UTAH CLOUD SEEDING PROGRAM

INCREASED RUNOFF/COST ANALYSES

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Summary

From the analyses in this report, the estimated average annual increase in runoff due to cloud seeding in Utah is 249,600 acre-feet. This is an average annual increase of 13.0 percent. The estimated project cost for the 1999-2000 season is $254,300. The resulting cost per acre-foot is about one dollar ($1.02).

Introduction

The Utah Legislature passed the Utah Cloud Seeding Act in 1973. Utah has operated a cloud seeding program since 1974. The program is run by local sponsors contracting with a weather modification company to provide the cloud seeding operations. The state provides financial assistance to these sponsors ranging from 30 to 50 percent of project costs, based on the availability of state funds and the magnitude of local projects.

The purpose of this study is to estimate the amount of runoff developed by cloud seeding and the cost per acre-foot. The procedures used to make these estimates are:

1. Estimate the total average annual runoff from the areas that are being seeded (target areas).
2. Estimate the increase in April 1 snow water content due to cloud seeding, based on target and control analysis.
3. Determine the relationship (equations) between annual runoff and April 1 snow water content for major gaged rivers and streams in the target areas.
4. Estimate the increase in average annual runoff due to cloud seeding, based on 1, 2 and 3 above.

5. Compute the estimated cost per acre-foot by dividing the project cost by the increase in average annual runoff determined in 4 above.

Cloud Seeding Project Areas and Operational Cost

Utah has four active cloud seeding project areas, as shown in Figure 1. The winter storm systems in these areas are being seeded with ground-based generators using silver iodide. The Central and Southern Utah Project (CSUP), comprised of the Central/Southern Utah and the Tooele County project areas, is sponsored by the Utah Water Resources Development Corporation. The Northern Utah Project (NUP), comprised of the West Box Elder and the East Box Elder/Cache County project areas, is sponsored by the Bear River Water Conservancy District and Cache County. North American Weather Consultants is the contractor for each of these projects.

The estimated cost for the Northern Utah Project is $87,800 for the 1999-2000 season. The estimated cost for the Central and Southern Utah Project is $166,500 for the 1999-2000 season. The total estimated cost for both projects is $254,300. For the 1999-2000 season, the state, through the Division of Water Resources, is cost-sharing with the local sponsors at 50 percent ($127,150).

Average Annual Runoff in the Cloud Seeding Project Areas

As part of the State Water Plan, the Utah Division of Water Resources has published annual stream flow charts for the 1941-1990 period for most streams in the state. The division has also published hydrologic inventories and water budget reports for most areas of the state. Based on data from these reports, an estimate of the average annual runoff for the 50-year 1941-1990 period has been made for the cloud seeding project runoff areas. A summary of the estimated annual runoff data is shown in Table 1. The estimated runoff data for each runoff area in the project areas are tabulated in

