Alternative Water Resources

Closing New Mexico's Projected Water Budget Gap by Developing New Sources of Water.

This Report was Prepared by The Jemez y Sangre Water Planning Council Technology Committee - December 10, 2007
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I. Summary and Introduction

Summary

This report is a review of the projected increases in demand in New Mexico over the next 40 years which are likely to create the need for increased water supplies and a guide to alternative water resources and technologies which may potentially be used to increase the supply of water to satisfy the projected increases in demand.

The information is intended as a guide to local planners for their initial review of available water resources and technologies which might be used in Region 3 or other parts of New Mexico. The water resources and technologies include: large-scale surface capture; recovering and treating both shallow and deep brackish water; cleanup of produced (byproduct) water from oil and gas field and coal bed methane operations; and enhanced precipitation from cloud seeding. Although "total reuse" was considered (See Appendix C), the focus of the activity of the Technology Committee was additions to supply rather than reductions in consumption. Potential costs and potential quantities of additional water are also presented to help in selecting water resources and technologies for more detailed consideration.

The report was prepared by the Technology Committee of the Jemez y Sangre Water Planning Council, The information was developed by a combination of literature search and consulting with people working in these fields. We thank all members of the Technology Committee and the many experts who donated their time and in some cases incurred substantial out of pocket costs in order to advance the work of the Technology Committee.

Introduction

Development of the western United States has depended in large part on securing water for agriculture, industry and basic human needs. With water, communities and families thrive. Without water, they must move to other locations. Except for periods of prolonged drought, New Mexicans have benefited from a reliable supply of water for the last 400 years. But that reliability has been clouded by doubts that sufficient water will be available for expected increases in demand through the year 2040.

In fact, there are several reasons to be concerned about a decrease in historical water sources:

- Depletion of ground water reserves, particularly in eastern New Mexico.
- Increased loss to evapotranspiration due to an observed warming trend.
- Decrease in winter mountain precipitation due to the warming trend.
- Possible interference with natural precipitation due to pollution.

Combined with increased demand due to population growth, the potential for a serious deficit in the balance between supply and demand (i.e. the water budget) exists. This report reviews the statewide projected growth in demand for water and provides information on a number of different water resources that exist in New Mexico and which could be developed. We start with a statewide perspective because each Region exists within the framework of a statewide water budget. Simply transferring paper or even wet water from one region to another cannot solve the problem if there is a statewide water budget deficit.

Projected Growth in Demand for Water: We have reviewed the demand projections from the regional plans of each of the 16 Water Regions and have done our best to tabulate the data (Appendix B). Because the numbers were developed by 16 different organizations, possibly using different guidelines and standards, it is likely that the totals are not completely accurate. Nevertheless, the tabulation of the data shows a large increase in demand by the year 2040. Which in the absence of an increase in supply will represent a large deficit in the water budget. Some regions are updating their plans and this will change the demand (and possibly also the supply) totals slightly but most likely will not greatly change the projected deficit for New Mexico although it may change the situation for individual regions.

Demand is expected to increase from about 3,300,000 acre-feet per year (afy) in the year 2000 to about 4,000,000 afy in 2040. Without an increase in supply, the most serious deficiency resulting from the increase in demand will be in Municipal/Domestic and Commercial/Industrial water use, which is projected to nearly double over the 40 year planning period, an increase of about 400,000 afy. These figures do not include replacement of aquifer depletion, which has been occurring over the past 50 to 100 years. When this is factored in, the increase in demand may be in the order of 500,000 afy. To put this in perspective, this is about five times the amount of water allocated to New Mexico from Colorado in the San Juan/Chama project.

TOTAL NEW MEXICO BENEFICIAL USE: DOES NOT INCLUDE RIPARIAN, RESERVOIR AND OTHER ET LOSSES IN THE DELIVERY OF WATER

Source: Regional Water Plans

Acre Feet per Year	Agriculture	Municipal and Domestic	Commercial Industrial	Total
Year 2000	**2,766,853**	**308,851**	**202,633**	**3,278,337**
Year 2040	**3,054,847**	**646,056**	**277,397**	**3,978,300**
Absolute Increase 2040 over 2000	**287,994**	**337,205**	**74,764**	**699,963**
Percentage Increase 2040 over 2000	**10%**	**109%**	**37%**	**21%**

Distribution of Demand Increases

The demand numbers included in the Regional Plans are likely in practice to be revised over time from those that were submitted for a number of reasons including:

- conservation efforts can reduce and in some case significantly reduce the demand. All efforts to conserve water should be vigorously encouraged. The Region 3 Plan Update shows the result of effective conservation efforts in closing the gap particularly in the early years of the plan.

- the increase in demand for agricultural use in the above tabulation of the Regional Reports is likely to adjust to the availability of water supply augmented by water from only the lowest cost-solutions. The literature indicates that there will be few buyers of water for agricultural use at a cost of $100 afy or more.

- the literature suggests that with the current price structure for goods and services in the U.S. commercial/industrial use will be impacted when water costs more than $500 an acre foot per year.

Clearly higher water prices will bring demand down and supply up thus closing any projected gap. But closing the gap by having water prices increase is a rough way to bring demand and supply into balance and may have many consequences not all of which can be anticipated. Higher prices will call forth the new sources of supply discussed in this report. Costs greater than the value of water at some point could become a drag on a community's and perhaps the state's economy.

Planning in advance for new supplies may make the transition smoother and avoid to some extent massive transfers of water out of agriculture.

Meeting this demand presents real challenges. The San Juan Chama Project and the Navajo Indian Irrigation Project are the major additions to supply that are reported in the Regional Plans. The NIIP is associated primarily with additional agriculture consumption so it is unlikely to provide much water that is available for M&D (Municipal and Domestic) and C&I (Commercial and Industrial) use other than in Gallup. The San Juan Chama Project will meet only about 20% of the projected gap between M&I and C&I supply and demand. This additional water will improve the situation in the early years of the 2000 to 2040 planning period but most likely will be fully utilized well before the mid-point of the planning period.

The Regions agree that no single supply alternative will satisfy their future needs for more water. It will require careful planning and employment of multiple alternatives. This report is intended to provide information useful to planners in considering the alternatives that are open to them.

Meeting the combined increase in Municipal/Domestic and Commercial/Industrial demand presents some very difficult problems which is another way of saying that the cost to New Mexicans will be very high.

The increasing demand for water along the Rio Grande corridor and overuse of ground water makes it difficult to deliver to Texas the amount of water required under the Rio Grande Compact**.** The Office of State Engineer (OSE) has recognized the problem and has co-sponsored a series of meetings among the three Regions comprising the Middle Rio Grande Basin to look for ways to deal with the current shortfall and meet the projected increase in demand.

The lower value of water for agricultural use is the basis for the belief that water will continue to be reallocated from agriculture to municipalities. However, only two Regions have projected decreases in agricultural use (Mora-San Miguel and Middle Rio Grande

Regions) and the rest have projected the same or increased use. The dairy farm industry in Lea County alone calls for doubling agricultural water consumption, more than offsetting the projected decrease in the two Regions showing a decrease. It may prove difficult to continue transferring large amounts of water from agricultural to municipal use. The impacts of such transfers, such as the problems related to the migration of people from rural areas to metropolitan areas, may be severe.

Climate Change Issues.

The Climate Study issued by NMENV warns of a warming trend and more variable year to year levels of precipitation. The impact of warming on precipitation levels is a matter that has not been well resolved, probably because the impacts will vary depending on certain factors. Warmer temperatures will certainly increase evapotranspiration, meaning greater delivery losses and greater Consumptive Irrigation Requirements (CIR) in agriculture.

Higher temperatures are not likely to negatively impact summer precipitation and may enhance summer precipitation levels (prior to the impact of higher ET losses). Some predict that mountain temperatures may experience a greater warming trend than in lower elevations and it is possible that higher temperatures will reduce winter precipitation because winter precipitation requires that water relatively close to the ground freezes before the precipitation falls as snow or melted snow (rain). Although bulk water freezes at 0^{o}C, pure water existing as a fine mist in clouds requires temperatures to be colder than approximately minus 15 ^{o}C for significant snowfall to develop. A warming trend may well reduce the number of occurrences of supercooled liquid water (SLW) cloud being sufficiently cold for natural glaciation and snow creation to take place. It is not simply a matter of a changing mix of snow to rain: the total amount of winter precipitation may be reduced.

Thus demand may be higher and supply lower than reported in the Regional Plans if there is substantial warming.

