

Utah Cloud Seeding Program

Increased Runoff/Cost Analyses

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Introduction

Cloud seeding in Utah began in the early 1950's. In 1973 the legislature passed the Utah Cloud Seeding Act and large-scale seeding projects have been ongoing ever since. Currently there are four projects being sponsored. These include the Central and Southern Utah project areas, the Northern Utah project areas, the West Uintas project area, and the High Uintas project area. Local sponsors run the program and the cloudseeding operations are contracted out to a weather modification company. The Utah Division of Water Resources provides financial assistance to the sponsors.

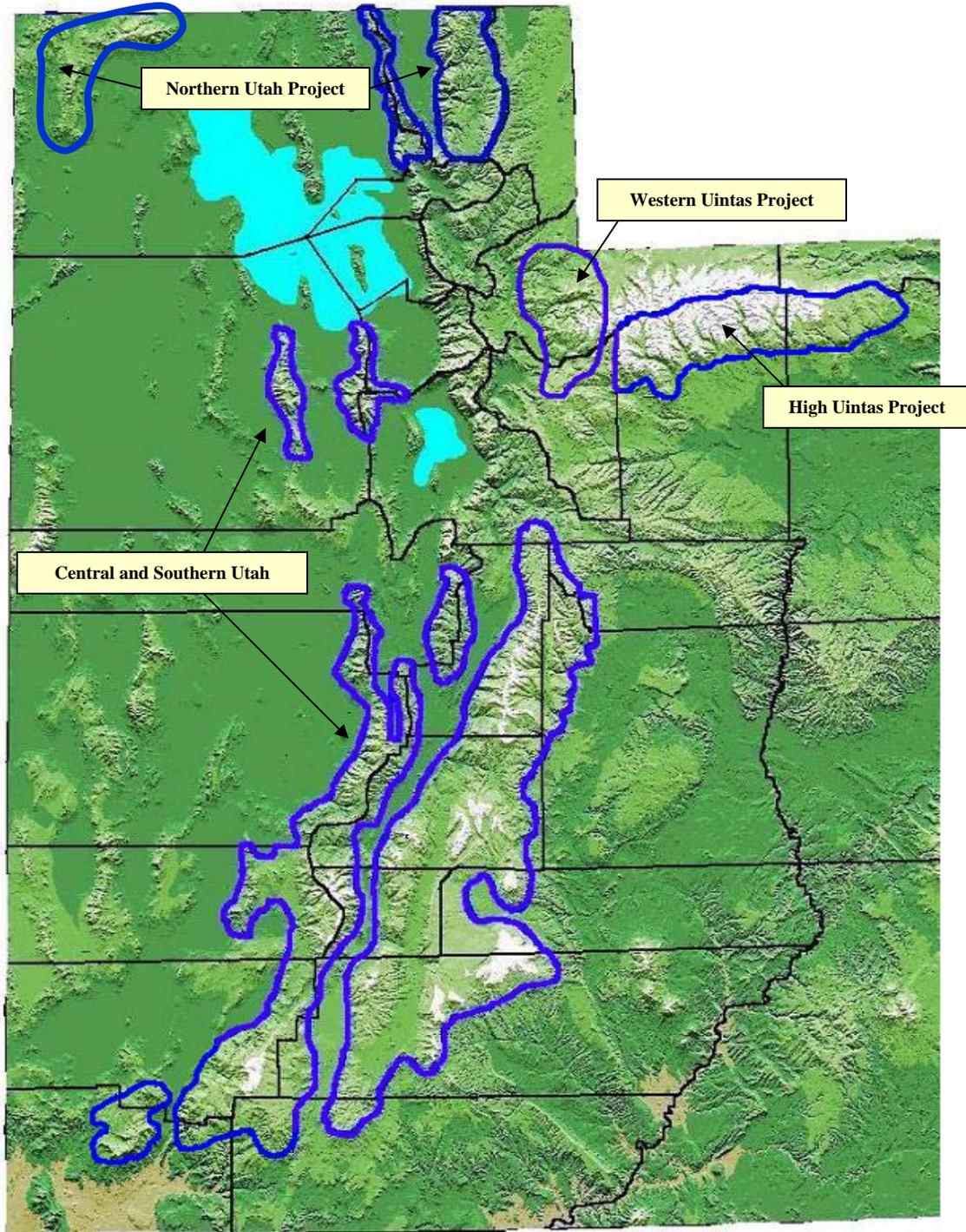
Cloud seeding seems to be a viable way to augment the natural water supply. The purpose of this study is to estimate how much of an increase in runoff should be expected and how much it costs per acre-foot of water. The procedures used to make these estimates are:

