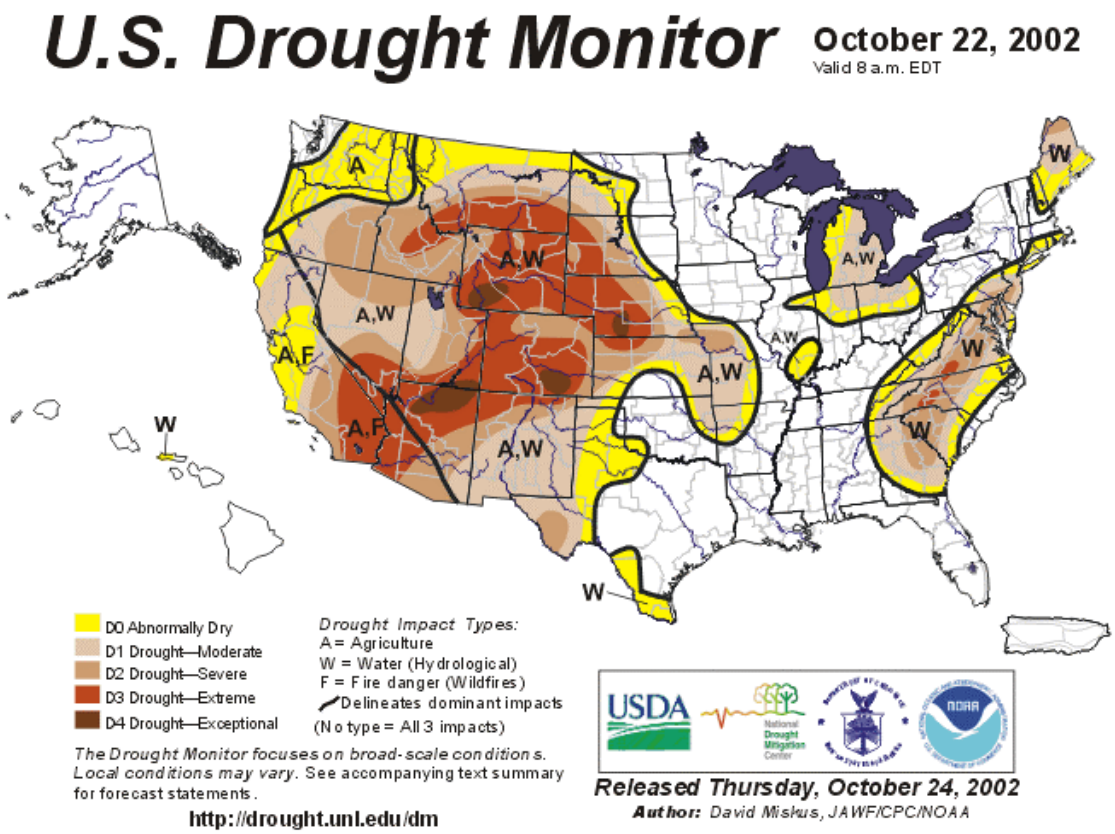
APPENDIX A

DROUGHT CONDITIONS IN SPRING, SUMMER, AND FALL AND FORECAST FOR NEAR FUTURE

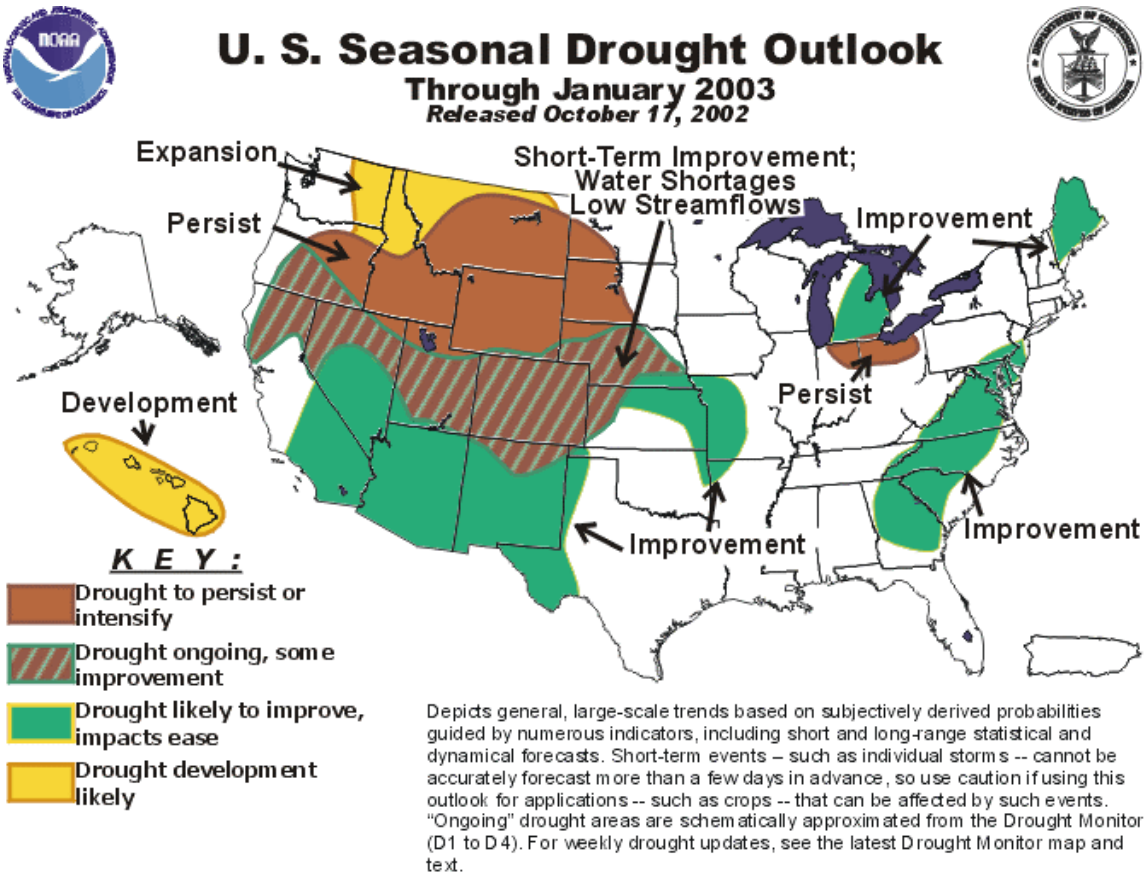
The several maps below use a graphic representation of the drought situation in Colorado between late April and October of 2002. In the Spring all of Colorado was in a condition of severe to extreme drought. The most extreme conditions were in the southern half of the state in the Arkansas, Rio Grande, and San Juan basins, though these conditions did reach into the South Platte on the east and the Colorado mainstem and Gunnison in the west.




U.S. Drought Monitor
July 2, 2002
Valid 8 a.m. EDT
A,W
W
A,F
W
(A,W,F)
(A,W,F)
(A,W,F)
W
W
A,F
A
D0 Abnormally Dry
D1 Drought—Moderate
D2 Drought—Severe
D3 Drought—Extreme
D4 Drought—Exceptional
Drought Impact Types:
A = Agriculture
W = Water (Hydrological)
F = Fire danger (Wildfires)
Delineates dominant impacts
(No type = All 3 impacts)
The Drought Monitor focuses on broad-scale conditions. Local conditions may vary. See accompanying text summary for forecast statements.
http://drought.unl.edu/dm
USDA
Released Wednesday, July 3, 2002
Author: Michael Hayes, NDMC



These conditions intensified by July and in the western part of the state the drought was rated as exceptional in all parts of the Colorado basin. In the east, conditions remained severe to extreme. By October, there was some let up in the west, but the extreme conditions still covered more than three-quarters of the state. The outlook for the state is for continued drought, but with some reduction in intensity. The outlook for Colorado puts the state in the band between worsening conditions to the north and substantial improvement to the south.