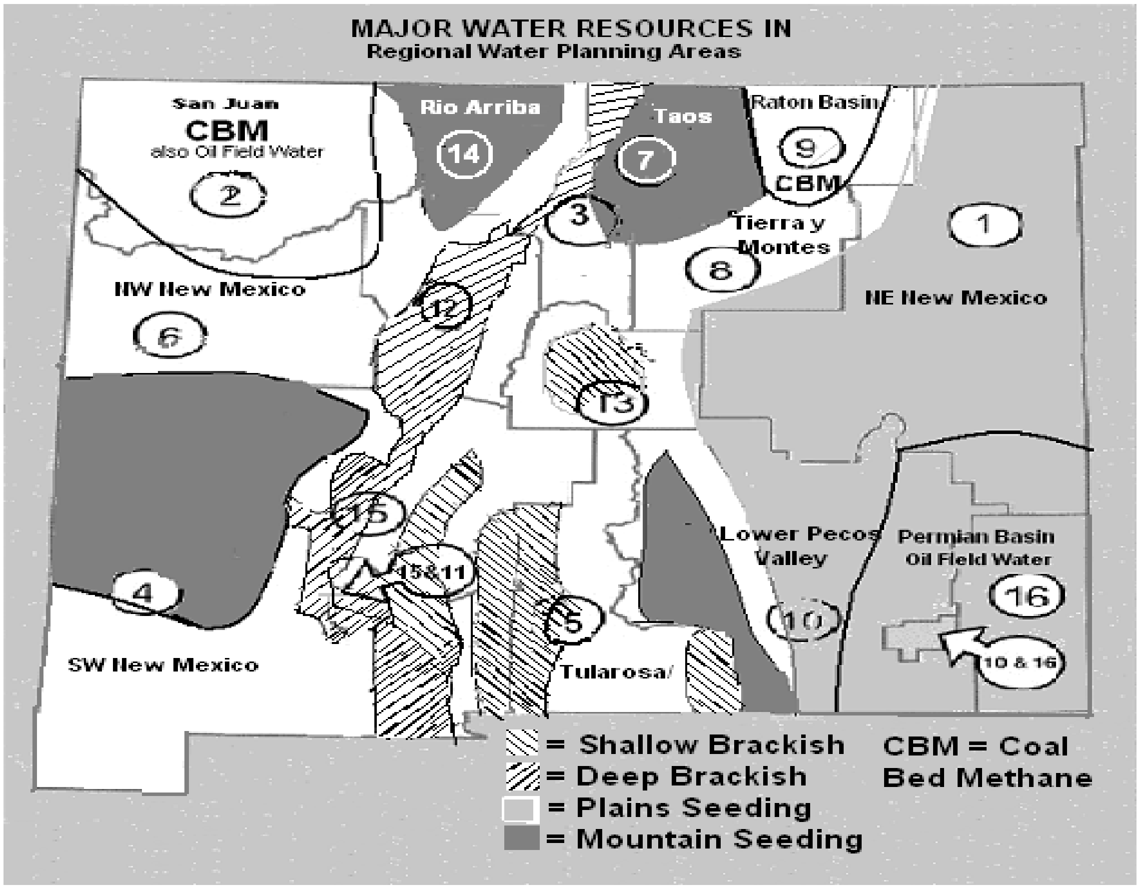
II. Alternative Water Resources and Technologies for Developing these Resources

There are many water sources that can be accessed with modern technologies, thus increasing our water supply. The most practical approaches are listed below. The information in this table is a summary of the information provided in Appendix A.

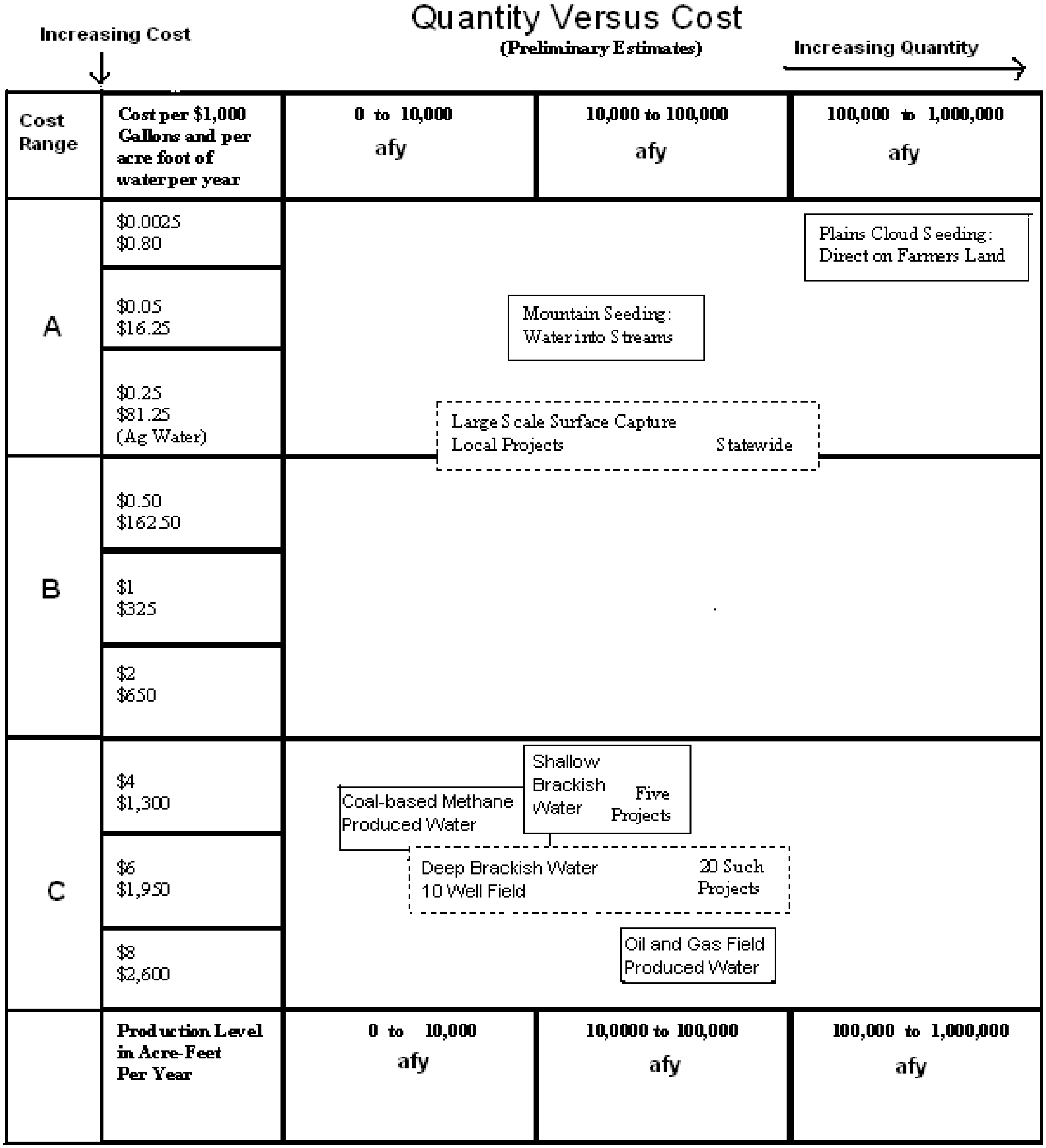
Water Source	**Technologies Involved**	**Quantity Available.**	**Environmental and other Challenges**	**Dealing with these Challenges**	**Cost per Acre Foot**	**Timing of Measurable Impact**
Recover and Treat Shallow Brackish Water less than 2,500 feet deep and more than 1,000 PPM of dissolved solids	Desalination.	Recoverable reserve is in the order of millions of acre-feet.	• This is too costly for agricultural use. • Municipal use often will mean inter-basin transfers. • Brine disposal • Increasing the salinity of connected freshwater wells • Requires a water right	Probably these projects need to be developed for local non-agricultural use rather than for use at any great distance from the project.	$750 to $1,500	5 to 10 years
Recover and Treat Deep Brackish Water greater than 2,500 feet deep and more than 1,000 PPM of dissolved solids	Desalination. Horizontal drilling Techniques may be beneficial.	Very large--in the order of hundreds of millions of acre- feet.	• Regulatory Issues • Will need to show that the deep aquifer is confined and does not impair aquifers or streams nor create subsidence problems. • Brine disposal	Appropriate exploration, selection and testing of deep water targets, controlling production levels and use horizontal drilling	$1,500 to $2,500	Middle Rio Grande 5 to 10 years. Elsewhere, 10 to 15 Years
Cleanup of Byproduct (Produced) Water from Gas and Oil Field Operations	Removal of organic compounds and desalination	About 80,000 afy	• Water quality. • Use of recovered produced water will generally require a water right.	Improved technologies need to be developed for cleaning up this type of produced water.	$2,000 to $3,000	Unlikely until other water sources prove inadequate
Cleanup of Byproduct (Produced) Water From Coal Bed Methane Operations	Removal of organic compounds and desalination	About 20,000 afy.	• Ownership of the water when not used as power plant coolant • Water quality • Distance from the point of use	Water quality for most uses can be achieved because of the low total dissolved solids. Legislation may be required to deal with ownership	$500 to $2,000	Near-term for use as power plant coolant.
Large-scale Surface Capture	Low-Tech. Might be done in combination with aquifer storage and retrieval.	Controlled by topography and near-surface clays or caliche. Perhaps in the order of tens of millions of acre- feet.	• Regulatory Issues • Possible impairment of aquifers and stream flow • Toxic materials being captured e.g. after storm events and flows across roads with antifreeze.	Could be solved by water sharing arrangements. Proper location and design of projects is crucial	Probably under $100	5 Years. Pilot Projects will first have to address State Engineer Concerns

Water Source	Technologies Involved	Quantity Available.	Environmental and other Challenges	Dealing with these Challenges	Cost per Acre Foot	Timing of Measurable Impact
Enhance Natural Precipitation Levels by Seeding Clouds with Ice Nuclei **Winter Mountain Seeding**	Ground-based Seeding Agent Delivery, Computer Modeling, Chemical Tracers, Statistical Analysis	20,000 afy (Pilot Project) to 200,000 afy per Operational Project.	• Concerns about potential toxicity and downwind impacts • Difficulty in measuring the additional water produced. • Logical areas to seed often do not line up with existing political jurisdictions • Ownership of the additional stream flow	Studies show toxicity not a problem and there are other seeding agents besides silver iodide. Downwind impacts shown to be generally positive	Mountain stream flow $10 to $25.	5 Years a Pilot Project with Intense Efforts to quantify the enhanced precipitation is required first
Enhance Natural Precipitation Levels by Seeding Clouds with Ice Nuclei **Summer Plains Seeding**	Aircraft-based seeding agent delivery and radar for quantifying the additional precipitation	One half to one inch per acre on the plains for summer seeding.	• Concerns about potential toxicity, downwind impacts, and violent weather • Difficulty in measuring the additional water produced. • Landowners benefit whether or not they contribute to the funding	Same as above re toxicity and downwind impacts. Suspension of seeding based on predefined criteria avoid situations when violent weather might occur	Plains precipitation on farmers' lands--$1 .	Near-term where there is support for funding.