1. Estimate the total average annual runoff from the areas that are being seeded.
2. Estimate the increase in April 1st snow water content due to cloud seeding based on target and control analysis.
3. Determine the relationship (equations) between annual runoff and April 1st 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 Costs

There are currently four large-scale cloud seeding projects being sponsored, as shown in Figure 1. Most of the cloud seeding activity in Utah occurs during the December-March period. The storms are being seeded with ground-based generators using silver iodide. The Northern Utah project, comprised of the West Box Elder and the

Figure 1. Current Cloud Seeding Project Areas



East Box Elder/Cache County areas, is sponsored by the Bear River Conservancy District and Cache County. The Central and Southern Utah Project, comprised of Central/Southern Utah and Toelle County areas, is sponsored by the Utah Water Resources Development Corporation. The West Uintas Project is sponsored by the Weber Basin Water Conservancy District and the Provo River Water Users Association. The High Uintas project is sponsored by the Central Utah Water Conservancy District, the Duchesne County Water Conservancy District, and the Uintah Water Conservancy District. The contractor for all of the projects is North American Weather Consultants located in Sandy, Utah.

For the 2003-2004 season, the cost for the Northern Utah Project was \$76,507, the cost for the Central and Southern Utah Project was \$159,674, the cost for the Western Uintas Project was \$65,682, and the cost for the High Uintas Project was \$75,999. That is a total of \$377,862. The Division of Water Resources was cost sharing with the local sponsors at 38% (\$142,448).

Average Annual Runoff in the Cloud Seeding Project Areas

To determine the amount of increased runoff due to cloud seeding, it was necessary to estimate the average annual runoff in the different project areas. The Utah Division of Water Resources has published annual stream flow charts for the 1941-1990 period for most streams in the state. Based on data from these charts and hydrologic inventories, an estimate of the average annual runoff for the 50-year period has been made for the cloud seeding project areas. A summary of the estimated annual average runoff is in Table 1.

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	57,000
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
Western Uintas	WUP	492,000
High Uintas	HUP	773,300
Total		3,181,500
Northern Utah Project (NUP)		481,800
Central and Southern Utah Project (CSUP)		1,435,200
Western Uintas Project (WUP)		492,000
High Uintas Project (HUP)		773,300

Precipitation Increase

The increase in precipitation due to cloud seeding is determined by using a technique called target and control analysis. The technique is based on variables that are affected by cloud seeding such as precipitation and snowpack. The control sites are unseeded areas located upwind from the target sites. The target and control analyses have been made and published by North American Weather Consultants. The data and analyses have been reviewed and confirmed by the Division of Water Resources. A summary of the results from the analyses follows.

Cloud seeding in the Eastern Box Elder/Cache County area has been ongoing for 16 years beginning in 1989. There were 23 cloud seeding generators in the project area for the 2003-2004 winter season. Target and control regression analyses show an average increase in precipitation of 16% and an average increase in April 1st snow water content of 10%.

The West Box Elder project area has been operating for 12 years now. Cloud seeding began in 1989 but was suspended during 1998, 1999, 2002 and 2003. The project area has 10 cloud seeding generators. The target area has no precipitation gages but it does have two snow courses. A target and control regression analysis shows an average increase in April 1st snow water content of 18%.

Cloud seeding began in Tooele County in 1976 and continued through 1982. Seeding resumed in 1989 through 1992 and again in 1996. The project area has been seeded a total of 20 seasons. The project area has eight cloud seeding generators. Target and control regression analyses show an average increase in precipitation of 20% and an average increase in April 1st snow water content of 18%.

The primary target area of the Central/Southern Utah project has had 27 seeded seasons. It has operated continuously since the water year 1974, with exception of the period from 1984-1987. There were 62 cloud seeding generators in the project area for the 2003-2004 winter season. Target and control regression analyses show an average increase in precipitation of 15% and an average increase in April 1st snow water content of 4%.

Ten winter seasons of cloud seeding have now been conducted in the Western Uinta Mountains. There are 14 cloud seeding generators in the project area. Target and control regression analyses show an average increase in precipitation of 1.3% and an average increase in April 1st snow water content of 2.3%.

The High Uinta Mountain region has been seeded for only 2 years now. There are 20 cloud seeding generators in the project area. Target and control regression analyses indicates an average 5% increase in precipitation and an average 6% increase in April 1st snow water content.