Figure 1

CURRENT CLOUDSEEDING PROJECT AREAS

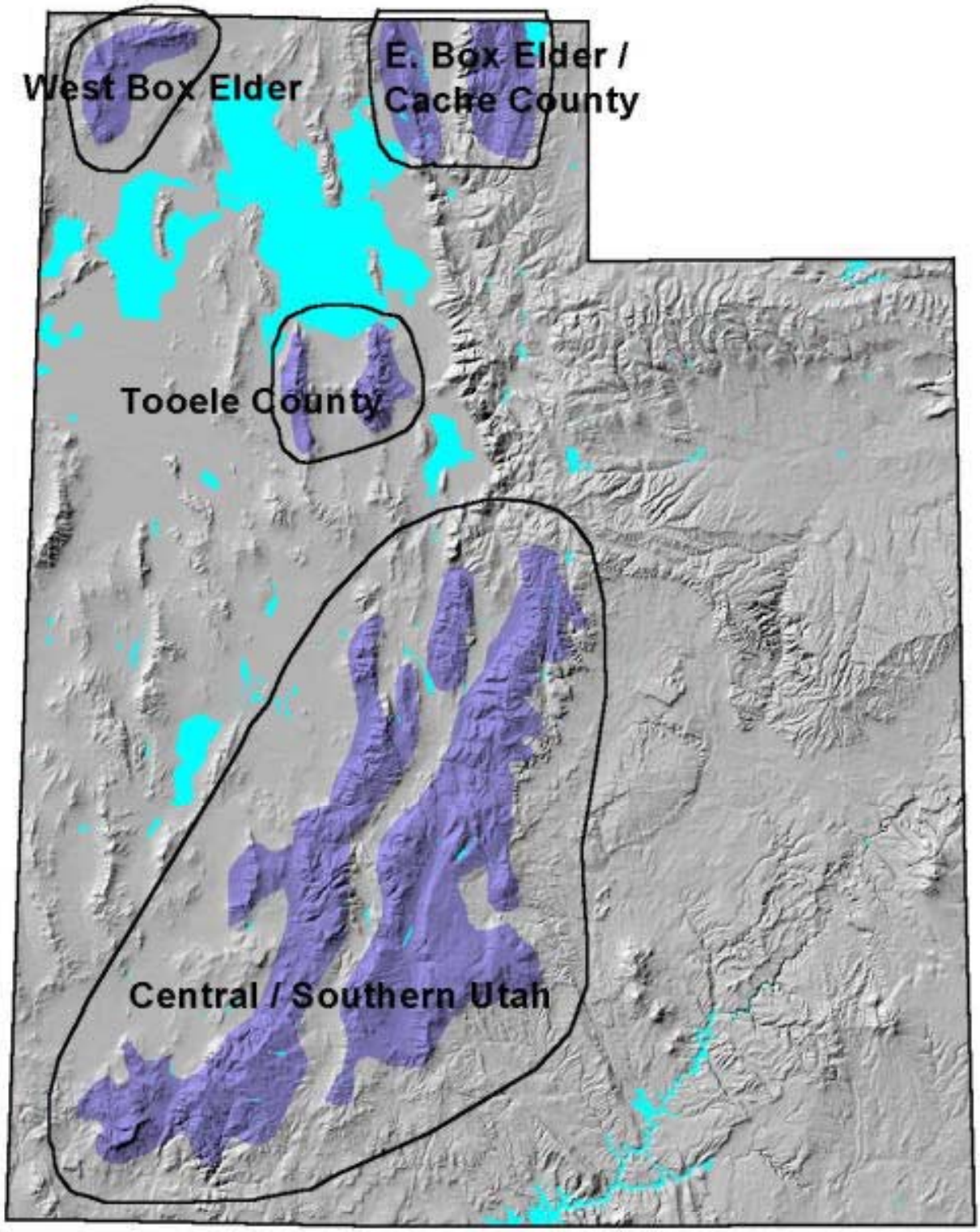

Table 1.
CLOUD SEEDING PROJECT AREA ESTIMATED AVERAGE ANNUAL RUNOFF
1941-1990

Project Runoff Areas	Project	Annual Runoff (acre-feet)
Cache County	NUP	424,000
West Box Elder	NUP	57,800
Tooele County	CSUP	43,300
Sevier River	CSUP	653,000
Cedar-Beaver	CSUP	135,000
West Colorado	CSUP	411,500
Virgin River	CSUP	192,400
Total		1,917,000
Northern Utah Project (NUP)		481,800
Central and Southern Utah Project (CSUP)		1,435,200

Appendix A. The annual runoff for the Northern Utah project areas is 481,800 acre-feet. The annual runoff for the Central and Southern Utah project areas is 1,435,200 acre-feet. The total annual runoff for both projects is 1,917,000 acre-feet.

Precipitation Increase from Cloud Seeding

Most of the cloud seeding activity in the Utah project areas occurs during the December-March period. Target and control analyses, using precipitation gages in the cloud seeding project areas (target areas) and control precipitation gages in upwind unseeded areas located in Idaho, Nevada and Arizona, have been made and published (see References) by North American Weather Consultants. The data and analyses have been reviewed and confirmed by the Division of Water Resources. In addition, target and

control analyses have also been made for April 1 snow water content. The April 1 snow water content analyses are important because relationships can be developed to estimate runoff based on April 1 snow water content.

The Central/Southern Utah project area has operated continuously since water year 1974, with the exception of the extremely wet period from 1984-87. The project has had 22 seeded seasons. The project area has 66 cloud seeding generators. Using a target and control regression analysis for December through March precipitation, the Central/ Southern Utah project area indicates a 14 percent average increase in precipitation for this period. A similar analysis using April 1 snow water content shows an average increase of 7 percent.

Seeding began in the Tooele County project area in 1976 and continued through the 1982 water year. Seeding resumed in 1989 through 1992 and again in 1996 to 1999. The project area has had 15 seeded seasons. The project area has nine cloud seeding generators. Target and control regression analyses show a December-March precipitation average increase of 19 percent and an April 1 snow water content average increase of 20 percent.

The East Box Elder/Cache County project area has operated 11 years beginning in 1989. The project area has 22 cloud seeding generators. Target and control regression analyses shows a December-February precipitation average increase of 20 percent and an April 1 snow water content average increase of 18 percent.

