HYDROLOGIC IMPACTS ON THE SALT RIVER DUE TO CHANGES IN IRRIGATION SYSTEMS

Steven K. Sando
John Borrelli
Donald J. Brosz

April 1985 WWRC-85-16

Final Report

Submitted to

Wyoming Water Research Center
University of Wyoming
Laramie, Wyoming

Submitted by

Department of Agricultural Engineering
University of Wyoming

ABSTRACT

The Salt River drainage basin (Star Valley) is an agricultural watershed of 829 mi^2 in western Wyoming. Starting in 1971 several irrigation projects were completed that converted surface irrigation systems to sprinkler irrigation systems on approximately one-half of the irrigated acres in the valley. This conversion resulted in less total water being diverted from streams for the sprinkler systems than was the case for the surface systems on the same irrigated acreage.

Salt River stream flows were hydrologically analyzed and a comparison made of the flows prior to and after conversion to sprinkler systems. A test of mean monthly flows showed that spring flow increased significantly (α = 0.05) by 58.7% following the conversion to sprinklers. The Salt River flows were also compared with flow of the Greys River, it drains a non-agricultural watershed immediately adjacent to the Salt River, using the double mass analysis. This test again showed higher spring flows and also lower fall flows were evidently a consequence of irrigation practices rather than climatological factors.

Analysis of annual flood peaks was accomplished by several hydrologic and statistical tests. Included were a comparison of flood frequency distributions, a test of stationariness and a test of homogeneity. These tests revealed that mean annual flood peak increased significatnly (α = 0.05) by 47.0%.

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

In parts of the semi-arid West, the availability of sufficient water is one of the primary factors limiting agricultural production. For this reason, the development of irrigation systems with increased water application and conveyance efficiencies has been desirable to make better use of the limited available water. Due to surface-groundwater relations in agricultural watersheds, increasing water application and conveyance efficiencies can affect the flow regime of a stream causing higher spring flows and lower fall flows (Interagency Task Force on Irrigation Efficiency, 1978). This can be an undesirable effect, especially in the downstream portions of the watershed where impacts are expected to be most extreme.

The Salt River drainage basin (Star Valley) in Lincoln County, Wyoming presents a unique opportunity to study some of the overall watershed effects of increased irrigation application efficiencies. There are two primary reasons for this. Firstly, starting in 1968, several irrigation projects were constructed in the Star Valley which resulted in a switch from surface irrigation to sprinkler irrigation on approximately one-half of the irrigated acres in the valley (Gasseling, 1984). The first major project was completed in 1971 and the last major project was completed in 1974. Secondly, the presence of the Greys River immediately adjacent to the Salt River drainage basin is another factor which makes the Salt River situation a valuable research opportunity. The Greys River maintains a roughly similar flow of water as the Salt River, but it is essentially devoid of irrigated agriculture throughout its length. Its close proximity as well as these other factors makes the Greys River an excellent tool for comparison with the Salt River.

Objectives

The main objective of this study was to document the changes in streamflow characteristics caused by changes in irrigation water application and conveyance efficiencies. This evaluation was to be limited to the Salt River in Lincoln County, Wyoming where documentation was available on historical irrigation patterns, streamflows and climatic parameters. The specific objectives were:

1. To determine the changes in volume and peak flows in the Salt River for the various months caused by the change to sprinkler irrigation.

2. To investigate other factors (e.g. climatic patterns, urban construction, etc.) that could potentially cause streamflow changes.

3. To estimate changes in the volume of water consumptively used by crops after the change to sprinkler irrigation.

4. To describe some of the physical changes occurring to the Salt River streambed based on interviews with ranchers, SCS personnel and Game and Fish personnel.

5. To qualitatively project (based on the case study of the Salt Rivere and appropriate literature) the type of changes that may occur if major changes in water application and conveyance efficiencies were to occur.

Site Description

The Salt River has a drainage area of 829 square miles and is located in Lincoln County on the west-central edge of Wyoming (Figure 1). The waters forming this river flow out of the Salt River mountain range on the east, the Caribou and Webster ranges on the west, and the Dry Creek, and Swift Creek on the east and Crow Creek, Stump Creek, and Spring Creek on the west. The Salt River flows northerly through the Star Valley for about 50 miles before it enters Palisades Reservoir near Alpine Junction, Wyoming. The average discharge of the Salt River was 776 cfs for the 29 year period prior to 1983 and the maximum discharge was 3870 cfs on June 1, 1971. The Salt River and its tributaries are the source of water for agriculture in the Star Valley where there are approximately 60,000 irrigated acres.