Table 2 shows a summary of the results for the project areas.

Table 2.				
Summary of Cloud Seeding Project Areas				
Project Area	Number of Cloud Seeding Generators 2003-2004 Season	Seeded Years	Precipitation Increase during Seeding Period	April 1 st Snow Water Content Increase
Central/Southern Utah	62	27	15%	4%
Tooele County	8	20	20%	18%
East Box Elder/Cache County	23	16	16%	10%
West Box Elder	10	12	NA	18%
Western Uintas	14	10	1.3%	2.3%
High Uintas	20	2	5%	6%

Annual Runoff Estimated from April 1st Snow Water Content

April 1st snow water content is often considered a predictor of the spring runoff to come. Because spring runoff is a large percentage of annual runoff, snow water content can also be a predictor of annual runoff. Regression equations were derived by relating annual runoff to April 1st snow water content. The snow water content was then increased by 10 percent and the equations were used to determine what the increase in annual runoff would be.

The 10 percent increase was chosen arbitrarily. It represents an easy reference to relate expected increases in runoff and is in the expected range of increased April 1st snow water content due to cloud seeding. The actual increases in April 1st snow water content are used in the following analysis to estimate the increase in runoff for each project area. Table 3 shows the gaged streamflow stations used for each project area, the correlated SNOTEL/snow course stations, the regression equation correlation coefficients, and the percent annual runoff increase for a 10 percent increase in April 1st snow water content.

Estimated Increased Runoff and Cost per Acre-Foot

The percent increase in annual runoff for a 10 percent increase in April 1st snow water content was estimated for each streamflow station. All of the streamflow stations in each project area were then volume weighted to determine the average percent increase in annual runoff for a 10 percent increase in snow water content for the entire project area. See Appendix B for calculations. This weighted value was then multiplied by the actual percent increase in April 1st snow water content determined from target and control analysis and divided by 10 to obtain a runoff factor. The runoff factor was multiplied by the average annual runoff for the project area to determine the increase in annual runoff due to cloud seeding. The results are shown in Table 4. The estimated average annual increase in runoff for all of the projects combined is 222,965 acre-feet. This is about a 7 percent increase overall. The increase in runoff for the Northern Utah Project is 63,661 acre-feet. The Central/Southern Utah Project increase is 75,539 acre-feet. The Western Uinta Mountain project increase is 13,240 and the High Uinta Mountain project increase is 70,525.

The cost analysis results are shown in Table 5. The cost for the 2003-2004 cloud seeding project is \$377,862. With the estimated increased runoff being 222,965 acre-feet, the cost per acre-foot equals \$1.69. This cost will fluctuate year-to-year as a longer record of data is collected. The April 1st snow water content reflects climate variations such as drought therefore as more years of data are collected a better average can be determined.

Table 3. Increase in Annual Runoff for a Ten Percent Increase in April 1st Snow Water Content

Stream Gages	Correlated SNOTEL / Snow Course Stations	Correlation Coefficient	Annual Increase
10109001	LOGAN RIVER COMBINED FLOW	0.85	10.7%
10113500	BLACKSMITH FORK	0.80	13.7%
10104700	LITTLE BEAR NEAR AVON	0.83	9.5%
10172952	DUNN CREEK NEAR PARK VALLEY	0.85	16.0%
13077700	GEORGE CREEK NEAR YOST UTAH	0.83	11.3%
10172800	SOUTH WILLOW CREEK NEAR GRANTSVILLE	0.97	13.7%
10172700	VERNON CREEK NEAR VERNON	0.69	9.4%
09405500	NORTH FORK VIRGIN RIVER	0.91	12.2%
09406000	VIRGIN RIVER AT VIRGIN	0.93	11.3%
09409880	SANTA CLARA RIVER AT GUNLOCK	0.86	14.5%
10174500	SEVIER RIVER AT HATCH	0.91	11.7%
10194200	CLEAR CREEK NEAR SEVIER	0.78	13.9%
10205030	SALINA CREEK NEAR EMERY	0.84	15.4%
10215900	MANTI CREEK	0.84	12.0%
10183500	SEVIER RIVER NEAR KINGSTON	0.84	10.5%
10183900	EAST FORK SEVIER RIVER NEAR RUBYS INN	0.90	13.1%
10234500	BEAVER RIVER NEAR BEAVER	0.87	12.9%
10242000	COAL CREEK NEAR CEDAR CITY	0.88	11.7%
09310000	GOOSEBERRY CREEK NEAR SCOFIELD	0.82	12.5%
09310500	FISH CREEK ABOVE RESERVOIR, NEAR SCOFIELD	0.87	13.2%
09312600	WHITE RIVER BL TABBYYUNE C NEAR SOLDIER SUMMIT, WHITE RIVER #1, MAMMOTH-COTTONWOOD, CLEAR CREEK #1, PAYSON R.S.	0.87	16.3%
09317997	HUNTINGTON CREEK NEAR HUNTINGTON	0.88	7.8%
09326500	FERRON CREEK (UPPER STATION) NEAR FERRON	0.87	13.5%
09329050	SEVEN MILE CREEK NEAR FISH LAKE	0.76	12.5%
09330500	MUDDY CREEK NEAR EMERY	0.85	13.4%
09337500	ESCALANTE RIVER NEAR ESCALANTE	0.63	11.6%
10128500	WEBER RIVER NEAR OAKLEY	0.84	10.1%
10130500	WEBER RIVER NEAR COALVILLE	0.78	14.5%
10131000	CHALK CREEK	0.77	18.9%
10154200	PROVO RIVER	0.82	8.1%
09266500	ASHLEY CREEK	0.80	13.2%
09277500	DUSCHESNE RIVER NEAR TABIONA	0.83	17.2%
09299500	WHITEROCKS RIVER	0.79	11.6%
09279000	ROCK CREEK	0.80	17.9%