The West Box Elder project area operated for nine years from 1989 through 1997. The project area has 12 cloud seeding generators. The target area has no precipitation gages; however, there are two snow courses. A target and control regression analysis shows an April 1 snow water content average increase of 18 percent.

Table 2 shows a summary of the results for the project areas. The analyses show the average precipitation increase during the seeding period ranging from 14 to 20 percent and the April 1 average snow water content increase ranging from 7 to 20 percent. For the project areas in the northern part of the state, the average precipitation increases are about the same as the April 1 average snow water content increases. In the Central/Southern Utah project area, the average April 1 snow water content is one-half of the average precipitation increase. The reason for the difference may be due to earlier snowmelt in the southern part of the state compared to the control areas.

Table 2.
SUMMARY OF CLOUD SEEDING PROJECT AREAS

Project Area	Number of Cloud Seeding Generators 1999-2000 Season	Seeded Years	Precipitation Increase During Seeding Period	April 1 Snow Water Content Increase
Central/Southern Utah	66	22	14%	7%
Tooele County	9	15	19%	20%
East Box Elder/Cache County	22	11	20%	18%
West Box Elder County	12	9	N/A	18%

Annual Runoff Estimated from April 1 Snow Water Content

Regression equations relating annual runoff to April 1 snow water content were derived for the major gaged rivers and streams in the cloud seeding project areas. The equations were used to estimate the percent increase in annual runoff (water years) that would occur for a 10 percent increase in the April 1 snow water content. The gaged streamflow stations, correlated SNOTEL/snow course station(s), regression equation correlation coefficient, and the percent annual runoff increase for a 10 percent increase in April 1 snow water content are shown in Table 3. As expected, a 10 percent increase in the April 1 snow water content results in a greater than 10 percent increase in annual

Table 3.
INCREASE IN ANNUALRUNOFF FOR A TEN PERCENT INCREASE IN APRIL 1 SNOW WATER CONTENT

Streamflow Station	SNOTEL/Snow Course Stations	Correlation Coefficient	Annual Increase
10109001 Logan River Combined Flow	Tony Grove Lk, Bug Lk, Dry Bread Pond, Ben Lomond Pk, Monte Cristo	0.87	11.4%
10113500 Blacksmith Fork	Bug Lake, Monte Cristo, Ben Lomond Peak	0.81	14.3%
10104700 Little Bear near Avon	Ben Lomond Peak, Little Bear, Farmington	0.85	12.0%
10172952 Dunn Creek near Park Valley	George Creek Snow Survey	0.89	14.8%
13077700 George Creek near Yost Utah	George Creek Snow Survey	0.83	10.4%
10172800 South Willow Creek near Grantsville	Desert Peak, Mining Fork, Rocky Basin-Settlement, Vernon Creek	0.85	10.7%
10172700 Vernon Creek near Vernon	Vernon Creek, Rocky Basin-Settlement	0.76	11.9%
09405500 North Fork Virgin River	Midway Valley, Webster Flat, Kolob	0.93	11.6%
09406000 Virgin River at Virgin	Midway Valley, Kolob, Castle Valley, Webster Flat	0.94	10.3%
09409880 Santa Clara River at Gunlock	Long Flat, Kolob, Midway Valley	0.91	16.5%
10174500 Sevier River at Hatch	Midway Valley, Big Flat, Merchant Valley, Castle Valley	0.92	13.2%
10194200 Clear Creek near Sevier	Kimberly Mine, Box Creek, Pine Creek	0.75	18.8%
10205030 Salina Creek near Emery	Pine Creek, Pickle Keg, Dills Camp, Farnsworth Lake	0.86	19.5%
10215900 Manti Creek	Seeley Creek, Red Pine Ridge, Clear Creek #1, Payson R.S., Pine Creek	0.77	14.3%
10183500 Sevier River near Kingston	Midway Valley, Big Flat, Merchant Valley , Castle Valley	0.85	12.3%
10183900 East Fork Sevier River near Rubys Inn	Midway Valley, Kolob, Castle Valley	0.94	12.5%
10234500 Beaver River near Beaver	Kimberly Mine, Merchant Valley, Big Flat, Box Creek	0.89	13.6%
10242000 Coal Creek near Cedar City	Midway Valley, Webster Flat, Castle Valley	0.91	11.1%
09310000 Goosberry Creek near Scofield	Clear Creek #1, Red Pine Ridge	0.86	14.1%
09310500 Fish Creek near Scofield	Clear Creek #1, Red Pine Ridge, Mammoth-Cottonwood, Payson R.S.	0.89	16.0%
09312600 White River near Soldier Summit	White River #1, Mammoth-Cottonwood, Clear Creek #1, Payson R.S.	0.94	20.0%
09317997 Huntington Creek near Huntington	White River #1, Mammoth-Cottonwood, Clear Creek #1, Payson R.S.	0.82	11.9%
09326500 Ferron Creek near Ferron	Buck Flat, Dill's Camp, Pickle Keg, Farnsworth Lake	0.92	14.2%
09329050 Seven Mile Creek near Fish Lake	Farnsworth Lake, Box Creek	0.79	13.8%
09330500 Muddy Creek near Emery	Dill's Camp, Pickle Keg, Buck Flat, Farnsworth Lake	0.88	14.3%
09337500 Escalante River near Escalante	Midway Valley, Widstoe #3, Donkey Reservoir, Castle Valley	0.83	12.2%