The Star Valley is primarily an agricultural community and is one of the main dairy farming centers of Wyoming. Alfalfa hay and barley are the two main crops produced, with some land also being in native hay and pasture. Most of the soils in the valley are shallow and gravelly or stony. Average annual precipitation is between 18-20 inches in the Star Valley. Until the sprinklers were installed, late season water shortages were common. This has occurred although actual flow rates have decreased in the late season. This is a rare occurrence now, as the sprinklers have improved the water conveyance and water application efficiencies.

The Greys River flows through a narrow drainage basin on the other side of the Salt River Range immediately adjacent to Star Valley. It is bordered on the east by the Wyoming Range. The Greys River has a drainage area of 448 square miles, most of which is within the Caribou National Forest. It is essentially devoid of agricultural influence with less than 500 acres being irrigated from this river. The 30 year average discharge was 653 cfs in 1982, and the maximum discharge was 7239 cfs on June 19, 1971.

Delimitation and Scope of Study

Many different factors including geologic, climatic, hydrologic and physical variables affect the flow regime of a stream. These variables can differ significantly between drainage basins. Therefore, when studying the effect upon streamflow of agricultural practices within a watershed, it must be realized that the result may not have general application. Direct application of the results of this study can be

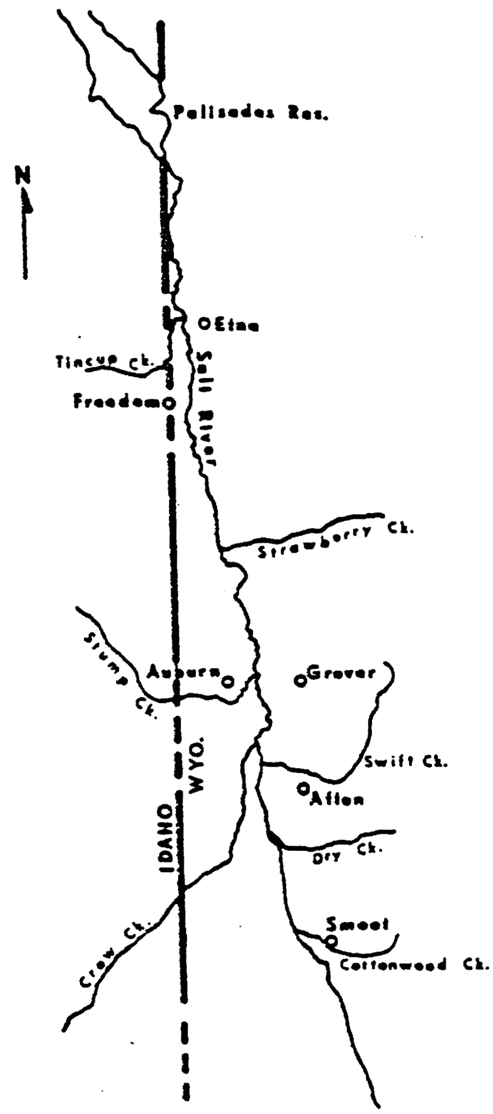

Figure 1. Location of the Salt River.

made only to drainage basins which are similar to the Star Valley with respect to all of the influential variables. This study will, however, be useful in making qualitative projections of what type of hydrologic changes in a watershed will be expected when increasing irrigation efficiencies.

LITERATURE REVIEW

Most of man's activities that affect streamflow can be grouped under one of the following categories (after Pitman, 1978):

1. Urbanization: increase of impervious area, abstraction of water supply, and discharge of sewage and other effluents.

2. Major dam construction: evaporation from reservoirs, abstractions for use, return flows, and flood attenuation.

3. Agricultural related impacts: small dam construction, irrigation and drainage effects, and changes in the infiltration and runoff characteristics of the earth surface by modification of vegetation and soil characteristics.

Of these impact categories, agricultural effects are the most widespread and will be discussed below.

Effects of Forestry Related Practices Upon Streamflow

Much of the information available on the effects of agricultural processes upon streamflow comes from forestry related studies. Harr et al. (1982) provide a broad review of forestry related impacts upon streamflow. Some of the general effects of logging activities upon streamflow are:

1. Increases in annual water yield, peak annual discharge and summer low flows following clearcutting and deforestation (Hornbeck et al., 1970; Harr et al., 1982). The increases in flow may be roughly proportional to the size of the area cleared (Dalms, 1971).