Not all of these technologies are available everywhere in New Mexico. The below map shows generally where these technologies are most appropriate. Large Scale Surface Capture Is not shown on this map as it is available in all sixteen regions. Every region has important water resources that can be developed.



Not every technology has the same potential in terms of quantity of water that can be made available and of course the cost per thousand gallons or cost per acre foot varies from one resource/technology to another. This is shown below.



A Cost effective for all sectors including Agriculture

B Cost effective for Municipal/Domestic and Commercial/Industrial

C Cost effective probably only for Municipal/Domestic

III. Conclusions

Water resources and the technologies to make these resources available for consumption exist and are far in excess of the likely needs of New Mexico over the next 40 to 100 years. However there is a wide range of both costs and technological risk for the various resources.

It is not likely that the market will bring forth many of these resources because of a variety of factors. Action by the State of New Mexico is required for many of these resources to be developed. These actions include:

- Addressing the institutional obstacles to the development of some of these resources. Institutional obstacles are a major barrier currently for large scale surface capture and potentially for deep brackish water.
- Encouraging research institutions to address the technological and geological issues, especially for deep brackish water.
- Provide seed money for pilot projects, especially for cloud seeding and large scale surface water capture.
- Include these resources in published inventories of New Mexico's water resources and encourage the consideration of these resources as part of symposia and workshops where water resources, drought and climate change are discussed.
- Develop handbooks for use by implementers to assist in evaluating the use of these technologies.

Appendix A. Potential Water Resources and Technologies to Develop These Resources.

References in the following text are available upon request.

1.. Desalination--General: Processes for removing salts and other chemicals from ground water have been available on a commercial basis for nearly 40 years. Today there are over 15,000 desalting plants in operation worldwide with a production capacity of 8.6 billion gallons of fresh water per day (about 10 million acre feet per year), enough water for 43 million people. Most of these plants are located along coastlines because of the ease of disposing of the waste brine, but, with the projected supply-demand gap, there is growing interest in desalination in inland areas. Las Vegas, Phoenix and Tucson are considering desalination plants to supplement water supplies, and Scottsdale, Abilene and Ft. Stockton, Texas have already built moderate size desalination facilities. El Paso is planning a desalination plant of 30 million gallons per day (mgd), which would be the largest inland desalination plant in the U.S. The Bureau of Reclamation this year completed the construction of a $5 million federally funded research center in Alamogordo. The cost is high, but for municipalities concerned about long-term fresh water supply, desalination is a technically sound alternative.

New Mexico is fortunate to have a very large supply of fresh and brackish water, much of it in valley-fill sand and gravel aquifers in intermontane basins. Many of these basins are associated with the Rio Grande Rift, a structural depression which has determined the course of the Rio Grande. Additional brackish water is available as produced water (oil field and coal bed methane water). Surface water and fresh water aquifers should be adequate to meet needs in the Rio Grande corridor for the near term, barring a lengthy drought, but long-term water planning should take into account the large volumes of brackish water available for the future. Said another way, the problem is not a shortage of water in the future, but the cost of that water and legal constraints.

Those constraints include the Rio Grande Compact, which guarantees Texas a certain amount of water flowing in the Rio Grande from New Mexico into Texas. The current interpretation of the Office of State Engineer (OSE) is that ground water in the region is connected to surface water, meaning that pumping of brackish ground water in Rio Grande rift basins would capture water that otherwise would flow into the Rio Grande. This could reduce the flow of water to Texas, in violation of the Rio Grande Compact. In such cases the OSE requires the transfer of water rights. A possible exception might be deep brackish water in Rio Grande Rift basins, discussed in Section 5 below.

Sources of brackish water in New Mexico are shown in the following table.

Water Type	Total Dissolved Solids Parts per Million(ppm)	Source
Fresh	<1000 (drinking water < 500)	• surface water • shallow wells
Brackish	1000-10,000	• surface water (Pecos River) • shallow wells (Estancia Basin) • oil field and coal bed methane water • deep wells (Rio Grande Rift Basins)
Saline	10,000 – 35,000 (seawater = 35,000)	• oil field water • deep wells in the Permian and San Juan Basins
Brine	> 35,000	• oil field brine

Rivers such as the Pecos River, may become brackish as the result of salt buildup downstream from irrigated fields or from upwelling saline formation water and may require desalination; this is discussed below in Section 2. The potential of shallow (<2500') brackish water aquifers, such as in the Estancia and Tularosa Basins is discussed in Section 3. Oil field and coal bed methane waters are discussed in Section 4. Deep wells in Rio Grande Rift basins are possible future sources of brackish water and are discussed in Section 5. Costs to process saline water will be much greater than for processing brackish water in New Mexico; desalination of saline water will lag far behind desalination of brackish water and is not discussed here.

Currently there are two processes to remove salts, thermal (distillation) and membrane (filtering). Filtering through a semipermeable membrane is called reverse osmosis (RO). Electrodialysis (ED) uses charged electrodes to cause dissolved ions to pass through semipermeable membranes, leaving behind fresh water. The best-known thermal process is distillation, where boiling the water and condensing the water vapor leaves fresh water. Most earlier plants were multistage flash distillation units, but membrane plant capacity now nearly equals that of thermal. ED is more economical when salinities are less than 3,000 parts per million (ppm), while RO is most frequently used at salinities from 5,000 to 10,000.

Costs vary widely as a function of salinity; the cost of desalting seawater (35,000 ppm) is three to five times that of desalting brackish water. Because energy costs may be 50% to 75% of operating costs, and because membrane processes use less energy, rising energy costs favor RO and ED. In remote areas, like the Navajo Indian Reservation in northwestern New Mexico, where ground water is becoming increasingly saline, a solar-powered desalination plant may be the cheapest option for the supply of fresh water. The Jemez y Sangre Region 3 Water Plan White Paper 4a notes that capital and operating costs (in 1985 dollars) for desalination of brackish water, using RO or ED, is in the range of $1.50 to $2.50 per 1,000 gallons of produced water, ($500 to $830 per acre foot), not including cost of brine disposal or distribution costs. Brine disposal may cost as little as $0.05 per 1000 gallons for lined evaporation ponds or as much as $1.85 for crystallization and burial in landfills, the most likely methods of disposal. Pipeline costs are estimated at $25,000 per inch diameter per mile. When those are included, desalted water generally costs more than traditional water supplies. However, in 2003, a firm (represented by the former State Engineer) made a proposal to desalt brackish water in the Estancia Basin, dispose of the brine, and deliver 10 mgd to the City of Santa Fe for less than $4.00 per 1000 gallons, which is less than the current City water cost (see discussion in Section 3 below).

In the event of severe supply shortage, using desalted water should have less cultural impact than living without adequate water supplies. However, the need for transfer of water rights to produce brackish water would, over the long-term, put additional pressure on agricultural communities.

2. Desalination--Surface water: Salt buildup may occur in rivers downstream from intensive irrigation and may require desalination. South of Carlsbad, total dissolved solids (TDS) in the Pecos River, between the Pierce Canyon Gage and the Texas state line measure 10,000 ppm. In March, TDS in the river may reach over 15,000 ppm. It is likely that some of the salt is derived from upwelling of formation brackish water emerging beneath the Pecos River. Desalination would be an expensive alternative, but at some point it may be required to satisfy the Pecos River Compact.

3. Desalination--Shallow brackish water aquifers (i.e., Estancia and Tularosa Basins): A federally funded water desal research center at Alamogordo will be tapping brackish water from the Tularosa Basin, which contains an estimated 100 million acre feet of brackish water. The City Manager for Alamogordo said “the cost of acquiring new fresh water supplies has increased to a level that desalination of local brackish groundwater is now competitive with developing and bringing in fresh water from remote locations.”

In January, 2003, a firm called Resource Solutions Group, LLC, whose principals include Eluid Martinez, former State Engineer, and Dr. John Hernandez, Professor, New Mexico State University, made a proposal to deliver to Santa Fe and northern Torrence Counties 10 mgd (about 11,000 afy) of desalinated water from the Estancia Basin. They said that they have identified about 1 million acre feet of brackish water which could be pumped from valley-fill sand and gravel without impairing existing water rights. Mr. Martinez stated that the recharge in the Estancia Basin was sufficient to expect that the life of the project would exceed 40 years.

Their proposal provided for drilling shallow wells to produce brackish water (about 2500 ppm) in the eastern Estancia Basin. The recharge for the Basin is primarily on the west side, from outcrops in the Manzano Mts. In the western part of the basin the water is fresh and is used for irrigation and for municipalities. The Resource Solutions Group claimed that withdrawal of brackish water for desalination from the eastern part of the Basin should not impact groundwater in the western part of the Basin. In fact, withdrawing brackish water in the eastern part of the basin should benefit users of water to the west by lowering the potentiometric head of brackish water relative to that of the fresh water.