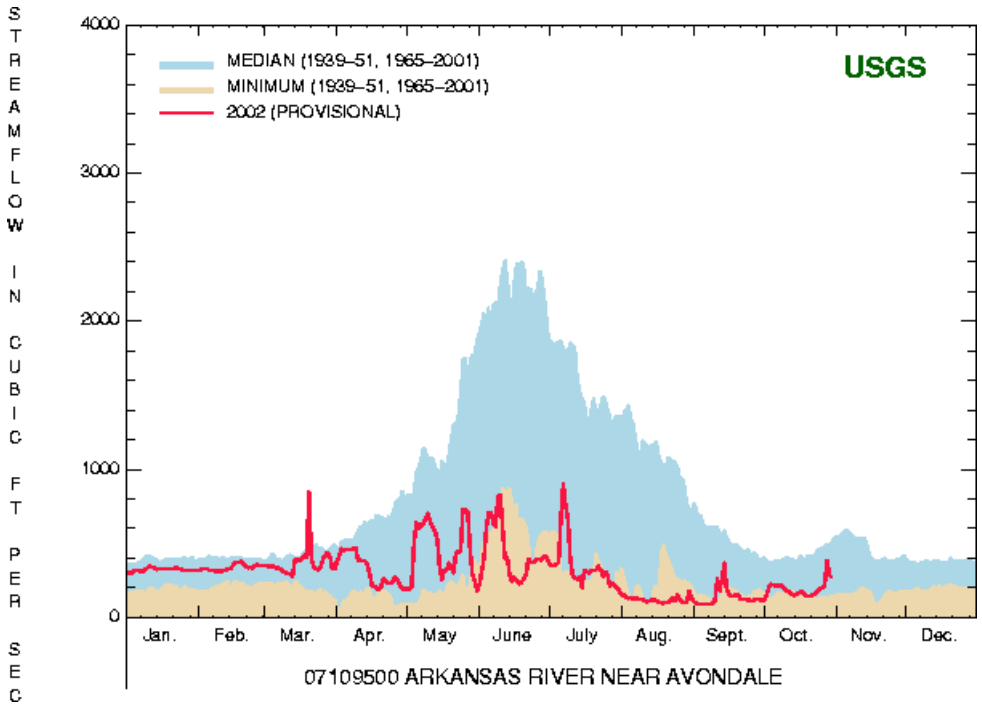


Depicts general, large-scale trends based on subjectively derived probabilities guided by numerous indicators, including short and long-range statistical and dynamical forecasts. Short-term events – such as individual storms -- cannot be accurately forecast more than a few days in advance, so use caution if using this outlook for applications -- such as crops -- that can be affected by such events. "Ongoing" drought areas are schematically approximated from the Drought Monitor (D1 to D4). For weekly drought updates, see the latest Drought Monitor map and text.

APPENDIX B

AN EXAMPLE OF COMPARATIVE HYDROGRAPHS FROM THE ARKANSAS RIVER

Basin by basin the circumstances were very poor. The figure below offers an example from the Arkansas. The figure contains the median flows (blue), a constructed hydrograph of the previous low flows for all the years of record (tan), and provisional estimates flow the 2002 flows (red). By almost any measure, 2002 is the record low flow year. Similar figures for other stations around the state show conditions that are very much like these.



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APPENDIX C

CAPACITY OF ALL STORAGE RESERVOIRS IN COLORADO AND THEIR PRIMARY USE

RESERVOIR CAPACITY IN COLORADO

TOTAL CAPACITY (acre-feet) 7508500 M&I CAPACITY 1982690 26%

Name	Capacity	Basin	Complete Project/Owner	M&I
Eleven Mile Canyon	98000	1	Denver Water	98000
Horsetooth	152000	1	CBT	80560
Cheesman	79000	1	Denver Water	79000
Carter	112000	1	CBT	59360
Spinney Mountain	54000	1	Aurora	54000
Misc Poudre	250000	1		50000
Standley	43000	1		43000
Gross	42000	1	Denver Water	42000
Misc. Big T	180000	1		36000
Aurora	32000	1	Aurora	32000
Chatfield	27000	1		27000
Antero	26000	1	Denver Water	26000
Marston	20000	1	Denver Water	20000
Misc Boulder	94000	1		18800
Button Rock	16000	1		16000
Ralston	16000	1	Denver Water	16000
Misc St. Vrain	65000	1		13000
Arvada	8000	1		8000
Fortune	7000	1		7000
McLellan	5000	1		5000
Cherry Creek	13000	1		2600
North Sterling	75000	1		
Riverside	65000	1		
Thornton Gravel Lakes	12000	1		12000
Empire	38000	1		

