Exhibit 45A: Detailed Discussion of Alternative 45—Reservoir Management

Acknowledgements: This discussion, which follows the same basic format as the fact sheet it accompanies, provides additional details and information that support the conclusions presented in the fact sheet. It was written by Robert Leutheuser of Leutheuser Consulting as part of the "Evaluation of Alternative Actions for Technical, Physical, Hydrological, Environmental, Economic, Social, Cultural, and Legal Feasibility and Water Quality Issues and Legal Overview" contracted to Daniel B. Stephens & Associates, Inc.

1. Definition of Alternative

"Reduce open water evaporation in storage reservoirs by retaining water at higher elevations or latitudes, or by reducing surface areas."

> *"Under the provisions of the Rio Grande Compact, NM must reserve a certain amount of water in the Elephant Butte Reservoir for use by Texas. Both the shape of the reservoir, which has been compared to a champagne glass, and the location, which is in a hot area of the state, contribute to a high percentage of evaporation. Water lost to evaporation is not counted toward the deliverable to Texas. Proposal is to reduce the amount of water lost to evaporation by any of various means, including,*
>
> > *1. Cover Elephant Butte Lake with surfactants, a thin layer of goop that would reduce evaporation. SNL is working to develop a non-hazardous product that would do this.*
> >
> > *2. Store some or all of the water in a cooler region. With a better management plan, it might be possible to minimize the water sent to Elephant Butte and keep it in a cooler region of the state. Or, it may be possible to negotiate a new agreement with Texas and Colorado within the Compact.*
> >
> > *3. Aquifer storage and recovery may solve some of the legal obstacles to alternative storage."* (Middle Rio Grande Water Assembly)

There are several groups of alternative actions that are evaluated in this analysis:

45A Move stored water to reservoirs at higher elevations / more northern latitudes;

a. Move water to an existing storage space
b. Move water to currently unauthorized storage space in an existing reservoir
c. Move water to a new reservoir

45B Dredge reservoirs to improve volume-to-surface area ratios

45C Apply surfactants to stored water surfaces.

The moving of water stored in Elephant Butte Reservoir is addressed in Alternative A-46, "Inject water treated to drinking water standards for aquifer storage and recovery (ASR) in appropriate locations throughout the water planning region."

2. Approach

- Develop ranges of water savings that could be realized by remanaging the storage of water in existing reservoirs under hypothetical conditions, and moving the storage to higher elevation/latitude reservoirs.

- Index documented construction and O&M costs, as available, for unbuilt reservoirs at higher elevations / more northern latitudes, to current year dollars.

- Obtain easement acquisition costs for Abiquiu Reservoir from the City of Albuquerque.

- Obtain costs for reservoir dredging and calculate hypothetical water savings.

- Complete a literature search and consult with Sandia National Laboratories regarding the treatment of water surfaces with products to reduce rate of evaporation.

- Identify environmental issues through the review of contemporary environmental documents.

3. Alternative Analysis: 45A—Move Storage to Higher Elevations/More Northern Latitudes

3.1 Technical Feasibility

Background: The principal of reducing reservoir losses to evaporation by storing water at higher elevations and/or more northern latitudes is sound. In addition to the locations having lower average annual temperatures, the topography of the landscapes in which the reservoirs are or would be located *generally* tend to provide for a higher volume-to-surface area ratio, which would also contribute to reductions in evaporation per unit of water stored.

The Middle Rio Grande water planning region is currently served by a system of reservoirs which have been constructed over the last 70 years to enhance water supply and provide flood control. Figure 45A-1 shows the location of reservoirs; Table 45A-1 summarizes the key reservoirs in the system. Elephant Butte Reservoir is included in Table 45A-1 because of its importance to the Middle Valley's (i.e., the valley between Cochiti Dam and Elephant Butte Reservoir) water budget vis-a-vis the Rio Grande Compact accounting procedures[1]. The once-planned, but never-constructed Wagon Wheel Gap and Indian Camp reservoirs are included because they are considered in the analysis.

Of the total upstream storage capacity of 465,760 acre-feet (ac-ft)[2], 424,369 ac-ft[3], or about 90 percent, is dedicated to Middle Valley water users. All flood control facilities upstream of the Middle Valley directly or indirectly benefit the Middle Rio Grande planning area.