Costs were estimated at about $80 million to be funded by the private sector. Plant construction costs would be about $17.5 million ($1.75 per 1000 gallons of capacity per day) and operating and maintenance would be roughly $1.35 per 1000 gallons. Brine disposal would be in lined evaporating pans. The remainder of the cost would be for drilling and completing the wells, plus a 65-mile pipeline to Santa Fe. The firm stated they could deliver 10 million gallons per day of fresh water to Santa Fe for less than $4.00 per 1000 gallons.

The proposal met objections from the Estancia Basin Regional Water Plan members and governmental agencies. They claimed that:

- The relationship between fresh water in the western part of the Basin and brackish water in the eastern portion should be documented by monitor wells.
- There may not be sufficient recharge on the eastern side of the Basin to supply the projected withdrawals for desalination.
- It may take many more wells than anticipated to achieve the projected production rates.
- Water should not be exported from the Estancia Basin until it has a sustainable water supply.

The Santa Fe City Council voted to reject the proposal, and to date no other interested parties have emerged. While desalination holds great potential for providing fresh water to future generations, cases like this indicate the difficulty in getting them approved and operational.

4. Desalination--Produced Water (oil field and coal bed methane water): For each barrel of oil produced in the U.S., an average of 10 barrels of water is produced. In New Mexico this amounts to a total of about 80,000 acre feet per year (afy), mostly in the Permian Basin in southeastern New Mexico. The produced water is fresh (100 ppm) to highly saline (100,000 ppm). A new source of natural gas since the ‘90s, coal bed methane (CBM) also produces large amounts of water, but the water is much fresher and contains bicarbonate, not sodium salts. CBM is natural gas produced from fractures in coal beds. New CBM fields are being developed in the Raton Basin in northeastern New Mexico, where associated water totals nearly 2000 afy, and in the San Juan Basin in northwestern New Mexico, where associated water amounts to about

10,000 afy. Regulation of brackish oil field waters and CBM water used for oil field operations or as a cooling agent in the generation of electricity is under the jurisdiction of the Oil Conservation Division, not the Office of State Engineer.

Produced waters require treatment to remove salts and chemicals and are a special case of desalination. Before removal of salts, oil field waters require removal of chemicals, especially organic compounds called BTEX (Benzine, Toluene, Ethelbenzine and Xylene). Sorption-based technologies are available, but costs vary widely, ranging from $0.20 to $8.33 per 1000 gallons of water with capital costs of up to $300,000. One promising process uses surfactant-modified zeolite (SMZ) for sorption of the organics, followed by air stripping and routing of the air stream to a bioreactor where bacteria use the BTEX as a food source. This process, coupled with air sparging, was estimated to cost as little as $0.49 per 1000 gallons with an initial operating cost of $18,300. Pretreatment of oil field brines before removal of salts is necessary because the organics will clog the salt removal filters. Estimated costs to treat oil field brines are shown in the table below, based on published transportation costs in the San Juan Basin, desalination and brine disposal costs as summarized in Section 1, above, and pre-treatment costs of $0.50 to $2.00 per 1000 gallons.

Processing Steps	**Transport**	**Pre-treatment**	**Desalination**	**Brine Disposal**	**Total**
Cost/1000 gals	$0.17-$0.76	$0.50-$2.00	$1.50-$2.50	$0.05-$2.10	$2.22-$7.36

Texas A&M University has developed a portable desalination unit using microfiltration membranes to remove substances that might plug RO membranes. Reject brine is injected into the formation from which it was produced. As much as 70% of the brackish water can be recovered as fresh water. The total cost of producing fresh water ranges from about $4.00 to $8.00 per 1,000 gallons, including disposal costs (but not including transportation costs), based on a 10-year lifetime and allowing for maintenance and replacement.

In contrast, transportation and disposal of the brine in salt water disposal wells (depleted oil wells) or water flood injection wells may cost only $0.29 to $1.02 per 1000 gallons. Partly because of the higher cost to treat the brine, as well as the value of the additional oil produced by water flooding, 95% of oil field brine in the U.S. is disposed of in salt water disposal or water flood injection wells. CBM water should require less treatment and may be suitable for a variety of uses.

Potential beneficiaries of produced water are those who may use the produced water to replace previously used fresh water; they are shown below:

Oil Field Water	CBM Water
• Oil field operations (water flooding, cement jobs, make-up water for fracing) • Roads and construction • Long-range option—carbon sequestration: (brine + CO2 from power plant + catalyst + pH control = carbonate + treated brine for use in cooling power plant)	• Power plant cooling • Agriculture • Drinking water

5. Desalination--Deep Brackish Water Aquifers (>2500 feet) in Rio Grande Rift Basins: New Mexico is blessed with an abundance of deep ground water in basins along the Rio Grande Rift. The Rift is a deep, fault-bounded depression which originates in central Colorado and continues through central New Mexico into west Texas and Mexico. The largest of these basins in New Mexico are the Albuquerque Basin (40 miles wide by 100 miles long), the Espanola Basin (20 by 40 miles) and the Taos Basin (the southern part of the San Luis Basin in Colorado, 10 by 50 miles,). South of the Albuquerque Basin, the rift zone bifurcates into several smaller, shallower basins. Basin-fill sediments total up to 14,000 feet in thickness and consist of sand, gravel, clay, gypsum and associated volcanic rocks, together termed the Santa Fe Group. In the words of a veteran New Mexico geologist "This lithostratigraphic unit constitutes one of the great aquifer systems of southwestern North America" and holds "vast quantities of economically recoverable, fresh to slightly saline, ground water" (Hawley et al, 1994). No estimates have been made of the amount of water in storage (theoretically recoverable water) in the rift zone, but one estimate for the southern Española Basin alone totals 56 million acre feet, almost 30 million acre feet of which is below a depth of 2500 feet. The authors (Lewis and West, 1995) state that the "aquifer contains sufficient water to supply existing demands for many hundreds of years if legal and administrative issues are ignored".

In the larger basins the shallow section is fresh water-bearing and is the ground water supply for municipalities. Together with surface water, this large supply of fresh water should supply the region for many years. However, for purposes of long-range planning, it is important to include the deeper, brackish water as an additional future supply. Another reason for studying deeper aquifers is that the OSE does not regulate water below a depth of 2500 feet and with total dissolved solids (TDS) greater than 1000 ppm.

The statute, NMSA72-12-25 [Aquifer containing nonpotable water at a depth of twenty-five hundred feet or more excluded from underground basin] reads “No past or future order of the state engineer declaring an underground water basin having reasonably ascertainable boundaries shall include water in an aquifer, the top of which aquifer is at a depth of twenty-five hundred feet or more below the ground surface at any location at which a well is drilled and which aquifer contains nonpotable water. Nonpotable water for the purposes of this act means water containing not less than one thousand parts per million of dissolved solids.” The State Engineer, however requires proof that the deep aquifer is not hydraulically connected to the Rio Grande and that withdrawals will not impact adjacent wells or impair the overlying fresh water aquifer. There are only a handful of wells deeper than 2500 feet, all abandoned oil or gas exploratory wells, none of which tested the Santa Fe Group, so it will be very difficult to satisfy these requirements. However, doing so would point to a source of “new water”, so it is worthwhile to examine the possibilities that: a) the aquifer below 2500 feet may have TDS greater than 1000 ppm, b) the aquifer may be confined; that is, hydraulically separated from the overlying fresh water aquifer and the river and c) that porous and permeable aquifers exist at depth.

> a) Total dissolved solids: There are very few references to TDS in New Mexico rift basins, and what data there are vary widely. Wilkens, (Wilkens,1998) reports that in the southern Albuquerque Basin a suface resistivity survey indicates sodium chloride (NaCl) concentration of about 8000 ppm at depths down to 1300 feet, in the western Albuquerque Basin a NaCl brine (>30,000 ppm) enters the fresh water aquifer due to upward movement of deep circulation water; and in the northern part of the basin chlorides as high as 1300 ppm with silica of 91 ppm indicate ground water flow from the Jemez geothermal reservoir. In the Mesilla Basin in southern New Mexico and northern Mexico, upward-flowing geothermal water with large concentrations of chloride is encountered in the southeastern parts of the basin and on the eastern side, geothermal water with large concentrations of chloride, silica and potassium mix with cooler, less mineralized water (Wilkins, 1998).
>
> These scattered data, together with the occurrence of gypsum in the middle Santa Fe Group in the Albuquerque Basin indicate that we may expect that deeper aquifers with older water will have salinities greater than 1000 ppm.
>
> b) Confined aquifers: The shallow aquifer in all rift basins is considered to be regionally unconfined; that is, hydraulically connected to the river. However, in the Espanola Basin, “lack of hydraulic connection between pumping wells in one layer and nearby observation wells in deeper of shallower layers has been observed in many tests, a further indication that either local confining conditions or very low vertical permeability values are common in the basin” (Keating et al, 2002) These locally confining layers are impermeable clay. If clay-rich lake beds covered a large area, it is likely that the impermeable clay would act as an

aquitard (seal), and the underlying aquifer would be confined. That is what occurs in the center of the San Luis Basin, immediately north of the Taos Basin. A lake formed in the center of the basin in Pleistocene (Ice Age) time and probably earlier, depositing a thick sequence of clay. An abandoned oil exploratory well north of Alamosa, Colorado encountered 2000 feet of lake bed sediments (Chapin and Cather, 1994). "These clays (blue clay of drillers logs) form the highest aquitard between the upper unconfined aquifer and the lower confined (Alamosa Fm and Santa Fe Gp) aquifer in the basin, both of which are critical water resources in the basin" (Machette, 2004).