2. Decreases in streamflow after afforestation and re-establishment of vegetation following timber harvest (Pitman, 1978; Harr et al., 1979).

3. Increases in peak flows on watersheds where road building and other logging activities have compacted soils (Harr et al., 1975; Harr et al., 1979).

These forestry studies indicated that agricultural activities which manipulate the type and amount of vegetation and the runoff characteristics of the soil can have significant impacts upon the surface hydrology of a watershed.

Effects of Land Cultivation Upon Streamflow

Cultural practices associated with conventional agriculture also affect surface water relationships. Changing land use from natural vegetation to cultivated vegetation can influence the hydrologic cycle in the following general ways (after FAO, 1973):

1. Changes in the type and density of vegetation affect evapotranspiration rates by altering crop canopy characteristics and rooting characteristics.

2. Physical manipulatiion of the soil affects soil intake properties by altering permeability and potential for depression and detention storage.

3. Changes in rooting characteristics of the vegetation and physical properties of the soil will affect soil water storage which will in turn influence infiltration and runoff rates.

4. The above changes will affect infiltration which in turn will affect groundwater-surface water relationships.

In general, the above alterations will cause an increase in runoff and streamflow following conversion of natural vegetation to intensively cultivated crops (Moore and Morgan, 1969).

Effects of Drainage Upon Streamflow

Another agricultural practice which can affect streamflow is land reclamation by drainage. Drainage refers to the underground installation of drainage works to lower the water table and create an appreciable aerated zone (FAO, 1973). Since this drained water is typically discharged into the stream system, the general hydrologic effects of drainage is to increase streamflow (Novikov and Polumeiko, 1980; Bulavko, 1977; Benz and Doering, 1975).

Effects of Irrigation Upon Streamflow

Irrigation is one of the most influential of all agricultural practices with respect to streamflow and hydrologic impacts. Starosolszky (1980) provides a comprehensive review of the effect of irrigation practices upon water resources. Major hydrologic effects of irrigation are summarized as follows:

1. Where water for irrigation is diverted from stream channels, seasonal streamflow depletions occur (Frederick, 1982).

2. Conveyance and application of irrigation water increases evapotranspiration rates and deep percolation into groundwater aquifers.

3. Increased groundwater recharge of agricultural lands can result in higher late season streamflows, (IATF, 1978).

4. Where irrigation water is pumped from groundwater aquifers, declines in groundwater levels can occur and may result in streamflow declines (IATF, 1978).

Effects of Increasing Irrigation Efficiencies Upon Streamflow

Efficiency for an irrigation system can be defined as the percentage of water originally diverted from the stream channel which is applied to the field, stored in the root zone and consumptively used by the crops. Increasing irrigation efficiencies has been proposed as one of the primary means of dealing with water supply and quality problems in agricultural watersheds. Sprinkler irrigation systems can increase irrigation efficiencies over flood systems in the following ways:

1. Since water is diverted directly from the stream into pipelines, conveyance efficiency is increased over open, earthen canals often used in flood systems.

2. More uniform distribution of water results in higher water application efficiencies with sprinkler systems.

3. Higher frequency of irrigation allows less water to be applied per irrigation allowing water to be applied at critical growth stages.

While some case studies have documented crop yield and water quality effects of increased irrigation efficiencies (IATF, 1978; Robinson et al., 1968), documentation of quantitative effects on streamflow is lacking. Projected effects of improved irrigation efficiencies upon streamflow are increased early season flows and declines in late season flow due to lower groundwater levels (Brosz, 1980; Geraud, 1977).

METHODS

Streamflows were not measured as part of this study. Records from existing U.S.G.S. stream gages were used. Usable gaging stations were not located above the irrigated areas, a preferred situation, but this disadvantage was offset by the fortuitous location of the Greys River adjacent to the Salt River. Presented below are descriptions of the gaging stations and methods used in the various analyses.

Analysis of Streamflow Data

Data from two U.S.G.S. gages were used in the primary analyses in this study. The locations of all U.S.G.S. gages employed in this study are shown in Figure 2. U.S.G.S. station #130275 on the Salt River is located above Palisades Reservoir near Etna, Wyoming, (latitude 43° -04' -47": longitude 111°-02'-12"). The data from this station consists of a complete record for the period of 1954-present. U.S.G.S. station #130230 on the Greys River is located above Palisades near Alpine, Wyoming, (latitude 43° -08' -35": longitude 110°-58'-34"). A complete record for the period 1954-present also exists at this station.