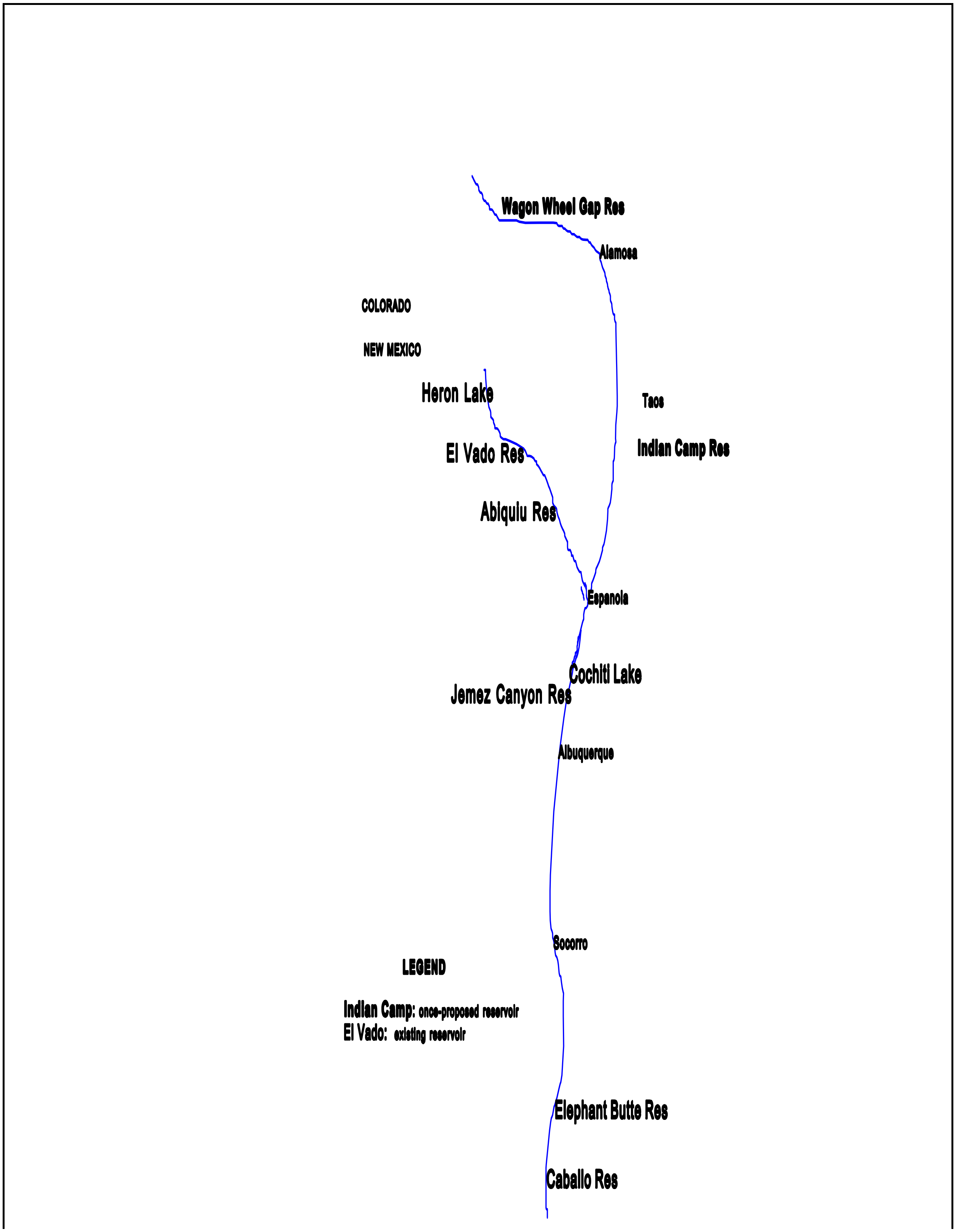

Figure 45A-1: Location of Reservoirs and Selected Once-Planned Reservoirs

Table 45A-1: Key Reservoirs that Influence Water Management in the Middle Rio Grande Planning Area

Reservoir	Owner/ Operator	Capacity (ac-ft)				Elevation Top of Max. Pool (ft msl)
		Total	Conservation	Flood Pool	Designated Sediment Pool	
Wagon Wheel Gap [a]	NA	500,000	300,000	200,000	0	8,700
Indian Camp [a]	NA	5,500	3,000	2,000	330	7,325
Heron	Reclamation	401,000	401,000 [b]	0	0	7,186
El Vado	Reclamation MRGCD	180,560	180,560	1,200 [c]	0	6,879
Abiquiu	USACE	1,215,000	640,000 [d]	502,000	77,000	6,350
Cochiti	USACE	582,019	0 [e]	492,000	105,000	5,460
Jemez Canyon	USACE	97,425	0	73,000	44,213	5,232
Elephant Butte	Reclamation	2,065,000	2,065,000	50,000/ 25,000 [f]	0 [g]	4,407

[a] Reservoir once planned, but never constructed.
[b] Storage provides for an annual firm yield of 96,200 ac-ft for San Juan-Chama Project water. No storage of native water authorized.
[c] November-April flood pool within the 180,560 ac-ft conservation pool.
[d] Current authorization: 200,000 ac-ft of conservation storage
[e] About 50,000 ac-ft is stored to maintain authorized 1,200 surface-acre recreation pool.
[f] Considered to be discretionary flood space within conservation storage: 50,000 ac-ft May-October; 25,000 ac-ft November-April.
[g] No official sediment pool was designed into Elephant Butte. Since construction, there has been about 558,000 ac-ft of lost storage capacity (Reclamation, 2000).

ft msl = Feet above mean sea level   Reclamation = Bureau of Reclamation   USACE = U.S. Army USACE

Because of its importance to water management in the Middle Rio Grande planning area, an additional explanation of conservation storage in Abiquiu Reservoir is warranted. Public Law 97-140 (1981) authorized the storage of 200,000 ac-ft of San Juan-Chama Project water in the reservoir. The City of Albuquerque obtained the necessary inundation easements, up to an elevation of 6,220 feet above mean sea level (ft msl). In 1999, the volume of available space was about 184,000 ac-ft because of sediment deposition. The City and the U.S. Army Corps of Engineers (USACE) signed a storage agreement allowing the City to store up to 170,900 ac-ft, and the USACE manages the remaining conservation storage space. In 1988, Public Law 100-52 was passed also allowing the storage of “native” water (not imported from another river basin) in the previously authorized space, for which New Mexico State Engineer permits would be required. No such permits have been issued to date.

New Technologies and Status

No new technologies are required to transfer water storage from downstream reservoirs to *existing storage spaces*, or *additional spaces in existing reservoirs*. The shifting of storage depends on available water supplies and available space in reservoirs. The ability to move storage in the Rio Grande Basin is highly influenced by institutional and legal considerations, most notably state water law, federal law, Native American law, the Rio Grande Compact and environmental laws.

Nor are new technologies required for the *construction of new dams and reservoirs*. Such construction, however, would take advantage of new technologies that may lead to reductions in construction costs. These technologies are not on the critical pathway to making decisions regarding whether or not new reservoirs would be constructed. Institutional, legal, and economic considerations would ultimately determine whether or not a new reservoir would be constructed.

Infrastructure Development Requirements

In the case of moving storage from one reservoir to another's *existing storage space*, there are no infrastructure development requirements *Using currently unauthorized storage space in an existing reservoir*, i.e. Cochiti Lake or Abiquiu Reservoir, would require the modification of reservoir-associated facilities, such as boat ramps, camping and picnicking grounds, etc., possible relocation of roads (depending on storage quantity added), and possible relocation of residences at Abiquiu Reservoir. The *construction of a new dam*, reservoir, and appurtenant structures requires considerable infrastructure development.

Total Time to Implement

Total time required to "move" Elephant Butte Reservoir storage to *existing upstream reservoir space* is dependent on hydrologic cycles and the resolution of legal and institutional issues. Both are beyond the scope of this effort to predict.

To *use currently unauthorized storage space to an existing reservoir* (e.g. Abiquiu or Cochiti) would require the acquisition of lands and/or easements and the relocation of facilities. This could take 5 to 10 years. However, it would also require, as a prerequisite, Federal legislation which would be predicated on the resolution of legal, water rights, Native American, and environmental issues. Contemporary experience in the West indicates that this could take 15 to 20 years to accomplish, if possible at all.