**Table 4.
Cloud Seeding Project Area Estimated Increased Runoff**

Project Areas	Average Annual Runoff (ac-ft)	Increase in April 1 SWC* (percent)	Increase in Runoff** (percent)	Runoff Factor*** (percent)	Increased Runoff (ac-ft)
Cache County	424,000	10.0	11.8	11.8	50,032
West Box Elder	57,800	18.0	13.1	23.6	13,629
Tooele County	43,300	18.0	12.0	21.6	9,353
Sevier River	653,000	4.0	11.8	4.7	30,822
Cedar-Beaver	135,000	4.0	12.4	5.0	6,696
West Colorado	411,500	4.0	11.9	4.8	19,587
Virgin River	192,400	4.0	11.8	4.7	9,081
Western Uinta's	492,000	2.3	11.7	2.7	13,240
High Uinta's	773,300	6.0	15.2	9.1	70,525
Total	3,182,300				222,965
Northern Utah Project	481,800				63,661
Central and Southern Utah Project	1,435,200				75,539
Western Uinta Project	492,000				13,240
High Uinta Project	773,300				70,525

*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% increase in April 1 SWC divided by 10.

**Table 5.
Increased Runoff and Cost for the Cloud Seeding Projects**

Project	Increased Runoff (ac-ft)	Cost (\$)	Cost (\$/ac-ft)
Northern Utah	63,661	76,507	1.20
Central and Southern	75,539	159,674	2.11
Western Uinta Mountains	13,240	65,682	4.96
High Uinta Mountains	70,525	75,999	1.08
Total	222,965	377,862	1.69

Conclusion

The first increased runoff/cost analysis was performed after the 1999-2000 winter cloud seeding season by the Division of Water Resources. Since then, the state of Utah has experienced a significant drought. These drought years have affected the data record and have been a factor in the difference in estimated runoff and cost that was determined in the 2005 analysis. As more years of data are collected a better average can be determined. A summary of the 2000 vs 2005 results is shown in Table 6. The total cost per acre-foot increased from \$1.02 in 2000 to \$1.69 in 2005.

Overall the runoff results may be a conservative estimate. By using April 1st snow water content we are underestimating the results compared to using December through March precipitation amounts.

**Table 6.
Comparison of 2000 vs 2005 Cloud Seeding Project Area Results**

Project Areas	Increase in April 1 SWC 2000	Increase in April 1 SWC 2005	Increased Runoff (ac-ft) 2000	Increased Runoff (ac-ft) 2005		
Cache County	18.0	10.0	94,600	50,000		
West Box Elder	18.0	18.0	12,300	13,600		
Tooele County	20.0	18.0	9,800	9,400		
Sevier River	7.0	4.0	65,800	30,800		
Cedar-Beaver	7.0	4.0	12,200	6,700		
West Colorado	7.0	4.0	40,000	19,600		
Virgin River	7.0	4.0	14,800	9,000		
Western Uinta's	NA	2.3	NA	13,200		
High Uinta's	NA	6.0	NA	70,500		
					Cost/ac-ft	
Total			249,600	\$1.02	222,800	\$1.69
Northern Utah Project			106,900	\$0.82	63,600	\$1.20
Central and Southern Utah Project			142,600	\$1.17	75,500	\$2.11
Western Uinta Project			NA	NA	13,200	\$4.96
High Uinta Project			NA	NA	70,500	\$1.08