Data from three other gaging stations were used to confirm the results of the double mass analysis. U.S.G.S. gaging station #100410 on Thomas Fork is located near the Wyoming-Idaho state line in Lincoln County, Wyoming, (latitude 42°-04' -120" : longitude 111° -01' -30"); U.S.G.S. gaging station #092080 on La Barge Creek is located near the La Barge Meadows Ranger Station in Lincoln County, Wyoming (latitude 42°-30' -30" : longitude 110°-40'-10"); and U.S.G.S. gaging station #091885 on the Green River is located at the Warren Bridge near Daniel, Wyoming (latitude 43° -01'-08": longitude 110°-07'-03"). All of these stations have periods of record that include the period of 1954-present.

Comparison of Means and Variances

In all analyses, the period of October, 1954 to April, 1971 was assigned to represent the pre-sprinkler period and the period May, 1971 to September, 1982 represented the sprinkler period. The mean monthly flow in acre feet for the pre-sprinkler period was compared to that for the sprinkler period for each month using the T-test for unequal sample sizes (Snedecor and Cochran, 1974). The comparison was made on both the Salt River and Greys River flow data. An F-test was also used to compare the variances of the data of these two periods. All analyses in this study were performed on the Cyber computer system at the University of Wyoming. The MINITAB statistical package was employed wherever applicable.

Flow-Duration Curves

Flow-duration curves were prepared for the pre-sprinkler and sprinkler periods on the Salt River to determine possible changes in