The total time required to plan, design, and construct *new reservoirs* (in this analysis, at the Wagon Wheel Gap site in southern Colorado and the Indian Camp site south of Taos) is equally difficult to predict. In a political and legal vacuum, the dams and appurtenant structures could be constructed in maybe 5 years following the completion of all planning, design, and land acquisition activities. However, the Western United States is rife with contemporary examples of new water projects being tied-up for three decades in the planning phases, e.g. the Animas-La Plata Project in southwestern Colorado.

3.1.1 Physical and Hydrological Impacts

Effect on Water Demand

Increasing water supplies through the reduction of evaporative losses would have no effect on water demand.

Effect on Water Supply

The purpose of reducing reservoir evaporative losses is to increase water supply.

Water Saved

There are numerous factors beyond surface evaporation rates that influence the amount of water that would be saved by storing water in reservoirs at higher elevations and/or more northern latitudes. From a physical standpoint, the ratio of volume-to-surface area is extremely important. From a management standpoint, water management decisions based on professional interpretation and institutional/legal requirements dictate amount of storage, duration of storage, rates of releases, timing of releases, water exchanges, etc. All of these have tremendous impacts on how much water is actually saved, if any at all.

The volume-to-surface ratio is determined by the shape of the reservoir basin and how much water is in the reservoir at any given time. For example, a reservoir that has a surface area of 10 acres for 100 ac-ft of stored water has a volume-to-area ratio of 10. Another reservoir with a surface area of 10 acres for a volume of 50 ac-ft of stored water has a volume-to-area ratio of 5. Assuming the same evaporation rate, the second reservoir would suffer twice the evaporation *per unit of stored water* as the first reservoir. Reservoirs are not regularly shaped, therefore the volume-to-surface ratio changes constantly with changes in the volume of the water stored. Generally, evaporation per unit of water decreases with more-full reservoir conditions.

This analysis relies heavily on the USACE, Albuquerque District's 1989 report entitled *Reevaluation of the Rio Grande Operating Plan*. The purpose of the study was ". . . to analyze the operation of Federal reservoirs in the Upper Rio Grande Basin above Fort Quitman, Texas for the purpose of identifying areas for improving flood control protection and optimizing beneficial use of the waters of the Rio Grande." *All evaporation data used in this analysis, except for Wagon Wheel Gap and Indian Camp reservoirs, are presented in or derived from this report and reflect 1981-1987 evaporation rates.*

Static Analysis: Table 45A-2 summarizes the amounts of water that could be saved annually (assuming constant reservoir elevations) by moving stored water from Elephant Butte Reservoir to upstream reservoirs. The hypothetical cases presented are the more plausible scenarios that could be considered in the future, such as moving 50,000 ac-ft, not 100,000 ac-ft to El Vado Reservoir due to that reservoir's total capacity.

As can be seen, there are a range of opportunities to reduce evaporative losses. The savings increase when water is moved from less-full Elephant Butte conditions, where the evaporative losses are greater (as expressed as a percentage of stored volume). For example in moving the 100,000 ac-ft from a 1-million ac-ft pool, to a 100,000 ac-ft Abiquiu pool, there is an annual savings of 6,200 ac-ft. But when the same quantity of water is moved from a 2 million ac-ft pool, the annual savings are reduced to 4,200 ac-ft. Similarly, water savings are increased when like quantities of water are moved to more-full receiving reservoir conditions.

In the cases arrayed in Table 45A-2, the highest percentage savings occur in moving 50,000 ac-ft of storage from a less full Elephant Butte (1-million ac-ft pool) to a more full El Vado pool (100,000 ac-ft). The lowest percentage savings—14 percent—occurs when water is moved from a more-full Elephant Butte Reservoir to a less-full Cochiti Lake. The most attractive water savings opportunities involve moving water from a less-full Elephant Butte Reservoir to a more-full Abiquiu Reservoir.

Table 45A-2. Hypothetical Water Savings Realized Reductions in Evaporation Resulting from the Transfer of Storage from Elephant Butte Reservoir to Upstream Reservoirs

Elephant Butte				Destination Reservoir				Water Savings	
Volume (ac-ft)		Evaporation				Evaporation			
Storage Volume	Water Moved	% of Storage	Annual (ac-ft)	Name of Reservoir	Volume Before / After Move (ac-ft)	% of new storage	Annual for Moved Water (ac-ft)	(ac-ft)	percent
1,000,000	50,000	12.7	6,350	Cochiti	50,000/100,000	9.2	4,600	1,750	28
1,000,000	50,000	12.7	6,350	El Vado	50,000/100,000	5.0	2,500	3,850	61
1,000,000	50,000	12.7	6,350	El Vado	100,000/150,000	4.6	2,300	4,050	64
1,000,000	100,000	12.7	12,700	Cochiti	50,000/150,000	8.1	8,100	4,600	36
1,000,000	100,000	12.7	12,700	Abiquiu	100,000/200,000	6.5	6,500	6,200	49
1,000,000	100,000	12.7	12,700	Abiquiu	200,000/300,000	5.4	5,400	7,300	57
2,000,000	50,000	10.7	5,350	Cochiti	50,000/100,000	9.2	4,600	750	14
2,000,000	50,000	10.7	5,350	El Vado	50,000/100,000	5.0	2,500	2,850	53
2,000,000	50,000	10.7	5,350	El Vado	100,000/150,000	4.6	2,300	3,050	57
2,000,000	100,000	10.7	10,700	Cochiti	50,000/150,000	8.1	8,100	2,600	24
2,000,000	100,000	10.7	10,700	Abiquiu	100,000/200,000	6.5	6,500	4,200	39
2,000,000	100,000	10.7	10,700	Abiquiu	200,000/300,000	5.4	5,400	5,300	50
1,000,000	100,000	12.7	12,700	Wagon Wheel	300,000/400,000	1.0 [a]	1,000	11,700	92
2,000,000	5,000	10.7	535	Indian Camp	500/5,500	7.6 [b]	380	155	29

[a] Data derived from "Appendix E - Water," assumed to be companion material to U.S. Bureau of Reclamation's 1955 report, *Revised Supplemental Report on Rio Grande & Weminuche Pass Divisions, San Luis Valley Project, Rio Grande Basin, Colorado.* Source dates of evaporation unknown.