runoff. A higher percent of the increased snow water runs off because the base conditions account for most of the losses such as infiltration and evaporation.

The choice of a 10 percent increase in April 1 snow water content was arbitrary. It represents an easy reference to relate expected increases in runoff and is in the expected range of increased April 1 snow water content due to cloud seeding. The actual increases in April 1 snow water content are used in the analysis below to estimate the increase in runoff for each project area.

Estimated Increased Runoff and Cost per Acre-Foot

The annual increase in runoff for a 10 percent increase in April 1 snow water content for each streamflow station in Table 3 is volume-weighted for all streamflow stations in each river basin in the cloud seeding project areas. These weighted values are multiplied by the increase in the April 1 snow water content from the target and control analysis and divided by 10 to obtain a runoff factor. The increase in annual runoff due to cloud seeding is estimated by multiplying the average annual runoff by the runoff factor. The results are shown in Table 4. The estimated average annual increase for the total cloud seeding project area is 249,600 acre-feet. The Northern Utah Project increase is 106,900 acre-feet. The Central and Southern Utah Project increase is 142,700 acre-feet.

The increased runoff, project cost and cost per acre-foot of water developed from the cloud seeding projects are shown in Table 5. The total estimated cost of both projects for the 2000 water year is $254,300, resulting in a cost of about one dollar ($1.02) per acre-foot of water developed from cloud seeding. The costs per acre-foot for the Northern Utah Project and the Central and Southern Utah Project are $0.82 and $1.17, respectively.

The above estimated costs per acre-foot of water developed by cloud seeding are for surface runoff and do not include increased recharge to the groundwater system. The April 1 snow water content for the Central/Southern Utah project area some years may not represent the peak snow water content because of early snowmelt in the southern portion

Table 4.
CLOUD SEEDING PROJECT AREA ESTIMATED INCREASED RUNOFF

Project Areas	Average Annual Runoff (acre-feet)	Increase in April 1 SWC* (percent)	Increase in Runoff** (percent)	Runoff Factor*** (percent)	Increased Runoff (acre-feet)
Cache County	424,000	18.0	12.4	22.32	94,600
West Box Elder	57,800	18.0	11.8	21.24	12,300
Tooele County	43,300	20.0	11.3	22.60	9,800
Sevier River	653,000	7.0	14.4	10.08	65,800
Cedar-Beaver	135,000	7.0	12.9	9.03	12,200
West Colorado	411,500	7.0	13.9	9.73	40,000
Virgin River	192,400	7.0	11.0	7.70	14,800
Total	1,917,000				249,600
Northern Utah Project	481,800				106,900
Central and Southern Utah Project	1,435,200				142,600

*April 1 snow water content.
**Increase in annual runoff for a 10% increase in April 1 SWC.
***Runoff Factor (percent) equals increase in April 1 SWC times increase in runoff for a 10 percent increase in April 1 SWC divided by 10.

Table 5.
INCREASED RUNOFF AND COST FOR THE CLOUD SEEDING PROJECTS

Project	Increased Runoff (acre-feet)	Cost ($)	Cost ($/acre-foot)
Northern Utah	106,900	87,800	0.82
Central and Southern Utah	142,652	166,500	1.17
Total	249,600	254,300	1.02

of the state compared to the control stations. If data were available to include these two factors, the cost per acre-foot would be less.

REFERENCES

1. Griffith, Don A., and Mark E. Solak, *A Summary of Operations and Evaluation of a Cloud Seeding Program in Cache County, Utah During the Water Year 1999*, TRC North American Weather Consultants, Sandy, Utah, 1999.

2. Griffith, Don A., and Mark E. Solak, *Summary of 1999 Water Year Operations and Evaluation of a Cloud Seeding Program in Central and Southern Utah*, TRC North American Weather Consultants, Sandy, Utah, 1999.