Lake beds are known to have been deposited also during the early phase of rifting. In the Socorro, La Jencia and Albuquerque Basins, the middle Santa Fe Group consists of finer grained clastics as well as gypsum and mudstone deposited in playa lakes. In the Socorro and La Jencia Basins, the upper part of the Popatosa Formation is a confining unit consisting of playa deposits and mudstone. The remainder of the Popotosa Formation constitutes the lower part of the aquifer system (Wilkens, 1998).

Although there is no water production from deep Santa Fe Group aquifers in the Albuquerque Basin, the same playa lake facies is present on the flanks of the basin. "The lower Santa Fe Group records deposition in internally drained basins (bolsons) where streams terminated onto broad alluvial plains with ephemeral or intermittent playa lakes bounded by piedmont deposits" (Connell, 2001). Lake beds have also been identified on the edge of the Espanola Basin. "Some of the mudstone deposits west of Pojoaque are associated with shallow lakes because locally greenish colors (indicating reduced conditions) grade laterally to more reddish colors (indicating more oxidized conditions)" (Johnson et al, 2004). Also, an abandoned oil exploratory well, Yates, LaMesa No. 2, on the south flank of the basin, encountered green shale with bryozoan (fossil) fragments and shaley, fossiliferous beds over a 70 foot interval overlying a basal sandstone unit. As much as 450 feet of clay and sandy clay in the Tesuque Formation are reported near the Santa Fe Airport and are interpreted as lake or playa lake deposits. (Koning, 2006).

It will require testing of selected abandoned oil exploratory tests, and perhaps additional drilling to prove the existence of deep, confined aquifers, but the geologic conditions indicate the possibility that confining beds exist.

c) Porous and permeable aquifers: During the early phase of rifting the climate was warmer and drier, and locally extensive, thick eolian sand (dune sand, Zia Formation) was deposited in the Albuquerque Basin (Bartolino and Cole, 2002 and Hawley et al, 1994). About 1100 feet of Zia Formation was measured in outcrops on the Zia Pueblo and 2500 to 2800 feet of Zia Formation was encountered in two exploratory test wells east of the outcrops (Connell, 2001).

> The dune sands are typically well sorted, massive to cross-bedded, weakly to moderately cemented and should be an excellent aquifer. Hawley and Haase (1992) note that the Zia Formation “may form a large part of a deep aquifer system in the northwestern Albuquerque Basin”.
>
> In the southern Espanola Basin a water well had “an estimated 900 feet of moderately well sorted, nearly unconsolidated sand present in the silty basal portion of the Tesuque Formation---which may represent an ancient, unusually persistent stream channel” (Spiegel and Baldwin, 1963). Yates, LaMesa-2 logged 250 feet of sandstone in the basal Santa Fe Group, immediately beneath the lacustrine deposits. This section has been cased, so it is possible to reenter and test the aquifer at a minimum cost. A seismic reflection at the approximate level of this basal sand in the LaMesa-2 appears on all seismic lines reviewed in the southern Espanola Basin, indicating widespread distribution of the sand member. Along the Santa Fe River, Koning measured about 300 feet of pebbly sandstone in poorly exposed basal Tesuque Formation outcrops (Johnson, et al, 2004). He interpreted this section as ancient Santa Fe River channel deposits and correlated it with the basal sand in LaMesa-2. At depth, porosity and permeability will be lower than in shallow aquifers, but, given the excellent reservoir characteristics reported in some basins, suitable deep aquifers may exist.
>
> The major obstacle to claiming that deep, slightly brackish water may be exempt from OSE regulation and is “new water” seems to be the question of hydraulic connection with the river. While a case can be made for the possibility of a deep, confined aquifer, proving that claim will require reentry and testing of selected abandoned oil exploratory tests and probably drilling and testing of new wells.

Planners will have to consider a problem that has emerged in the Buckman Well Field in the Española Basin. Pumping at high rates has caused not only large cones of depression around the wells, but also reservoir compaction. This has resulted in surface subsidence and irreparable damage to the aquifer. An alternative to drilling vertical wells (where the aquifer is stressed around the bore hole) is to drill deviated or horizontal wells and distribute that stress over a distance of a quarter or half a mile. Drilling horizontal wells is a standard practice in the oil industry and costs may be competitive with the current very high costs of City of Santa Fe wells: the last four wells the City drilled and completed near the Buckman Well Field to a depth of about 1200 feet cost $2.75 million per well, or about $2500 per foot. The following cost estimates provide for drilling and completing near-horizontal wells with a production capacity of 460 afy per well, or 285 gpm per well (75% of the average production rate at Buckman from 1990 to 1999) and desalinating the brackish water.

Estimated Cost for a Deep, 10-well Field	$ million
Capital cost	
• 10 wells, 6000 feet deep @ $3 million	30
• 30 miles of 20” pipeline @ $25,000/inch/mile	15
	45
Annualized cost	
• Capital cost ($ 45 million @ 6%)	2.7
• Operating cost ($10,000/well/month)	1.2
• Water treatment ($2.80/1000 gals or $910/af x 4600 afy)	4.2
	8.1
Unit cost	
• Cost/afy ($8.1 million / 4600afy)	$1,760
• Cost/1000 gals ($1760 / 326)	$ 5.40

If one uses a more conservative production rate of 50% of the average production rate at Buckman from 1990 to 1999, the cost per afy would be $2,700 and the cost per 1000 gallons would be $8.30. These costs are nearly competitive with current City of Santa Fe water rates and those rates are scheduled to increase. Drilling, completion and pipeline costs will certainly escalate in the future, but, most likely, so will the cost of alternative sources of supply.

There is little doubt that there is a very large supply of economically recoverable brackish water below a depth of 2,500 feet in Rio Grande Rift basins. This supply will not be called on in the near-term, because shallow, fresh water aquifers are available. However, it is a possible source of supply that water managers should be aware of and include in their long-term plans. In order to qualify as “new water”, it will be necessary to demonstrate that deep, confined aquifers exist, which ensure that fresh water aquifers and surface water are not impaired. Geologic and hydrologic studies should be conducted on the Santa Fe Group sediments in abandoned oil exploratory tests, and plans should be made to reenter and test selected wells. A review of existing seismic reflection profiles may also be of use in mapping the extent of low velocity shale beds which may serve as confining beds. Preliminary geological studies are planned for later this year by Scott Baldridge at LANL.

Problems	Solutions
The residual salt is an environmental hazard and may be expensive to remove.	Not all methods of salt disposal are expensive. For instance, in the hot, arid Southwest, using lined evaporating pans and disposing the salt in landfills would be relatively inexpensive.
Use of desalinated surface water and shallow brackish water will require water rights, many of which will come from agriculture, putting additional pressure on a centuries-old culture.	Transfer of water rights from agriculture has been happening for many years. As long as there is a willing buyer and a willing seller, the market will prevail.
Water users in basins with shallow brackish water have objected to exporting the brackish water to municipalities in need of water.	In cases like the Estancia Basin, it may take many years before residents realize the benefits of developing the brackish water resources. As water prices escalate, it may be easier to put together a deal which will directly benefit all water users in the basin.
Oil field water is expensive to treat. The alternative of disposing of it in abandoned oil wells costs less than half as much.	Most oil field water will remain untreated and will be used in oil field operations. In this case, produced water replaces fresh water that otherwise might be used.
Much of the oil field and coal bed methane water is produced some distance from municipalities or agricultural areas	In New Mexico, most of the CBM water is produced in the San Juan Basin in the northwest part of the state. There, CBM water could be used as a cooling agent in the large power plants.
Production of deep brackish water will require demonstrating the existence of a confined aquifer with good porosity and permeability. This will be expensive, with no assurance of positive results.	There are very few other potential sources of very large amounts of “new water”. While expensive, the rewards could be very large. Geologic conditions in several basins seem to favor the possibility of confined aquifers. Geophysical data and well samples from abandoned oil wells may be available at a modest cost.
Municipal wells produce at a high rate, which leads to water table draw-down, aquifer compaction and surface subsidence. Resting the wells may allow the water table to recover, but compaction and subsidence are irreversible and ultimately will limit productivity of the wells.	Horizontal or near-horizontal wells can be drilled in either shallow or deep aquifers. This distributes the stress of drawdown over thousands of feet instead of inches around a vertical borehole, thus reducing compaction. Although no additional water will be produced, experience shows that production rates in horizontal wells are higher than in vertical wells.
The Jemez y Sangre Regional Water Plan does not encourage the drilling of additional municipal wells. It notes that the groundwater resource is essentially non-renewable and that the ground water is being mined (outflows exceed recharge in the Buckman Well Field).	The drilling of wells for brackish water will require that neither the fresh water aquifer nor surface water will be impaired. Thus it could tap into a large water supply that otherwise would never be used, and, in doing so, would not endanger existing wells or the river.

6. Large Scale Surface Capture. Although cloud seeding is the least expensive way of increasing the water supply in New Mexico, another approach which is also reasonably inexpensive is to capture water on the ground before it is lost to evapotranspiration (ET). This is an approach that can be utilized in all 16 of the New Mexico Water Regions.

Roof capture has already become established as a very useful way to collect water primarily for landscaping purposes. But roofs are not the only surfaces from which water can be collected. Water can be captured off of the ground where there are surfaces that are either naturally impermeable (rocky and caliche surfaces for example) or made impermeable by treatment. To do large scale surface capture, you need an appropriate surface from which precipitation is captured and a way to store (and possibly treat) the water that is captured.