[b] Data derived from U.S. Bureau of Reclamation, 1970, *Volume 2A Definite Plan Report San Juan-Chama Project*. Source dates of evaporation unknown.

The volume of water saved is proportional to the volume of storage that is “moved” upstream. In considering the 5,500 ac-ft Indian Camp Reservoir, once proposed as part of the unbuilt San Juan-Chama Project’s Taos Unit, it is evident that in spite of its relatively high elevation and low evaporation rate, there would not be enough water savings, about 155 ac-ft, to justify its construction.[5]

The Wagon Wheel Gap Reservoir was once proposed as a feature of the Bureau of Reclamation’s Closed Basin Project. As a large reservoir located both at a high elevation and a more northerly latitude (on the Rio Grande near Creede, Colorado), the evaporation savings could be tremendous: around 90 percent.

Water Operations Analysis: The *Reevaluation of the Rio Grande Operating Plan* (USACE, 1989) used the reservoir/routing model HEC-5 to evaluate three sets of water management plans: 1) enhance flood control; 2) add conservation storage; and; 3) move Elephant Butte Reservoir storage upstream. All plans were compared to current operations at the time. The analyses included all operational variables, including dynamic reservoir storage, conveyance losses, and evaporation losses.[6] Although the results were principally influenced by operational decisions, they included a Wagon Wheel Gap Reservoir and can shed some light on magnitudes of savings *as expressed in reductions of excess releases from Elephant Butte Dam,* defined as releases greater than downstream irrigation demands (USACE, 1989). As summarized in Table 45A-3, moving 100,000 ac-ft of Elephant Butte storage to Cochiti Lake reduced the average annual excess releases from Elephant Butte by 1,250 ac-ft. In plans to *add* conservation storage to the Upper Rio Grande Basin, adding 100,000 ac-ft of storage to Abiquiu Reservoir or Cochiti Lake reduced average annual excess releases by 2,700 to 3,200 ac-ft, and added about 95,000 ac-ft of water annually to the Middle Rio Grande Valley water supply. Care needs to be exercised in using this information in that the operational assumptions used in the model do not reflect current operational constraints. The greatest reductions in average annual excess releases, about 7,500 ac-ft, occurred when storage is added to Wagon Wheel Gap Reservoir. In the USACE analysis, however, this water was managed for the benefit of Colorado water users.

Table 45A-3: Scenarios Evaluating Effects of the Remanagement of 100,000 Acre-Feet in the Rio Grande System [a]

Destination Reservoir	Total Excess Releases (1,000 ac-ft)	Reduction from "Current Operation"[b] (1,000 ac-ft)	Percent Change from "Current" Operation	Ave. Annual Reduction in Excess Releases (ac-ft)	Addition to Middle Rio Grande Valley water supply [c]
Plans to Move 100,000 ac-ft of Elephant Butte Reservoir Water to Upstream Reservoirs					
Abiquiu	295.3	11.1	3.6	569	0
Cochiti	282.0	24.4	8.0	1,251	0
Wagon Wheel Gap	292.1	14.3	4.7	733	0
Plans to Add 100,000 ac-ft of Conservation Storage to Upstream Reservoirs					
Abiquiu	254.2	52.2	17.0	2,677	95.0
Cochiti	243.4	63.0	20.1	3,231	96.5
Wagon Wheel Gap	159.8	146.6	47.8	7,518	0 [d]

Source: All data from, or derived from, USACE (1989), Table 26, assuming a 1,000 cfs channel capacity at Fort Quitman.

[a] Excess releases are defined in the report as releases from Caballo Reservoir in excess of downstream (Rio Grande Project) irrigation demands. These releases did not begin until Elephant Butte Reservoir filled.

[b] Current operations were defined as projected hydrology being managed by established flood control and Rio Grande Compact operating rules. For these analyses, the total excess releases under the current operations for the period of study was 306,400 ac-ft, or an annual average of 15,700 ac-ft.

[c] Only the alternatives which added conservation storage increased usable water supplies. In the study it was assumed the water would be used for irrigation, but it could have been destined to any water use in the Middle Rio Grande Valley.

[d] It was assumed all additions to water supplies due to Wagon Wheel Gap Reservoir were used in Colorado.

3.1.2 Environmental Impacts

45a. Existing Storage Space

The most significant environmental effects of "moving" stored water to upstream reservoirs in existing conservation pools would be the alteration of the shape of the hydrographs downstream from the points of storage and release. Depending on the management decisions, this would have the potential to affect both the riverine and riparian communities throughout the system between the change in storage points, such as between Abiquiu Dam and Elephant Butte Reservoir. The obligate endangered species that occupy the environments, such as the Rio Grande silvery minnow and the Southwestern willow flycatcher, could likewise be affected. In the past, water managers have been able to coordinate dynamic operational decisions so as to minimize the impacts, although increasingly regulatory compliance with the Endangered Species Act is required. There would be opportunities to deliver the upstream-stored water to the benefit of the communities and species. For example, late-spring deliveries could create periods of high flows for silvery minnow spawning, or overbank flooding for bosque rejuvenation or renovation.

The effects on the ecosystems associated with the reservoirs could also be mixed, depending on the water management decisions. If the management regimes promoted more stable water levels, the aquatic ecosystems would benefit. If the reservoir levels were managed so as not to have drawdowns during the fisheries' spawning seasons, the effects would be beneficial. However, if the resultant water level fluctuations were of greater magnitude and frequency, it would be harmful to the aquatic community. The same logic extends to the riparian areas associated with the reservoirs: water levels and timing of inundation can have direct effects on the riparian species composition. For the Southwestern willow flycatcher, proximity to water is also an important habitat quality variable. However, because the existing reservoir conditions are predicated on water level fluctuations and the "moved" water would managed within the established operational latitudes, the effects of moving stored water to upstream reservoirs would be expected to be *relatively* insignificant.

45b. Currently Unauthorized Storage Space in Existing Reservoirs

Adding storage space to an existing reservoir would have similar potential effects to the downstream riverine and riparian ecosystems as remanagement of water within existing spaces. The role of water management decisions would also continue to largely determine the nature and magnitude of the effects. However, there would also be additional impacts to the reservoir-associated environment where the additional storage is created. Categories of impact would include the reservoir lacustrine community, the general surrounding terrestrial environment, and the riverine and riparian communities associated with the inflowing river.