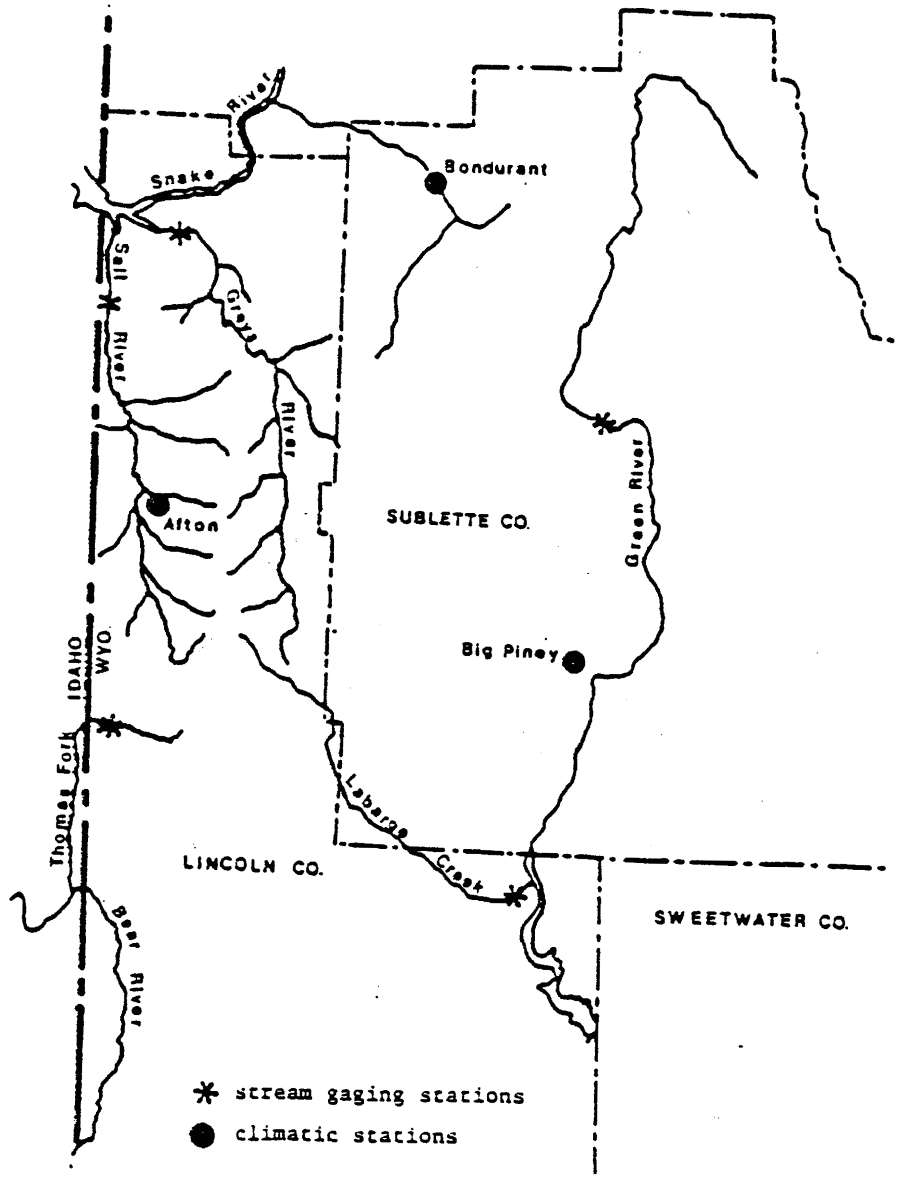

Figure 2. Locations of stream gages and climatic stations.

flow regime between these two periods. Mean flow values for each month were plotted against time in months to give average annual flow-duration curves for each period. These curves were also prepared for the Greys River for comparison to the Salt River.

Double Mass Analysis

The double mass analysis was used to test the consistency of the streamflow observations on the Salt River for the period of record (Kohler, 1949). In this procedure, for each month, yearly accumulated streamflow values of the Salt River were plotted against those of the Greys River. A consistent record will generate a relatively straight line of constant slope. A record where changes have occurred in either the streamflow or the operation of the gaging station will yield a broken line with two or more segments of different slope. This analysis can only reveal whether some type of change has occurred in the record for either of the two gaging stations used to perform the analysis. To confirm that the streamflow changes observed in this analysis represented changes in the record of the Salt River, the following procedure was used. Flow data from four stations in the general area, including the Greys River gage, were averaged. For each month, yearly accumulated streamflow values of the Salt River were plotted against the accumulated averaged values. Any observed changes in the streamflow record in this test would confirm that these changes represented variations in the record of the Salt River.

Synthetic Flows Analysis

Cumulative flows of the Salt River for the pre-sprinkler period were regressed against those of the Greys River for each month using the MINITAB statistical package. The line equations derived from these regressions were then used to generate synthetic cumulative flow values okf the Salt River for each month of the sprinkler period. These synthetic cumulative flows were then converted to yearly values for each month. The synthetic yearly values were used to simulate what flows for the Salt River might have been in the sprinkler period if the sprinklers had not been installed. A paired T-test (Snedecor and Cochran, 1974) was then employed to compare the means of the synthetic flow values with the observed flow values of the sprinkler period for each month.

Annual Flood Peaks Analysis

Annual flood peaks for the Salt River were analyzed following the multi-test procedure described by Buchberger (1981). Using this procedure, the following tests were performed.

First, the Log Pearson Type III distribution (Viessman et al., 1977) was developed for the Salt River annual flood peaks for the pre-sprinkled period and the sprinkler period, and the two distributions were compared. This procedure was also repeated for the Greys River.

Second, a test for stationariness was performed on the entire record of Salt River annual flood peaks to test for any long term trends. Least squares regression is used to express the annual peak flows as a function of time:

$$q_i = a + bt_i$$

where q_i is the peak dischare observed during year t_i, a is the regression constant, and b is the regression coefficient. A stationary series will exhibit a regression line slope that is not significantly different than zero. Therefore, the flollowilng hypotheses are tested: H_o: $b = 0$ versus H_1: $b \neq 0$. The appropriate test statistic is:

$$T = r\,[(n-2)/(1-r^2)]^{\frac{1}{2}} \sim t(n-2)$$

where r is the correlation coefficient of the linear regression and n is the number of years of data. The critical value of the test statistic, $t\,(1-\alpha/2)$, is obtained from any standard t-distribution table. Ho is reject if $|T|>T$.

Third, a test for independence was performed to confirm that successive annual flood peaks are independent of each other. Serial correlation measures the degree of linear dependence among successive observations of a series separated by k years. For independent series, the serial correlation coefficients, ($r(k)$: $k = 1, n-1$), are not significantly different than zero. Independence can be sufficiently tested by evaluating the following hypothesis: H_o:$\rho\,(1) = 0$ versus H_1: $(1) \neq 0$; where $\rho\,(1)$ is the population value of the first serial correlation coefficient. The equation for computing $r(1)$ is:

$$r(1) = [\Sigma(q_i\, q_i+1)-nq^{-2}]/[(n-1)S_q{}^2]$$

where q is the mean of the annual flood series, sq^2 is the variance of the annual flood series and all other variables are as previously defined. Confidence limits for $r(1)$ are computed by:

$$CL[r(1)] = \left\{-1 \pm Z_c[1-(\alpha/2)](n-2)^{1/2}\right\}/(n-1)$$

where $Z_c\,[1-(\alpha/2)]$ is the critical value of the standard normal deviate for a two-sided test at the α-level of significance. H_o is rejected if $r(1)$ falls outside these confidence limits.