References

1. Stauffer, Norman E. and Kevin Williams, *Utah Cloud Seeding Program Increased Runoff/Cost Analyses*, unpublished report, 2000.
2. Griffith, Don A., Mark E. Solak, and David P. Yorty, *Summary and Evaluation of 2003-2004 Winter Cloud Seeding Operations in the Box Elder and Cache Counties, Utah*, North American Weather Consultants, Inc., Sandy, Utah, 2004.
3. Griffith, Don A., Mark E. Solak, and David P. Yorty, *Summary and Evaluation of 2003-2004 Winter Cloud Seeding Operations in Central and Southern Utah*, North American Weather Consultants, Inc., Sandy, Utah, 2004
4. Griffith, Don A., Mark E. Solak, and David P. Yorty, *Summary and Evaluation of 2003-2004 Winter Cloud Seeding Operations in the Western Uinta Mountains, Utah*, North American Weather Consultants, Inc., Sandy, Utah, 2004
5. Griffith, Don A., Mark E. Solak, and David P. Yorty, *Summary and Evaluation of 2003-2004 Winter Cloud Seeding Operations in the High Uinta Mountains, Utah*, North American Weather Consultants, Inc., Sandy, Utah, 2004
6. Utah Division of Water Resources, State Water Plan, Basin Plans:
 - Bear River Basin – 2004
 - Cedar/Beaver Basin – 1995
 - Kanab Creek/Virgin River Basin – 1993
 - Sevier River Basin – 1999
 - West Colorado River Basin – 2000
 - West Desert Basin – 2000

Appendix A

Calculation of percent
increase in annual runoff

Stream	Project Area	Annual Runoff	Estimated Annual Increase for a 10% increase in SWE	Fraction of Total	Percent Increase in Runoff for the Entire Area
10109001 LOGAN RIVER COMBINED FLOW		18,164	10.4%	0.11798104	
10113500 BLACKSMITH FORK		94,249	13.1%	0.61218454	
10104700 LITTLE BEAR NEAR AVON		41,542	9.5%	0.26983442	
	Cache County Total	153,955			11.8%
10172952 DUNN CREEK NEAR PARK VALLEY		3,795	16.0%	0.38359471	
13077700 GEORGE CREEK NEAR YOST UTAH		6,098	11.3%	0.61640529	
	West Box Elder Total	9,892			13.1%
10172800 SOUTH WILLOW CREEK NEAR GRANTSVILLE		4,760	13.7%	0.61085351	
10172700 VERNON CREEK NEAR VERNON		3,032	9.4%	0.38914649	
	Toelle County Total	7,792			12.0%
09405500 NORTH FORK VIRGIN RIVER		76,545	12.2%	0.33025877	
09406000 VIRGIN RIVER AT VIRGIN		136,615	11.3%	0.58943534	
09409880 SANTA CLARA RIVER AT GUNLOCK		18,613	14.5%	0.08030589	
	Virgin River Total	231,773			11.8%
10174500 SEVIER RIVER AT HATCH		81,383	11.7%	0.33396507	
10194200 CLEAR CREEK NEAR SEVIER		26,549	13.9%	0.10894781	
10205030 SALINA CREEK NEAR EMERY		12,817	15.4%	0.05259597	
10215900 MANTI CREEK		21,298	12.0%	0.08740062	
10183500 SEVIER RIVER NEAR KINGSTON		88,402	10.5%	0.36276917	
10183900 EAST FORK SEVIER RIVER NEAR RUBYS INN		13,237	13.1%	0.05432135	
	Sevier River Total	243,688			11.8%
10234500 BEAVER RIVER NEAR BEAVER		37,495	12.9%	0.59461385	
10242000 COAL CREEK NEAR CEDAR CITY		25,563	11.7%	0.40538615	
	Cedar-Beaver Total	63,057			12.4%
09310000 GOOSEBERRY CREEK NEAR SCOFIELD		13,494	12.5%	0.06012687	
09310500 FISH CREEK ABOVE RESERVOIR, NEAR SCOFIELD		35,380	13.2%	0.15765296	
09312600 WHITE RIVER BL TABBYUNE C NEAR SOLDIER SUMMIT,		18,799	16.3%	0.08376607	
09317997 HUNTINGTON CREEK NEAR HUNTINGTON		64,235	7.8%	0.28622831	
09326500 FERRON CREEK (UPPER STATION) NEAR FERRON		46,208	13.5%	0.20590133	
09329050 SEVEN MILE CREEK NEAR FISH LAKE		10,980	12.5%	0.04892836	
09330500 MUDDY CREEK NEAR EMERY		27,877	13.4%	0.12422083	
09337500 ESCALANTE RIVER NEAR ESCALANTE		7,445	11.6%	0.03317527	
	West Colorado Total	224,418			11.9%
10128500 WEBER RIVER NEAR OAKLEY		152,267	10.1%	0.29464093	
10130500 WEBER RIVER NEAR COALVILLE		153,807	14.5%	0.29762015	
10131000 CHALK CREEK		52,369	18.9%	0.10133561	
10154200 PROVO RIVER		158,346	8.1%	0.30640331	
	Western Uintas Total	516,788			11.7%
09266500 ASHLEY CREEK		71,129	13.2%	0.20058908	
09277500 DUSCHESNE RIVER NEAR TABIONA		114,294	17.2%	0.32231872	
09299500 WHITEROCKS RIVER		83,134	11.6%	0.23444456	
09279000 ROCK CREEK		86,043	17.9%	0.24264764	
	High Uintas	354,601			15.2%