We are not talking about storm runoff, because storm runoff is likely to make it into streams and capturing that water would impair those who otherwise would be able to utilize that surface water. Landscape harvesting involves capturing water in situations where all or almost all of that water would otherwise be lost to evapotranspiration. Evapotranspirative losses reduce the supply of available water in New Mexico's water budget. Capturing water that would otherwise be lost to evapotranspiration is a way of helping the 16 Water Regions in New Mexico to increase their supply of water.

Large Scale Surface Capture is not something for the faint of heart to pursue. The State Engineer is reluctant to establish guidelines for allowable surface capture, but has indicated informally that they are willing to consider such projects on a case by case basis. We need to pursue surface capture projects that allow the State Engineer to develop guidelines for allowable surface capture projects. For example a rocky pool where there is little if any recharge and no outflows might be an ideal for a surface capture project. The State Engineer may initially take the position that although most of the water captured would otherwise be lost to ET, some of the water captured might have otherwise found its way into an aquifer and thus the permit should be denied. Such an approach is too inflexible and may eliminate an excellent source of water.

Perhaps 5% of the water captured might have entered the local aquifer. The operator of the project could be required to purify and inject into the aquifer twice the estimated potential impairment i.e. 10% of the water captured. For good measure, add another 10% of the water to be injected into the aquifer to assist with River Compact compliance and restoring the health of our aquifers. The operator in this case might then only receive 80% of the captured water and could decide if that level of capture would justify the cost of the project.

Operators of such projects could be individual farmers, acequias, municipalities, cooperatives, or private entities. After some experience, the various categories of possible impairment from such surface capture projects would be known. The levels of impairment might be related to surface permeability, distance down to groundwater, and topography. So the OSE could establish the sharing arrangements that would be associated with the various combination of factors determining the percentage of water captured that was really water saved from ET loss. Thus the administration of a surface capture permitting program could become manageable -- perhaps only projects where the potential impairment was 20% or less of the captured water would be allowed. The 20% is just a number used for discussion purposes and one might require that twice the potential impairment to downstream users be provided to them in one way or another plus some share provided back to the State for use for compliance with River Compact Obligations. The goal would be to reduce the immediate losses to evapotranspiration and create win-win situations for all involved.

In an average year, 100 million acre feet of water falls on New Mexico and perhaps 97 million acre feet is lost immediately to evapotranspiration. For sure where rain and snow fall directly on cultivated land it benefits the farmer and a large percentage of our precipitation benefits ranchers. So the value of the 97 million acre feet of precipitation that is lost relatively quickly to ET is certainly greater than zero, there is some benefit from that precipitation but a lower level of benefit than is achieved by water that comes under the control of man. If we could capture some small amount of this 97 million acre feet per year that is lost to ET before coming under the control of man, it would really help our situation.

Also surface capture can be part of a conjunctive use strategy i.e. using water captured from the surface when available, which is determined by precipitation levels and the size of the storage pond or equivalent, in lieu of well water or stream flow. So surface capture can be viewed as an element of a conservation strategy as well as a source of additional water.

The cost of surface capture water depends on a number of factors including:

A. if the surface captured water is the only source or one of multiple sources.

B. the uses of the surface captured water.

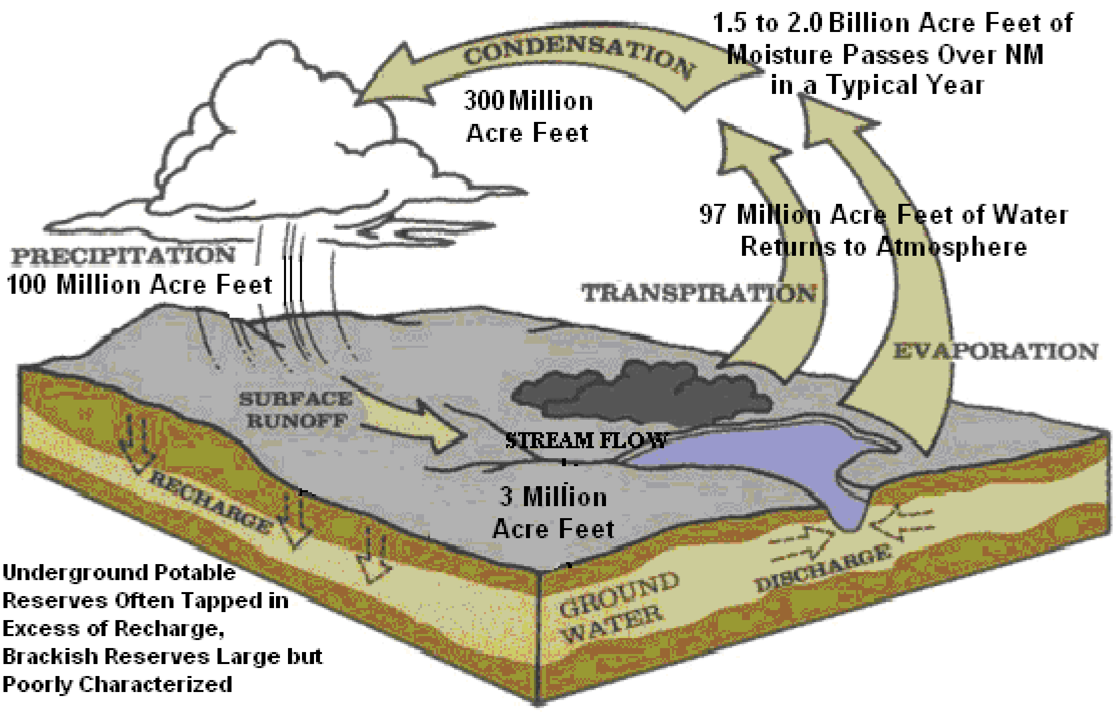
If captured surface water is to be the only source for the intended use, then the storage capacity has to be very large. The cost of storage capacity is likely to be in the order of Cost = $a(\text{Capacity})^x$ where x is likely to be less than 1 (i.e. the cost of storage should be less than linear). The coefficient "a" is empirically determined. As an example -- if the diameter of a spherical storage tank is doubled, the total capacity increases by a factor of eight (2^3) but the area of the tank only doubles. If the cost is proportional to the surface of the tank (assuming that thickness does not have to be increased) the cost per unit is likely to decrease to $2^2/2^3$ of the former cost, or 45% of the per unit cost of the smaller tank. That would be the case for above-ground storage (tanks) but of course the calculation needs to be adjusted for a thicker surface and or supports. But if storage pits have to be totally hollowed out, the cost would tend to be linear with the capacity since both would be related to the amount of material that has to be moved. But one should be able to find areas where a dam can be created without the need to fully excavate all of the material above the dam. Any area that is not perfectly flat would tend to have this characteristic (i.e. some of the capacity could be gained by ways other than removing material). Thus proper location of storage facilities is key to the economics of surface capture and the cost will vary from project to project.

The uses of the captured water will have an even larger impact on the cost. If surface captured water is to be used for agricultural purposes or domestic landscaping or for golf courses or municipal lawns, the treatment most likely would be minimal, perhaps settling to remove sediments in suspension or perhaps no treatment at all. If surface captured water is to be used for industrial purposes or for domestic use, the treatment may be quite costly.

More research needs to be done on the costs of surface captured water, but costs in the range of $100 an acre foot appear to be reasonable for applications where extensive treatment is not required and where the distance from the point of capture to the point of use is small.

7. Cloud Seeding as a Supply Alternative

Hydrologic Cycle
The Atmosphere Provides and is in Turn Replenished



Depiction of the hydrologic cycle. ***Precipitation is not "lost"***, *but is recycled through runoff, evaporation, and transpiration. New Mexico data added to a drawing created by B. Hove, of the ND State Water Commission. Precipitation of 100 million af is an approximation derived by multiplying the area of the state times annual precipitation. If less than one-third of moisture in clouds falls as precipitation, then 300 million af of moisture passes over the state annually as clouds. If only 20% of atmospheric moisture condenses into clouds, then 1.5 to 2.0 billion af of moisture passes over New Mexico annually.*

A. How and Why Cloud Seeding Works

Other than inflows from Colorado, our water supply is determined by the hydrologic cycle shown above. It rains or snows and this water falls to the ground and becomes ground water, runs off as surface water or is returned to the atmosphere through evapotranspiration (ET). Little, if any, water is destroyed. Generally speaking, the ET process works quickly (97% of precipitation is recycled by ET) or the water is put to beneficial use (3%) and then recycled by ET. We only borrow water. We don't consume it in the same sense that gasoline or heating oil is consumed.