The USACE looked at the environmental impacts that would result from adding 467,000 ac-ft (total space available at that time) of conservation storage to Abiquiu Reservoir (USACE, 1987). As with the initial inundation of any land area by a reservoir, there would be a period of increased biological productivity as the soil nutrients are released into the aquatic environment. Additionally, the increase in the size of the reservoir would numerically add volume to the aquatic environment. The USACE projected that a larger Abiquiu Reservoir could attract more bald eagles. It would also be likely that more waterfowl and shore birds would be attracted to the reservoir. For the additional storage of 467,000 ac-ft, the USACE estimated that an additional 2,600 acres of land would be inundated. (By comparison, the addition of 100,000 ac-ft of storage would result in the inundation of about 1,000 acres of land at full-reservoir conditions.) As water levels recede, all vegetation associations (annual grasses and forbs, piñon-juniper grassland, shrub-grassland, and canyon bottom/riparian forest) would experience some recolonization, but would be significantly different than their pre-inundation character. The fauna associated with the vegetation associations would likewise be altered. Of particular importance would be the riparian community associated with the Rio Chama at its point of inflow. Not only would prolonged inundation kill the existing vegetation, but the deposit of sediments would create new conditions, possibly favorable, for riparian recolonization during prolonged periods of drawdown.

Although not strictly an “environmental impact,” consideration of adding storage space to Abiquiu Reservoir must anticipate effects on the Rio Chama’s designation as a “Wild and Scenic River” upstream from the reservoir. Although the authorizing legislation (Public Law 100-633) specifically recognized Abiquiu Reservoir’s operational requirements, additional storage would conflict with other legislated and public use values.

For Cochiti Lake, a report prepared under the auspices of the Rio Grande Initiatives in the early 1990s is illustrative of impacts that can be anticipated when added storage space to a reservoir (Allen et al., 1993). An interagency team looked at the biological effects of a proposal which would occasionally and temporarily store an additional 5,000 ac-ft of water in Cochiti Lake June through October. As a result of higher water levels in Cochiti Lake from 1985 to1988, sediments formed a delta area upstream on the Rio Grande at the headwaters of White Rock Canyon. In the intervening 5 years between the last inundation and the preparation of the report, a riparian and wetland community developed in the delta which was emerging as important habitat for riparian-obligate species, waterfowl, and the bald eagle. The team concluded that the proposal would “have significant, negative impacts” on the delta riparian and wetland because of the periodic inundation.

It is assumed that Elephant Butte Reservoir would *generally* have less water in it (recognizing the more-full to full reservoir conditions would still occur but less frequency and for shorter durations). The magnitude of the effects would depend on the quantity of water moved upstream. However, a smaller pool of water would decrease the area of the lacustrine environment, and would increase the exposure of the riparian/wetland community below the reservoir's maximum surface elevation. Much of this community is located along the 23-miles of the Rio Grande Valley between San Marcial and "The Narrows" of Elephant Butte Reservoir. According to data presented in a Draft Environmental Statement prepared by the U.S. Bureau of Reclamation (Reclamation, 2000), at the time of report preparation there were about 8,500 acres of riparian and wetland communities in this reach, of which about 25 percent were monotypic stands of salt cedar. About 20 percent of the total area was rated as being "highly suitable" Southwestern willow flycatcher habitat. The water management decisions would significantly influence on the resultant character of the area.

45c. New Reservoirs

Construction of new reservoirs would have immediate, dramatic, and permanent environmental impacts on the terrestrial, riverine, and riparian environments inundated. The specific nature and extent of the impacts would depend on the location and size of the reservoir. A new reservoir would also change the downstream hydrographs and water temperatures, affecting both the riverine and riparian communities. Temporary effects would be experienced during the construction period, and additional indirect long-term impacts would accrue as the result of population influxes to the area, as are common around Western reservoirs. As with other options to store water at locations to reduce evaporative losses there would be the potential through water management decisions, to operate the reservoirs for environmental benefits.

3.2 Financial Feasibility

45a. Existing Storage Space.

The costs associated with moving Elephant Butte storage upstream to existing storage spaces in Abiquiu or El Vado reservoirs would be determined through negotiations with the managing entities of the storage spaces, the City of Albuquerque and the Middle Rio Grande Conservancy District (MRGCD), respectively.

In the past the MRGCD has charged other entities $2 to $5 an ac-ft per year plus 10 to 20 percent of the stored water to store water in El Vado Reservoir. The agreements also have stipulated that the owner of the stored water absorb a proportional share of the evaporative losses, and the MRGCD retains the first right to use the water if it was needed (Shah, 2001). It must be remembered, however, that the "water surcharge" is ultimately used in the Middle Rio

Grande planning area; the net transaction *for the planning area* would be differential evaporation rates and monetary payments. If 10,000 ac-ft were moved from a 1-million ac-ft Elephant Butte Reservoir pool to a 100,000 ac-ft El Vado Reservoir pool, the net savings in evaporation would be about 400 ac-ft for a year's storage. Assuming a charge of $5/ac-ft and an average annual evaporative loss of 20 ac-ft, the cost per ac-ft of avoided evaporation would be about $130. Similar arrangements could possibly be made with the City of Albuquerque to store water in its Abiquiu Reservoir conservation pool, with similar resultant costs.

Also in Abiquiu Reservoir, the USACE allows other San Juan-Chama contractors to store their water in the remaining 13,000 ac-ft of conservation storage space (within the authorization and City-owned easements, but above the City of Albuquerque's 170,900 ac-ft contracted pool). Storing entities are charged a pro rata share of operation and maintenance costs, which were $0.30 per ac-ft in 2001. If this entire space were to be used for water moved from a 1-million ac-ft 1- pool, the annual cost per ac-ft of the 1,000 ac-ft of evaporation avoided would be about $5 per ac-ft.[7]

45b. Currently Unauthorized Storage Space in Existing Reservoirs

In 1987, the USACE, Albuquerque District, issued a report reviewing the feasibility of adding conservation storage within Abiquiu Reservoir's maximum pool in addition to the authorized 200,000 ac-ft conservation pool. The cost estimates, *adjusted for inflation only*, in 2002 dollars, are presented in Table 45A-4. These costs include proportional construction repayment obligations to the USACE.