Another test for independence employs the "turning point." A turning point (T) occurs whenever $q_{i-1} > q > q_{i+1}$ or $q_{i-1} < q > q_{i+1}$. Confidence limits for T of an independence series are computed by:

$$CL(T) = \left\{2(n-2) \pm Z_c[1-(\alpha/2)]\,[1b_n-29)/10]^{\frac{1}{2}}\right\}/(3)$$

Independence is rejected if T falls outside these confidence limits.

Fourth, a test for homogenity was performed to determine whether or not the data consists of more than one population. The Mann and Whitney U-test was employed for this test. In this procedure, the data must be divided into two subsamples. The pre-sprinkler period and the sprinkler period were the two subsamples used. The entire flood series was than ranked in order of decreasing magnitude and two statistics, U_1 and U_2, were calculated by:

$$U_1 = uv + (u/2)\ (u+1)-R$$

$$U_2 = uv-U$$

where u is the number of observations in subsample 1, v is the number of observations in subsample 2, and R is the sum of the ranks assigned to subsample 1. U is defined as the smaller of U_1 and U_2. The test statistic T is computed by:

$$T = [U-(uv/2)]/[(uv/12)\ (u+v+1)]^{\frac{1}{2}} \sim N(0,1)$$

When tied observations occur that appear in both subsamples, a correction is computed by:

$$C = (1/12)\ (t^3-t)$$

where t is the number of observations tied at a given rank. The test statistic T is now computed by:

$$T = [U-(uv/2)]/ \left\{ [uv/n+1)]/12- \ C] \right\}^{\frac{1}{2}} \sim N(0,1)$$

Reject the hypothesis that both subsamples are the same population if $|T| > 1[1 - (\alpha/2)]$.

Fifth, the Salt River peak flows and the peak flow moving average were graphically plotted versus time to illustrate any trends occurring in the record. The moving average is computed by:

$$MA_i = (q_{i-4} + q_{i-3} + q_{i-2} + q_{i-1} + q)/5$$

This procedure was also performed on the Greys River peak flows.

Finally, a new Log Pearson Type III flood frequency distribution representative of present conditions on the Salt River was computed. This was done using the period of 1975-1982.

Analysis of NOAA Climatic Data

Climatic data from three NOAA stations were used in this analysis. Station #484095 is located at Afton, Wyoming (latitude 42° -44' -00" : longitude 110° -56' -00"); Station #480865 is located at Bondurant, Wyoming (latitude 43°-14'-00":longitude 110° -26' -00"); and Station #480695 is located at Big Piney, Wyoming (latitude 42° -27'-00": longitude 110°-05'-00"). The locations of these stations are shown in Figure 2. The period of record analyzed was 1954-1983. A small number of missing values occurred at all three stations. These values were estimated by regressing the record of the unknown station with the records of surrounding stations and then averaging the estimates determined by each of these regressions.

Comparison of Means and Variances

The mean monthly precipitatiion and temperature at Afton during the pre-sprinkler period were compared to using the T-test for unequal sample sizes (Snedecor and Cochran, 1974). An F-test was also used to compare the variances of the data of these two periods. These comparisons were made on the Afton precipitation and temperature data.

Correlation and Double Mass Analysis

The climatic data in the Greys River drainage were sparse with a very short period of record. Therefore, it was not possible to perform the same comparisons between the Salt River drainage climatic data and Greys River drainage climatic data as was done for the streamflows of the two rivers. It was necessary to attempt to verify that climatic trends in the Greys River drainage are not significantly different from those in the Salt River drainage. To accomplish this, climatic stations were selected which were close to the Greys River drainage and which had a period of record corresponding to the Afton climatic data. The two stations which fulfilled these requirements were Bondurant and Big Piney. Yearly precipitation and mean temperature values from the Afton station were regressed against those of each of the other two stations to obtain a correlation between the Afton data and the Bondurant and Big Piney data records. The T-test ratios for these regressions were used to test whether the trends in the data were significantly different.

The double mass procedure was also used to test whether climatic trends at the Afton station differed from the Bondurant and Big Piney stations. Total annual precipitation values from the Bondurant and Big Piney stations were plotted against the accumulated averaged precipitation values. These plots were then analyzed for breaks in slope to test for changes in the Afton precipitation record relative to the other stations. This procedure was repeated for mean annual temperatures.