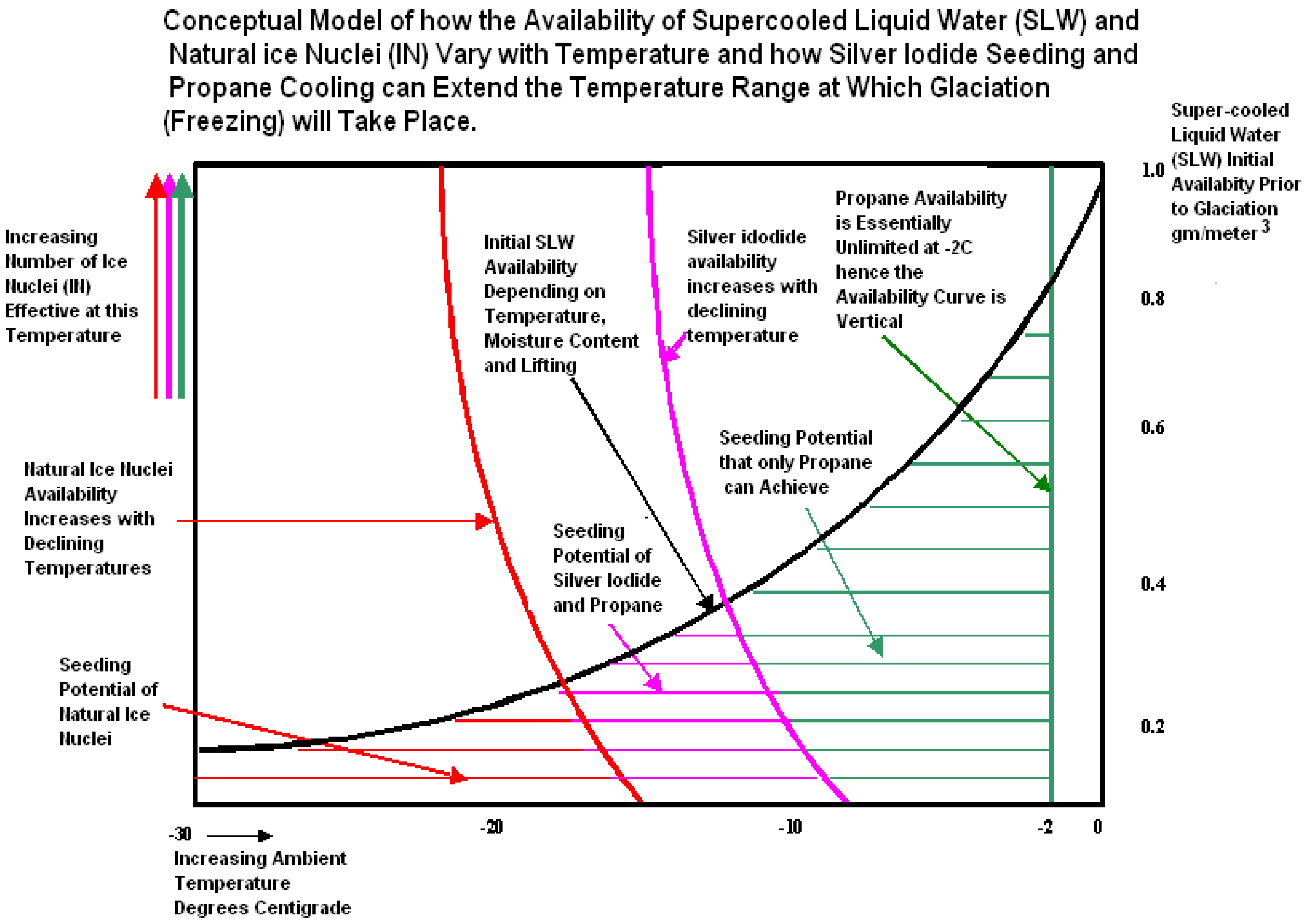
In clouds, water does not freeze at zero degrees Centigrade (32 degrees Fahrenheit). The microscopic size of the water particles and the purity of the water means that it will not freeze naturally until the temperature is well below zero degrees Centigrade. This very cold but unglaciated (unfrozen) water is called "supercooled liquid water (SLW) because it exists in a liquid form below the normal freezing point of water. If there were no impurities in the atmosphere, glaciation would not take place until the temperature of the SLW was -40^{o}F which as it turns out is also -40^{o}C. Fortunately there are impurities in the air, mainly various types of clay particles, that serve as ice nuclei (IN) and allow this SLW to freeze (glaciate) at warmer temperatures approximately –15C (5F) for vermiculite, which is the predominant IN in New Mexico, and a bit warmer for kaolin clays.

This frozen moisture falls as snow in the winter or melts and falls as rain if temperatures near the ground are above freezing. There are so-called warm rain processes that work without having to first glaciate the moisture but at our latitudes almost all of our precipitation requires glaciation to take place. Even on the warmest summer day, the upper parts of clouds are very cold.

The reason that only about 30% or less of the SLW in clouds falls as precipitation is that at times the SLW is too warm for the natural IN to be effective. There may also be times when there are not enough of the ice nuclei available. Cloud seeding is a way of accelerating the freezing of water droplets that are too warm to glaciate or for which there are insufficient IN by providing additional IN and IN that are able to be effective at warmer temperatures. The graphic below provides a semi-quantitative analysis of the processes involved.

The lined area below the curve that goes from almost the bottom left to the top right represents the amount of SLW (vertical scale is grams/cubic meter) that is available for glaciation at high elevations in New Mexico as a function of cloud temperature. Note that more water is available as the temperature increases. However, the leftmost curved line (red if seen on your screen or in a color printout) represents the relative quantity of natural ice nuclei. Note that the quantity of ice nuclei (IN) that is able to glaciate tiny water particles increases slightly with colder temperatures. What is most significant however is that the effectiveness of the IN is close to zero at temperatures much above -15^o Centigrade.

The area to the left of (colder than) the natural IN availability curve but under the SLW availability curve (shown as red lines on your screen or if printed in color) shows the amount of SLW that can be glaciated by natural ice nuclei. For states north of us this



Conceptual Model of how the Availability of Supercooled Liquid Water (SLW) and Natural ice Nuclei (IN) Vary with Temperature and how Silver Iodide Seeding and Propane Cooling can Extend the Temperature Range at Which Glaciation (Freezing) will Take Place.

has been shown to be about 30%. For New Mexico it may be less, perhaps as low as 25% for our mountains, because our winters are warmer.

Thus only a small fraction of the available water in clouds is able to be converted into ice by the natural IN. Since only about 20% of the available moisture condenses into clouds, the resulting precipitation is usually about 5 or 6% (25 to 30 percent of 20 percent) of the available moisture. That is why storms can move across the country. They only drop a small portion of the moisture available and they are being replenished by both ET and inflows from moisture-rich areas, in our case the Gulf of Baja California and the Gulf of Mexico.

The semi-vertical curved line to the right of the Natural IN curve shows the effectiveness of silver iodide as a function of temperature. Because Silver Iodide is effective at warmer temperatures, more of the available SLW can be glaciated. That is the central scientific basis for cloud seeding.

Even more of the SLW, essentially all of it, can be glaciated by using propane to cool the air. More information on propane cooling is available upon request.

B. Types of Cloud Seeding Projects

There are two main types of cloud seeding: plains seeding, done in the summer (growing season) by aircraft for precipitation augmentation or hail suppression, and mountain seeding, done primarily in the winter to achieve increased snowpack. The seeding agent for mountain seeding is usually released from generators on the ground because the zones of super-cooled liquid water (SLW) in winter clouds are very close to the ground.

The key differences are described in the following Table.

Factors Considered	**Plains Seeding**	**Mountain Seeding**
Beneficiaries	Farmers on whose land the rain falls.	• Water rights holders on streams or reservoirs. • Well owners benefiting from increased aquifer recharge.
Seeding agent	Silver iodide.	Silver iodide or propane.
Amount of benefit	One half to one inch of additional precipitation over a summer season.	8 – 14% increase in precipitation leading to a 9% to 17% increase in stream flow..
Cost	$1 per afy.	$10 to $25 per afy.
Size of area impacted	One aircraft can cover 2.5 million acres.	Relatively small target areas…100,000 to 500,000 acres.
Delivery method for the seeding agent	Aircraft to chase the clouds wherever they go.	Usually ground release to impact a particular target area.
Impact on the clouds	Increases convection, thus more moisture is pulled into the clouds, which in turn leads to more precipitation.	Increases the percentage of moisture in the clouds that is glaciated in the target area and to a lesser extent many miles downwind.

One important difference between plains and mountain seeding is that plains seeding covers a very large area, and the objective is to create much additional precipitation, even if the amounts landing on any one acre are not great. For mountain seeding, the goal is to create snowpack in the target area, where you want it, for spring runoff.

Plains seeding projects are frequently organized, funded and managed by local entities, while mountain seeding projects are often funded and managed by the state.

With plains seeding, the existence of improved radar and radar-based software means the aircraft has the ability to deliver the seeding agent to exactly where it is needed in the clouds, and to measure the impact of the seeding on cloud dynamics.