Table 45A-4: Cost Estimates for Adding New Storage Space to Abiquiu Reservoir (USACE, 1987)

Total Additional Storage (ac-ft)	Total Cost [a]	Average Annual Cost per Ac-ft
50,000	$14,920,000	$33.25
100,000	$28,730,000	$32.00
200,000	$56,825,000	$31.50
467,000 [b]	$151,270,000	$36.00

[a] Adjusted to 2002 dollars for inflation only.
[b] The maximum possible additional conservation storage.

If the additional storage was used to move 100,000 ac-ft of water from a 1 million ac-ft Elephant Butte Reservoir pool to a 200,000 ac-ft Abiquiu Reservoir pool in order to reduce evaporative losses, the annual cost per ac-ft of water saved 7,300 ac-ft) would be about $440.

One of the expenses in increasing storage behind existing dams would be obtaining easements. To add 100,000 ac-ft of conservation storage to Abiquiu Reservoir, easements would be required for an additional 1,000+ acres.

During the Abiquiu Dam and Reservoir pre-construction phase, the USACE obtained flowage easements for all lands that are subject to temporary inundation associated with the flood control operations, up to the reservoir's maximum water surface elevation. These easements disallow the construction of any permanent structures on the lands (Satz, 2003).

For Abiquiu Reservoir, the City of Albuquerque obtained 2,310 acres of storage easements up to elevation 6,220 feet msl in the 1980s. The agreements provided annual payments in the form of the right of each landowner to use a specified quantity of the City's San Juan-Chama Project-contracted water, all together totaling 433 ac-ft per year (Kelly, 2002). Using the current costs of $100/ac-ft/ year for San Juan-Chama Project water, as established by contemporary Endangered Species Act compliance program leases, the current leases would cost, on average, about $20/acre/year. The City of Albuquerque is exploring options to convert the existing 55-year easements to permanent easements through offering property owners cash payments in lieu of water payments. As these agreements have yet to be negotiated, no cost estimates are available.

In 2001 the USACE purchased in fee title about 16 acres of land for which it previously held a flowage easement, at a cost of about $2,300 per acre. Based on a cursory review, unimproved upland land prices in the general Abiquiu area *not associated with the reservoir or the Chama River*, were in the range of $3,000 - $5,000 per acre.

Using the USACE's recent transaction, acknowledging that because of the myriad of variables in the real estate market that it is only valid to establish a point of reference, the cost of obtaining the necessary additional storage easements to increase the storage in Abiquiu Reservoir by 200,000 ac-ft would be in the neighborhood of $2.5 million.

45c. New Reservoirs

In 2002 dollars, the cost to construct the 500,000 ac-ft Wagon Wheel Gap Dam and Reservoir would be about $150 million dollars[8]; the 5,500 ac-ft Indian Camp Dam and Reservoir would be about $35 million. These costs were derived from original Bureau of Reclamation planning document (Reclamation, 1955 and 1970) cost estimates, indexed to current dollars using the Bureau of Reclamation Construction Cost Trend data. The costs reflect the projects as they were designed at the time; they do not anticipate any additional contemporary features or mitigation measures that would likely be required. No cost estimates were available for operation and maintenance.

3.3 Conclusions

Moving water stored in Elephant Butte Reservoir to reservoirs with lower evaporation rates is sound water management and needs to be pursued at every given opportunity. The most realistic prospects from financial and environmental perspectives are storing additional water in Abiquiu Reservoir, either in the currently authorized space or in currently unauthorized conservation storage space.

PART II: ALTERNATIVE 45B—DREDGING

3.4 Technical Feasibility

Background: Reservoirs trap sediments transported by inflow water. The rate and pattern of deposition and the character of the sediment is governed by the upslope watershed, river morphology, inflow hydrographs, reservoir shape, and reservoir operations. Deposited sediments infringe upon the water storage capacity of a reservoir and alter the shape of a reservoir's bottom. It should be noted that the reservoirs that effect middle Rio Grande valley water management are large, and all have "sediment pools" designed into them (Table 45A-1) to accommodate sediment deposition.

As previously discussed, one of the variables influencing the amount of water lost through evaporation is the volume-to-surface area ratio; the higher the ratio, the lower evaporative losses for every unit of water stored. Sediment removal in the context of this discussion therefore, is limited to altering the evaporation per unit of stored water, not to recover lost storage space.

A review of literature revealed that, to date, reservoir dredging has been accomplished for the following purposes:

- Regain storage space in smaller reservoirs, primarily for municipal and industrial water supplies
- remove contaminated sediments
- restore capabilities of small sediment catchment impoundment
- improve or restore fisheries habitat
- reestablish inflow conveyance efficiencies

No documentation was found where dredging was pursued to reduce evaporative losses, nor on the scale that need to be anticipated in the Upper Rio Grande Basin. The largest scale dredging operation located in this literature search was 3,000 ac-ft from 1985-1995, removed from a 187,000 ac-ft reservoir in Taiwan.

3.4.1 Physical and Hydrological Impacts

Effect on Water Demand

Increasing water supplies through dredging would have no effect on water demand.

Effect on Water Supply

It is possible to increase a reservoir's volume-to-surface area ratio through dredging, thereby decreasing the rate of evaporation per unit of water stored. This can be best demonstrated through several examples involving two reservoirs that impact water management in the Middle Rio Grande planning area.

- *Example 1*, Abiquiu Reservoir: Average annual evaporation for a reservoir volume of 200,000 ac-ft is, as expressed as percentage of storage, is 6.5; for a volume of 150,000 ac-ft, evaporation is 7.6 percent. Assume that 50,000 ac-ft of material is dredged from the 150,000 ac-ft pool thereby providing 200,000 ac-ft of storage with the same surface area. As shown in Table 45A-5, there would be a 1,600 ac-ft annual reduction of evaporative losses.

Table 45A-5: Hypothetical Examples of Effects of Dredging Abiquiu Reservoir on Annual Evaporative Losses

Storage Space	Volume (ac-ft)	Surface Area (acres)	Annual Evaporation as % of storage	Volume:Area	Annual Evaporation (ac-ft)
unmodified 150,000	150,000	3,689	7.6	41:1	11,400
unmodified 200,000	200,000	4,207	6.5	48:1	13,000
dredged 150,000	200,000	3,689	5.7	54:1	11,400

- Example 2, Cochiti Lake: Following the same methodology, this time increasing the volume of a 50,000 ac-ft pool to 100,000 ac-ft pool by dredging, the annual water savings would be 4,500 ac-ft, as shown in Table 45A-6.