Analysis of Crop Water Use

Changes in irrigation systems can result in changes in crop yield which can affect surface hydrology by altering evapotranspiration rates. Therefore, in this study it was necessary to analyze the potential hydrologic impact of crop yield increases following the switch to sprinklers.

Native hay, alfalfa hay and barley are the primary crops grown in the Star Valley with most acreage being in alfalfa. Long term records of crop production are unavailable for the Star Valley, but crop records for the whole of Lincoln County exist. To estimate the increases in yield in the Star Valley following the switch to sprinklers, the following assumptions were made:

1. During the pre-sprinkler period, average yields in the Star Valley were equal to average yields for all of Lincoln County.

2. All acreage was planted in alfalfa.

Given these assumptions, yield increases in the sprinkler period were estimated by two methods:

1. Yield increases in the Star Valley during the sprinkler period were assumed to be equal to average yield increases in all of Lincoln County during this period. This represents a least impact analysis.

2. Crop yields in the Star Valley during the sprinkler period were assumed to increase by 100%. This represents a maximum impact analysis.

Using these estimates of crop yield increases, an alfalfa crop water function based on yields developed at Logan, Utah (Hill, 1983) was used to estimate increases in consumptive water use. This function is:

$$ET = (Y/0.325) + 0.857$$

where Y is the alfalfa yield in tons per acre, and ET is the seasonal crop water use in inches.

Potential reductions in streamflow due to increases in crop consumptive use would probably be most pronounced during late summer and early fall months. Therefore, proportions of the season crop water use which would be expected to occur in August, September and October were calculated to determine the impact of crop water use increases during these months upon streamflow. The percentage of seasonal consumptive use expected to occur in August, September and October was determined by using the alfalfa monthly consumptive use estimates calculated at Afton by Trelease et al. (1970). They determined that for alfalfa 21.6% of seasonal consumptive use occurred in Ausut, 12.6% in September and 3.9% occurred in October.

To estimate the impact of increased consumptive use during these months upon streamflow, the consumptive use estimates in inches were converted to acre-feet by assuming there are 60,464 crop acres in the Star Valley and using the following equation:

$$ET\ (ac\text{-}ft) = ET(in)/12) \times 60{,}464\ ac$$

The difference in this total evapotranspiration value between the sprinkler period and the pre-sprinkler period was then compared with the deviation in observed streamflow from the expected streamflows determined by the snythetic analysis. The purpose of this procedure was to estimate what portion of the reduced streamflows in the late summer and fall months might be attributable to increases in crop consumptive use.

Rancher Survey and Interviews

Much information relevant to this study was unavailable in the form of formal records. In an effort to provide some of this information, SCS, Game and Fish and county personnel were interviewed and a rancher survey was conducted. In the rancher survey, ranchers were contacted personally and asked to complete a written survey. A copy of this survey appears in Appendix A. A total of 32 ranchers were surveyed.

In addition to the rancher survey, Game and Fish, SCS and Lincoln County personnel were interviewed to determine their perception of some of the qualitative effects of the sprinklers. These individuals also provided valuable information where formal records were unavailable.

RESULTS AND DISCUSSION

Analysis of Streamflow Data

Streamflow is dependent upon many different physical, climatic and hydrologic variables. For this reason a great deal of natural variation will exist in streamflows records over time. This can make it difficult to accurately interpret results when analyzing streamflow records from different time periods. As many hydrologic and statistical tests as were relevant and practical were employed in this study in an attempt to properly interpret streamflow changes observed on the Salt River.

Comparison of Means and Variances

Results of the T-tests and F-tests for the comparison of mean monthly streamflows of the pre-sprinkler and sprinkler periods are presented in Table 1. In both tests, mean monthly streamflows for May and June were significantly higher ($\alpha = 0.05$) in the sprinkler period. The average increase for these two months was 58.7%. No other months showed significant differences between the pre-sprinkler and sprinkler periods. It is of note that flows increased slightly during the months of August through November in the sprinkler period when they would have been expected to decrease. This is attributed to greater precipitation in the late summer and early fall during sprinkler period. This is further discussed in following sections.