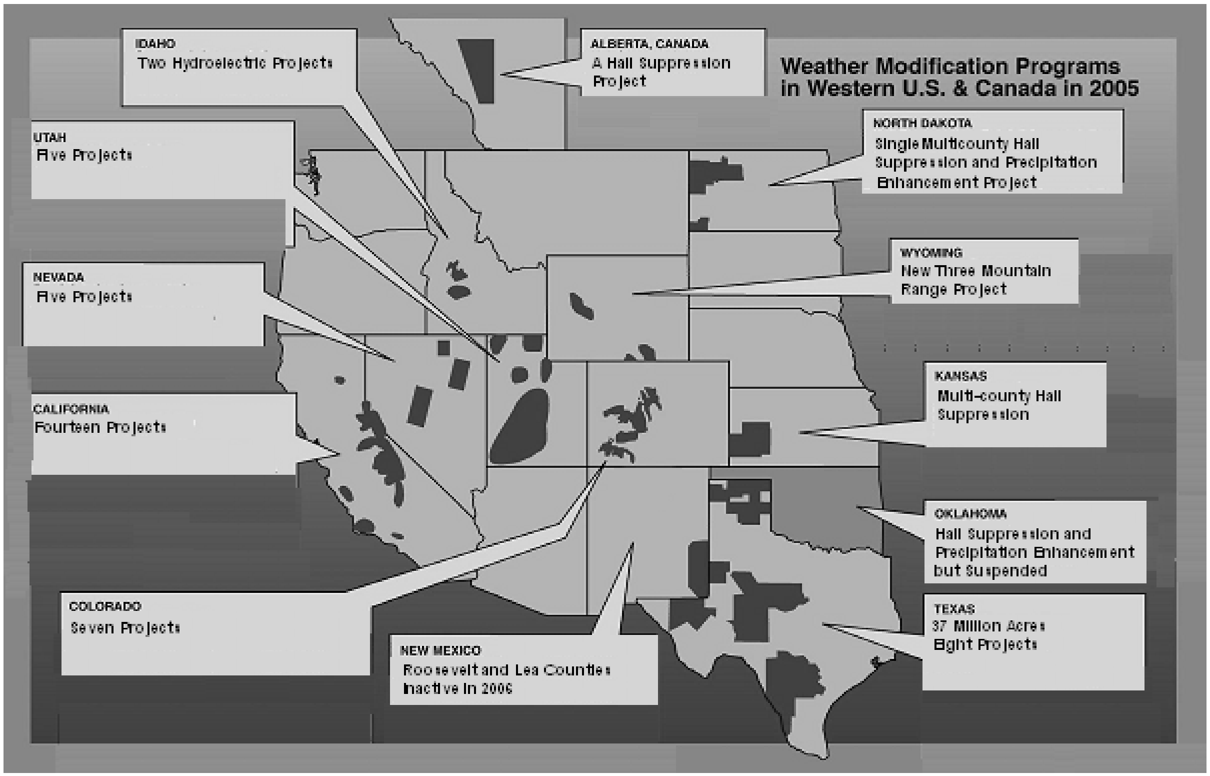
C. Costs

Plains precipitation on farmers' lands generally costs under $1 per acre foot whereas water in streams coming off mountains costs more, usually in the range of $10 to $25 per acre foot. The difference in the costs is mainly related to the scale of operations, with plains seeding involving multiples of 2.5 million acres (the coverage capability of a single aircraft) whereas mountain seeding projects generally are in the 100,000 to 200,000 acre size range. These costs are placed in perspective in the tables in Section II. Generally cloud seeding water is the lowest cost water available: however, the results of cloud seeding vary year by year and location by location and it is not as easy to quantify the additional water gained from cloud seeding. Most water sources are a point source, whereas cloud seeding is distributed over a large area. This leads to the variability of results that is associated with all weather phenomena.

Other than large scale surface capture, cloud seeding is probably the only approach that has costs consistent with the value of water in the agriculture sector.

D. Where cloud seed is taking place in the U.S.

Cloud seeding in the U.S. occurs mainly in the western U.S. and mid-west. Around the world there are perhaps twenty-five nations who have active cloud seeding programs. The project in SE New Mexico shown on this map has not been funded for the past two years. Programs in Wyoming, California and the Colorado River Basin States are expanding. Programs in Texas are under pressure due to reduced state funding.



A Ten Year Plan for Cloud Seeding in New Mexico is available upon request. Please contact Sigmund Silber at ssilber1@juno.com or (505) 473-7006.

Appendix B. Projected Growth in Water Demand through 2040

The following is a tabulation of the consumption information in acre-feet taken from the sixteen regional water plans commissioned by the Interstate Stream Commission.

	2000				2040			
	Agriculture	Municipal/ Domestic	Comm/ Industial	Total	Agriculture	Municipal/ Domestic	Comm/ Industial	Total
Region 1 NE NM	410,520	9,823	405	420,748	412,160	42,600	887	455,647
Region 2 San Juan	172,964	15,955	53,310	242,229	363,682	34,994	73,812	472,488
Region 3 JyS	61,700	27,000	0	88,700	61,700	48,000	0	109,700
Region 4 SW Nm	207,400	1,050	27,020	235,470	207,400	1,060	13,730	222,190
Region 5 Tularosa/ Sacrament	38,410	14,760	970	54,140	46,220	21,160	5,660	73,040
Region 6 NW NM	9,194	11,075	7,927	28,196	9,190	13,680	7,927	30,797
Region 7 Taos	35,395	3,938	2,667	42,000	39,095	8,252	3,561	50,908
Region 8 Tiera y Montes	95,690	6,040	360	102,090	89,700	8,010	520	98,230
Region 9 Colfax	74,020	3,600	740	78,360	73,440	4,760	740	78,940
Region 10 Lower Pecos	636,610	35,690	20,815	693,115	636,840	57,570	24,100	718,510
Region 11 Lower Rio Grande	451,000	35,000	9,000	495,000	451,000	84,000	15,000	550,000
Region 12 MRG	281,930	118,560	51,370	451,860	228,510	278,430	71,080	578,020
Region 13 Estancia	54,880	2,230	64	57,174	54,880	6,800	100	61,780
Region 14 Rio Arriba	25,100	1,600	0	26,700	25,100	3,200	0	28,300
Region 15 Socorro/ Sierra	79,380	5,050	1,710	86,140	80,080	6,440	2,660	89,180
Region 16 Lea County	132,660	17,480	26,275	176,415	275,850	27,100	57,620	360,570
Total New Mexico	2,766,853	308,851	202,633	3,278,337	3,054,847	646,056	277,397	3,978,300

Appendix C. Some Comments on Methodology

Water Budget.

For purposes of establishing a first approximation of the gap that needed to be closed we assumed that supply would remain essentially constant and tabulated the increases in consumption that were projected in the 16 Regional Plans. This of course is only a rough estimate because:

A. It did not take into account the increase in supply from San Juan Chama project.
B. It did not take into account any decrease in supply from climate change or overtaxing of aquifers.
C. It did not take into account the decreases in projected demand resulting from conservation efforts.

The purpose of looking at the water budget was simply to develop an appreciation for the size of the problem facing New Mexico and with respect to municipal /domestic and commercial/industrial we believe the approach was appropriate. Agricuture is hoarder to deal with as the level of consumption in agriculture adjusts more easily to the amount of water that is available that that is difficult to forecast. In one case, where more water is available from Indian Settlements, the level of demand is likely to increase pretty much in line with the increased availability of more water. Thus we placed less reliance on the water budget calculations with respect to the agricultural sector because we concluded that the agricultural sector is likely to be in balance at the end of the 40 year planning horizon but perhaps at a different level than it is today.

Technologies Reported on in this Report.

The Technology Committee has considered a very large number of technologies with respect to both increasing supply and reducing consumption. The matrix below shows our initial analysis of where we should be looking and how various technologies tie in with strategies for improving the water budget. Over time, our thinking evolved and certain technologies were dropped from our analysis. In general the criteria we applied were as follows:

- Potentially large impact especially in Jemez y Sangre Region 3.
- An area were the efforts of the Technology Committee were needed i.e. technologies that were well understood may not have needed the Technology Committee to focus on them e.g. roof capture.
- Of interest to members of the Technology Committee. The Technology Committee is all volunteer so it was essential that one or more members of the Committee were interested in the technology and felt competent to research that technology.
- The technology was a specific technology rather than a category. For example agricultural conservation may have met the first three criteria above but was viewed as a collection of technologies with no one technology meeting the criteria.

In some cases we simply were not able to figure out the technology. Run-off management proved to be too complex relative to the level of interest in the Committee except for the large scale surface capture component which we concluded has very high potential. Run-off management is likely to be very dependent on the topography, soil characteristics and depth to groundwater. Although there was some interest in studying this technology we concluded that the contribution we could make relative to the required level of effort did not justify the Technology Committee taking this one on except for the large scale surface capture component.

Total reuse was of great interest to some Technology Committee members but it was difficult to see how large-scale deployment could be achieved for such a capital intensive approach.

Most of the technologies studied and reported on are supply related although the boundary between more supply and reduced use is not always clear cut. Many technologies support a conjunctive use strategy which is the fifth row in the table below. That is especially the case and important when alternatives can be found to the use of other water sources for domestic landscaping and agriculture. There is another dimension related to water quality that is a factor but not discussed in this report. If a lower quality water source can be used, potable water can be redirected to uses that require potable water.

Consideration of technology is not a one-time event which can be completed in the normal sense that the word completed is generally used. One should continue to consider the impact of technology on the water budget. This report summarizes our findings to date and we believe can be very useful in that context.

We also considered certain other approaches to increasing the Supply of Water. One approach that seems to have a lot of merit is technology-related swaps. As an example one might fund the building of a shallow brackish water extraction and desalination project outside of New Mexico and in return negotiate a reduction in the amount of water flowing through New Mexico that must be allowed to flow into the state where the New Mexico funded project is built. This approach could be considered with respect to Cloud Seeding especially considering the interest in cloud seeding in the Colorado River Basin.

We are not reporting on the potential for swaps or other arbitrage type arrangements in this report. It could be the topic for a short report at a later time.

Jemez y Sangre Water Planning Council – New and Expanded Water Technologies Committee
Mapping of Technologies to Strategies (March 9, 2004)

	Technologies Discussed in the Approved Region 3 Water Plan				**Technologies not Previously Considered.**
Technology / Strategy	**Cloud Seeding**	**Desalination Surface and shallow and deep wells**	**Run-off Management**	**Reuse Technology**	**Water from Oil and Gas wells and use of abandoned pipelines**
Create “new” water		X			X
Increase the recharge of aquifers	X				
Increase surface flow into streams	X		(X)		
Address erosion, silting, and flood issues			X		
Reduce use of well, river and city water	X		X	X	
Innovative solutions with respect to acquisition of water rights	X	X			X