Name	Capacity	Basin	Complete Project/Owner	M&I
Jackson	36000	1		
Barr	32000	1		6400
Julesburg	32000	1		
Milton	30000	1		
Prewitt	29000	1		
Horse Creek	19000	1		
Duck/Altura	1000	1		
Pueblo	358000	2		118140
Twin Lakes	141000	2	Aurora	70500
Turquoise	129000	2	Aurora	64500
John Martin	603000	2		
Great Plains	266000	2		
Trinidad	120000	2		12000
Adobe Creek	71000	2		
Cuchara Valley	41000	2		
Lake Meredith	40000	2		
Horse Creek	28000	2		
Clear Creek	12000	2		
Mt. Elbert Forebay	12000	2		
Lake Henry	10000	2		
St. Charles	9000	2		
Dye	6000	2		
Holbrook	5000	2		
Brush Hollow	4000	2		
Deweese-Dye	2000	2		
Mt. Pisgagh	2000	2		
Sanchez	103000	3		
Platoro	60000	3		
Rio Grande	52000	3		
Santa Maria	44000	3		
Continental	23000	3		
Mountain Home	17000	3		
Terrace	15000	3		
La Jara	14000	3		

Name	Capacity	Basin	Complete Project/Owner	M&I
Smith	6000	3		
Beaver Park	5000	3		
Eastdale No. 1	3000	3		
Eastdale No. 2	3000	3		
Big Meadows	2000	3		
Head Lake	2000	3		
Blue Mesa	941000	4		
Morrow Point	117000	4		
Taylor Park	106000	4		
Ridgeway	94000	4		
Crystal	26000	4		
Paonia	21000	4		
Silver Jack	14000	4		
Crawford	14000	4		
Onion Valley	9000	4		
Overland	6000	4		
Fruitgrowers	5000	4		
Granby	540000	5	CBT	286200
Dillon	252000	5	Denver Water	252000
Williams Fork	97000	5	Denver Water	97000
Wolford Mountain	66000	5	Denver Water	66000
Green Mountain	152000	5	CBT	53200
Homestake	44000	5	Aurora	44000
Willow Creek	11000	5	CBT	5830
Clinton Gulch	4400	5		4400
Meadow Creek	2000	5		4300
Eagle Park	3100	5		3100
Ruedi	102000	5		20400
Vega	34000	5		
Rifle Gap	14000	5		2800
Jenny Creek	10000	5		
Grass Valley	5000	5		
Stagecoach	33000	6	Yampa	6600
Steamboat Lake	23000	6	Yampa	

Name	Capacity	Basin	Complete Project/Owner	M&I
Taylor Draw	14000	6	White	
Elkhead	14000	6	Yampa	
Yamcolo	10000	6	Yampa	
Big Beaver	8000	6	Yampa	
Lake John	7000	6	North Platte	
MacFarlane	7000	6	North Platte	
Stillwater	6000	6	Yampa	
Walden	5000	6	North Platte	
Meadow Creek	4000	6	North Platte	
Laune	4000	6	North Platte	
Pole Mountain	2000	6	North Platte	
N. Michigan Creek	2000	6	North Platte	
Lower Big Creek	1000	6	North Platte	
Agua Fria	500	6	North Platte	
Seymour	500	6	North Platte	
West Arapahoe	500	6	North Platte	
Buffalo	500	6	North Platte	
Ridges Basin	120000	7		120000
McPhee	381000	7		
Vallecito	130000	7		
Lemon	40000	7		
Cascade	23000	7		
Groundhog	21000	7		
Narraguinnep	19000	7		
Williams Creek	10000	7		
Jackson Gulch	10000	7		
Summit	6000	7		
Red Mesa Ward	1000	7		