Table 45A-6: Hypothetical Examples of Effects of Dredging Cochiti Lake on Annual Evaporative Losses

Storage Space	Volume (ac-ft)	Surface Area (acres)	Annual Evaporation as % of storage	Volume:Area	Annual Evaporation (ac-ft)
unmodified 50,000	50,000	1,187	9.4	42:1	4,700
unmodified 100,000	100,000	2,323	9.2	84:1	9,200
dredged 50,000	50,000	1,187	4.7	43:1	4,700

3.4.2 Environmental Impacts

The most enduring environmental impacts of a dredging operation are associated with the disposal of the dredged material. Because of the quantities of material required to save significant volumes of water, massive areas of land would be required for a disposal site. For example, on a flat surface, 50,000 ac-ft of dry spoil deposited on a Section of land (1 mile square; 640 acres), would create a truncated 85-foot tall pyramid with 3:1 side slopes.

The environmental effects of such an area, with annual additions of 1,000 ac-ft of spoil, would be enormous to the terrestrial ecosystem. Wet dredging presents additional challenges for spoil disposal, as disposal sites would have to located and designed to allow the draining of water from the material which could present water quality issues.

With wet dredging, there would be a mobilization of sediments in the surrounding water that would have a temporary effect on the reservoir ecosystem and likely long-term and severe impacts on the downstream riverine ecosystem (Monterrey Peninsula Water Management District, 1998).

The effects of the hauling of the sediment to the disposal site would significant because of the scale of the operation. In addition to the disruption of any fauna in immediate area because of the prolonged activity (for California example, the removal 620 ac-ft of sediment would take 5.7 years of hauling, 10 trucks/hour for 8-hour days [Monterrey Peninsula Water Management District, 1998]), there would be noise and air pollution issues.

3.5 Financial Feasibility

Recent estimates for New Mexico reservoir dredging include:

- Santa Cruz Reservoir: ~$7,500/acre foot (Resource Technology, Inc., 2002)
- Santa Cruz Reservoir: ~$14,500/acre foot (Reclamation, 1983) [9]
- Miami Lake (wet dredging): $7,000-$14,000/acre foot (DBS&A, 2002)
- Miami Lake (dry dredging): $2,500-$4,000/acre foot (DBS&A, 2002)
- Lake Alice (dry dredging): $9,500/acre foot (DBS&A, 2002) [10]

A contemporary estimate from California for removing 854 ac-ft of sediment, without mitigation costs, was $13,000 to $47,000 per acre foot (Monterey Peninsula Water Management District, 1998). The same high-end estimate was prepared for dredging 800 ac-ft from a reservoir in British Columbia, Canada (Ootsa-Nechako Watershed Protection Committee, 2002).

Offsite disposal is a major component of the costs, often constituting more than half of the total costs. This makes it very tenuous to project dredging costs on a non-site specific basis. However, for the purposes of this evaluation, a total cost of $7,500/acre foot is used for dredging in the dry, including disposal. This is very close to the average of the above values for dry dredging in New Mexico.

- Example 1. The cost for dredging 50,000 ac-ft in Abiquiu Reservoir would be $375,000,000. For the annual savings of 1,600 ac-ft, the cost per ac-ft of water saved would be approximately $234,000.

- Example 2: The cost for dredging 50,000 ac-ft in Cochiti Lake would also be $375,000,000, but because the annual water savings would be 4,500 ac-ft, the cost would be about $83,000/acre foot saved.

Maintenance costs would reoccur due to inflowing sediments refilling the dredged space, the rate of filling being influenced by the location of the dredge site, reservoir management, inflow hydrology, watershed condition, etc. The average annual sediment deposition in Abiquiu Reservoir from 1963 to 1997, was 978 ac-ft/yr. Assuming the same rate of deposition *in the dredged space*, the space would be filled in 51 years. The maintenance of the space (and annual evaporation savings) would cost $7,335,000/year. For Cochiti Lake, the 1972-1998 average annual rate of sediment deposition was 1,007 ac-ft. With the same assumptions, it would cost about $7,500,000 per year. These results are summarized in Table 45A-7.

Table 45A-7: Hypothetical Costs and Water Savings Associated with Dredging Existing Reservoirs

Reservoir	Initial Quantity Dredged (ac-ft)	Annual Quantity of Water Saved (ac-ft)	Estimated Project Cost	Initial Cost per acre foot water saved	Annual Dredging Quantity (ac-ft) [a]	Annual Dredging Cost
Abiquiu	50,000	1,600	$375 million	$234,000	978	$7.3 million
Cochiti	50,000	4,500	$375 million	$83,000	1,007	$7.5 million

[a] To maintain original 50,000 ac-ft dredged space.

3.6 Conclusions

It is economically infeasible to use dredging as a reservoir management tool to reduce evaporative losses on the large reservoirs that effect middle Rio Grande water management. However, where sediment deposition negatively interferes with a reservoir's mainstem delivery of water due to the formation of deltas, such as at the upper end of Elephant Butte Reservoir, dredging is a viable alternative to improve the efficiency of water delivery to the reservoir.

PART II: ALTERNATIVE 45C—SURFACTANTS TO REDUCE SURFACE EVAPORATION

3.7 Technical Feasibility

Background: Barriers between water surfaces and climatic variables can reduce the amount of water lost to evaporation. In the simplest of cases, plastic covers can be placed over relatively small bodies of water up to 5 to 10 acres in size (Hightower and Tadros, 2002). For large bodies of water, research and development in the past has been directed to application of surfactants (chemical films or molecular monolayers) to water surfaces to decrease evaporation by increasing surface tension. The testing conducted in the 1960s demonstrated that the technologies could limit evaporation, but were susceptible to wave action degradation necessitating reapplication every couple of days, rendering the process uneconomical. Advances in surfactant and polymer chemistry suggest that new products and techniques may prove to be more economical. The principal factors that must be addressed for surfactants to large reservoirs are: the stability of the film on the water; the film's self-healing properties; and, the ability to spread the film on the water surface (Gupta et al., 2002).