3. Griffith, Don A., *A Summary of Operations and Evaluation of a Cloud Seeding Program in Box Elder and Cache Counties of Northern Utah During the Water Year 1997*, TRC North American Weather Consultants, Salt Lake City, Utah, 1997.

4. Utah Division of Water Resources, State Water Plan, Basin Plans:
   Bear River Basin - 1992
   Cedar/Beaver Basin 1995
   Kanab Creek/Virgin River Basin - 1993
   Sevier River Basin - 1999
   West Colorado River Basin - 2000
   West Desert Basin - 2000

5. Utah Division of Water Resources, *Water Budget Report of the Columbia River Basin, Utah Portion*, unpublished report, 2000.

6. Utah Division of Water Resources, *West Desert Water Budgets*, unpublished report, 1999.

7. Utah Division of Water Resources, *Hydrologic Inventory of the Sevier River Basin*, 1991.

8. Utah Division of Water Resources, *Cloud Seeding Program Water Year 2000*, unpublished report, 2000.

APPENDIX A

AVERAGE ANNUAL RUNOFF 1941-1990
FOR THE
CLOUD SEEDING PROJECT AREAS
WATER YEAR 2000

CACHE COUNTY ESTIMATED RUNOFF 1941-1990

Source	Runoff (ac-ft)
Logan River	184,000
Blacksmith Fork	98,000
East Fork Little Bear	26,000
South Fork Little Bear	41,000
High Creek	21,000
Summit Creek	14,000
Miscellaneous	40,000
Total	424,000

WEST BOX ELDER ESTIMATED RUNOFF 1941-1990

Source		Runoff (ac-ft)
Raft River		39,900
Lynn	9,100	
Yost	5,700	
Clear Creek	14,400	
Goose Creek	10,700	
Grouse Creek		7,100
Pine Creek	2,000	
Ungaged	1,400	
Etna Area	3,700	
Park Valley		10,800
Indian Creek	2,900	
Dove Creek	900	
Fish Creek	2,200	
Dunn Creek	4,100	
Ungaged	700	
Total		57,800

TOOELE - RUSH VALLEYS ESTIMATED RUNOFF
1941-1990

Source		Runoff (ac-ft)
Tooele Valley		22,987
Box Elder Creek	3630	
South Willow Creek	4778	
North Willow Creek	3205	
Devenport Creek	1379	
Pine Creek	1430	
Middle Creek	4865	
Settlement Creek	3700	
Rush Valley		20,263
Vernon Creek	2070	
Bennion Creek	405	
Dutch Creek	125	
Harker Creek	270	
Clover Creek	3168	
Big Hollow Creek	2030	
Hickman Creek	2540	
Soldier	2422	
Ophir Creek	6205	
Mercur Creek	1028	
Total		43,250

SEVIER RIVER ESTIMATED RUNOFF
1941-1990

Subarea	Runoff (ac-ft)
Mammoth Creek	83,900
Panguitch	26,400
Otter Creek	19,200
East Fork	42,200
Piute Reservoir	12,500
Marysville	32,300
Richfield	55,100
San Pitch	207,000
Gunnison	45,000
Scipio-Levan-Eureka	13,800
Oak-Fool Creeks	16,400
Fillmore	74,200
Nephi-Salt Creek*	25,000
Total	653,000

*Not in Sevier Drainage Area

WEST COLORADO ESTIMATED RUNOFF
1941-1990

Source		Runoff (ac-ft)
Price River		96,300
Gooseberry	16500	
Ungaged Inflow	21800	
Mud Creek	11600	
White River	20600	
Beaver Creek	3300	
Willow Creek	8400	
Coal Creek	4100	
Miscellaneous	10000	
San Rafael		200,700
Huntington Creek	76100	
Cottonwood Creek	75900	
Ferron Creek	48700	
Dirty Devil		67,100
Muddy Creek	28700	
Ivie Creek	2900	
Fremont River	32300	
Pine Creek	3200	
Escalante		39,600
Paria		7,800
Total		411,500

CEDAR-BEAVER ESTIMATED RUNOFF
1941-1990

Source	Runoff (ac-ft)
Beaver River	63,100
Little Creek	1,300
Red Creek	1,000
Parowan Creek	12,100
Summit Creek	2,900
Coal Creek	24,200
Pinto Creek	13,400
Shoal Creek	17,000
Total	135,000

VIRGIN RIVER ESTIMATER RUNOFF
1941-1990

Source	Runoff (ac-ft)
Virgin @ Virgin	131,000
Santa Clara @ Gunlock	15,700
Miscellaneous	25,400
Kanab/Johnson	20,300
Total	192,400