Appendix B

Average Annual Runoff 1941-1990
for the Cloud Seeding Project Areas

Western Uintas		West Box Elder		Tooele-Rush Valleys		West Colorado	
Weber	312,000	Raft River	39,900	Tooele Valley	22,987	Price River	96,300
Chalk Creek	58,000	Lynn	9,100	Box Elder Creek	3,630	Gooseberry	16,500
Misc.	27,000	Yost	5,700	South Willow Creek	4,778	Ungaged Inflow	21,800
Beaver Creek	69,000	Clear Creek	14,400	North Willow Creek	3,205	Mud Creek	11,600
Weber River	115,000	Goose Creek	10,700	Devenport Creek	1,379	White River	20,600
Smith & Morehouse	43,000	Grouse Creek	7,100	Pine Creek	1,430	Beaver Creek	3,300
Provo		Pine Creek	2,000	Middle Creek	4,865	Willow Creek	8,400
Upper Provo River	36,000	Ungaged	1,400	Settlement Creek	3,700	Coal Creek	4,100
Shingle Creek	5,000	Etna Area	3,700	Rush Valley	20,263	Misc	10,000
North Fork	27,000	Park Valley	10,800	Vernon Creek	2,070	San Rafael	200,700
Weber/Provo Diversion	35,000	Indian Creek	2,900	Bennion Creek	405	Huntington Creek	76,100
Francis	65,000	Dove Creek	900	Dutch Creek	125	Cottonwood Creek	75,900
Misc.	12,000	Fish Creek	2,200	Harker Creek	270	Ferron Creek	48,700
Total	492,000	Dunn Creek	4,100	Clover Creek	3,168	Dirty Devil	67,100
		Ungaged	700	Big Hollow Creek	2,030	Muddy Creek	28,700
		Total	57,800	Hickman Creek	2,540	Ivie Creek	2,900
				Soldier Creek	2,422	Fremont River	32,300
				Ophir Creek	6,205	Pine Creek	3,200
				Mercur Creek	1,028	Escalante	39,600
				Total	43,250	Paria	7,800
						Total	411,500
High Uintas		Sevier River		Cache County			
Current Creek	41,400	Mammoth Creek	83,900	Logan River	184,000		
West Fork Duchesne	34,400	Panguitch	26,400	Blacksmith Fork	98,000		
Upper Duchesne	66,100	Otter Creek	19,200	East Fork Little Bear	26,000		
Upper Rock Creek	109,100	East Fork	42,200	South Fork Little Bear	41,000		
Brown Duck	6,900	Piute Reservoir	12,500	High Creek	21,000		
Lake Fork	82,500	Manysville	32,300	Summit Creek	14,000		
Red Creek	6,100	Richfield	55,100	Misc	40,000		
Yellowstone River	102,600	San Pitch	207,000	Total	424,000		
Uinta River	134,500	Gunnison	45,000				
Farm Creek	4,800	Scipio-Levan-Eureka	13,800				
White Rocks River	84,200	Oak-Fool Creeks	16,400				
Misc	100,700	Fillmore	74,200				
Total	773,300	Nephi-Salt Creek	25,000				
		Total	653,000				