New Technologies and Status

There are commercial products using advanced surfactant chemistry now available on the market to apply to water surfaces to reduce evaporation. One such product is Water$aver®, produced by Flexible Solutions International, a U.S. firm. Using food-grade chemicals (fatty alcohol) to form a molecular monolayer, it claims evaporation reductions of up to 40 percent with application every 2 to 2½ days. The largest water surface to which Water$aver has been applied, for which documentation could be located, was a 3 hectare (7.4 acre) industrial pond in Chennai, India, where experiments conducted by the Anna University (Flexible Solutions International, 2002) resulted in 25 to 40 percent savings (Capitol Reports, 2002).

Specifically referencing the needs for reducing evaporative losses from large reservoirs in arid climates, the Department of Energy's Sandia National Laboratories (SNL) completed initial research on two surfactant formulations (Gupta et al., 2002). The researchers conducted controlled small-scale experiments in laboratory and out-of-door settings evaluating the molecular monolayers mixed with organic solvents.

The SNL is also interested in exploring biosurfactants, organic surfactants produced by bacteria. Contemporary work with biosurfactants has resulted in evaporation retardation at about half the efficiency of other surfactants. If the efficiencies could be improved, there is the potential that the costs per unit of surfactant manufactured could be reduced dramatically, along with the possibility of onsite surfactant production (Hightower, 2002).

Infrastructure Development Requirements

It is likely that any surfactant product that would be used for regional water management purposes would be developed, marketed, and applied by the private sector. Accordingly, all infrastructure development would not be an issue for water managers. However, should the potential of onsite production be realized for biosurfactants, water management interests could be involved in the construction and management of the production facilities.

Total Time to Implement

Although the molecular monolayer approach to reduce evaporation is well-established, it is impossible to predict when, or even if, a surfactant will be developed that is effective in reducing evaporative losses from large reservoirs. It is apparent that more research and development of surfactants is required. Additional funding within the private sector will be driven by business decisions; funding within the public sector will be driven by public policy, national budget, and priority considerations. This is an attractive area for public/private funding partnerships, as well as interagency funding collaboration.

3.7.1 Physical and Hydrological Impacts

Effect on Water Demand

Increasing water supplies through the application of surfactants would not affect water demand.

Effect on Water Supply

The purpose of reducing reservoir evaporative losses is to increase water supply.

- *Water Saved*

The Middle Rio Grande Water Assembly's intent of exploring the feasibility of using surfactants is to reduce evaporative losses from Elephant Butte Reservoir. Although there is not a surfactant proven to work effectively on large reservoirs, for the purposes of this discussion, current product information is extrapolated to Elephant Butte Reservoir.

The range of water savings that could be realized is dependent upon the effectiveness of the surfactant, the volume of water in the reservoir, and evaporation rates. Assuming a 50 percent reduction in evaporation (range 25 to 70 percent), and a year-round application of the surfactant to Elephant Butte Reservoir, annual savings as summarized in Table 45A-8 could be realized.

Table 45A-8: Hypothetical Evaporative Savings Using a Surfactant on Elephant Butte Reservoir

Elephant Butte Pool Size (ac-ft)	Untreated Average Annual Evaporation Losses (ac-ft)	Treated Average Annual Evaporation / Evaporative Savings (ac-ft)	Tons of Product [1]
200,000	45,000	27,500	244
1,000,000	127,000	63,500	689
2,000,000	214,000	107,000	1,160

[a] Assuming application rates recommended by Water$aver, with year round applications every 2½ days.

3.7.2 Environmental Impacts

Environmental impacts of molecular monolayer surfactants still require research. However, Water$aver has received the designation as an "Environmentally Sound Technology" from the United Nation's International Environmental Technology Center (Capital Reports, 2002). Flexible Solutions International states that the use of food-grade chemicals results in no negative impact on the oxygen levels in the water, water temperature, nor aquatic life. The product "can be used safely and effectively to preserve water resources including raw water supplies, reservoirs, canals, lakes, ponds and recreation areas." (Capital Reports, 2002).

The SNL, in its recent experiments, simply had a gold fish in each of the out-of-door pools. The fish did not appear to be affected by the surfactant. Additionally, no differences were observed in dissolved oxygen measurements between the treated and untreated pool during the multiple-month experiment (Gupta et al., 2002).

3.2 Financial Feasibility

It must be stated clearly and unequivocally that *presently there is no surfactant available with a proven ability to function on a large reservoir*. With that said, the cost for the surfactant alone in the SNL's controlled small-scale experiments, was about $30 per acre foot of evaporative water saved (Gupta et al., 2002). The application of Water$aver in the example cited above, cost about $250 per acre foot of evaporative water saved (Flexible Solutions International, 2002).

3.8 Conclusions

Surfactants that would be effective in reducing evaporative losses from large reservoirs is still in the research stage. It is unknown whether or not such a product will ever be developed. However, because of the potential water savings benefits and potential cost effectiveness, research should be continued in this area. Funding is a limitation, so the supporting public should, in coordination with universities and other research organizations such as Sandia National Laboratories, petition legislators for federal and stated efforts by increasing funding for continued research in this area.

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[1] The City of Albuquerque also has the right to store up to 50,000 ac-ft of San Juan-Chama Project water in Elephant Butte Reservoir.

[2] Includes 96,200 ac-ft (annual firm yield) of San Juan-Chama Project water from Heron Reservoir.

[3] Includes 2,510 ac-ft of middle Rio Grande valley San Juan-Chama Project water in Abiquiu Reservoir under short-term contracts with the USACE in 2001.

[5] The Indian Camp Dam was proposed to be built on the Rio Grande del Rancho, about 10 miles south of the Town of Taos. The 155 ac-ft of annual water savings would be realized if the entire capacity of the reservoir (less a small "dead pool") were dedicated to Elephant Butte storage, moving 5,000 ac-ft from a 100,000 ac-ft Elephant Butte.

[6] The analyses were based on 1967 to 1987 actual flow records, which were projected 19½ years from a start date of, and reservoir conditions as of, September 1988.

[7] Public Law 100-52 authorized the storage of native water in the 200,000 ac-ft conservation space previously authorized solely for the storage of San Juan-Chama Project water.

[8] The USACE, in its 1989 *Reevaluation of the Rio Grande Operating Plan Report* estimated at the time that the construction costs for Wagon Wheel Gap Dam and Reservoir would be $300 million to $500 million. The source of the estimate is unknown.

[9] Additional cost due to a more distant sediment disposal site.

[10] Actual 1993 costs of removing and disposing 53 ac-ft of sediment in the dry at $7,517/acre foot, indexed to January 2002 costs.