Flow Duration Curves

Flow duration curves for the pre-sprinkler period and sprinkler period for the Salt River and Greys River are presented in Figure 3 and Figure 4, respectively. The Salt River curves show that spring flows increased substantially in the sprinkler period and remained roughly similar during the other months of the year. The Greys River flow regime changed comparatively little over the same period, with slight flow increases for the months of June through October. Exceptionally high water years in 1971 and 1972 probably account for the increased flows on the Greys River and also contribute to the degree of increase on the Salt River. It is important to note as a result of these high water years, the increase in fall (August-October) flows on the Greys River (21.8%) was considerably higher the Salt River (4.5%). This trend is further illustrated in the results of the double mass analysis.

Double Mass Analysis

Results of the double mass analysis of the Salt River flows versus the Greys River flows are presented for each month in Figures 5 through 16. The broken slopes in Figures 12 and 13 reveal that beginning in 1971 flows during the months of May and June for the Salt River increased relative to those of the Greys River. Streamflows during the months of August-November decreased on the Salt River relative to those

Table 1. Comparison of Salt River mean monthly streamflows for the pre-sprinkler and sprinkler period.

MONTH	Mean Flow (acft/mon) PRE-SPRINKLER*	SPRINKLER**	PERCENT DIFFERENCE	T VALUE	F RATIO
OCT	37,466	39,188	+4.6	-0.56	0.43
NOV	35,174	35,579	+1.2	-0.19	0.04
DEC	32,410	31,987	-1.4	0.21	0.05
JAN	28,154	27,528	-2.4	0.41	0.17
FEB	25,165	24,097	-4.3	0.80	0.53
MAR	26,700	30,293	+13.5	-1.69	3.98
APR	51,641	56,932	+10.2	-.067	0.50
MAY	88,422	130,239	+47.4	-2.30***	6.90***
JUN	64,492	109,559	+69.0	-2.70***	8.95***
JUL	45,532	62,244	+41.1	-1.89	4.52
AUG	38,396	41,136	+7.1	-0.62	0.46
SEP	38,614	40,531	+5.0	-0.531	0.34

* October, 1953 - April, 1971
** May, 1971 - September, 1982
*** Statistically significant at $\alpha = 0.05$

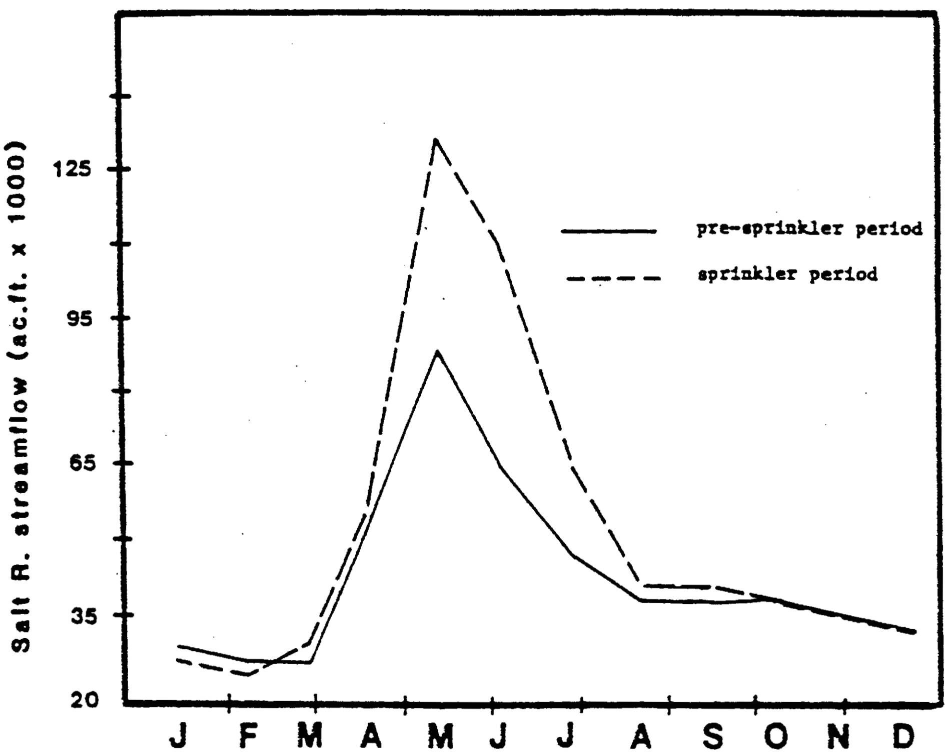

Figure 3. Mean flow duration curves of the Salt River for the pre-sprinkler and sprinkler periods.

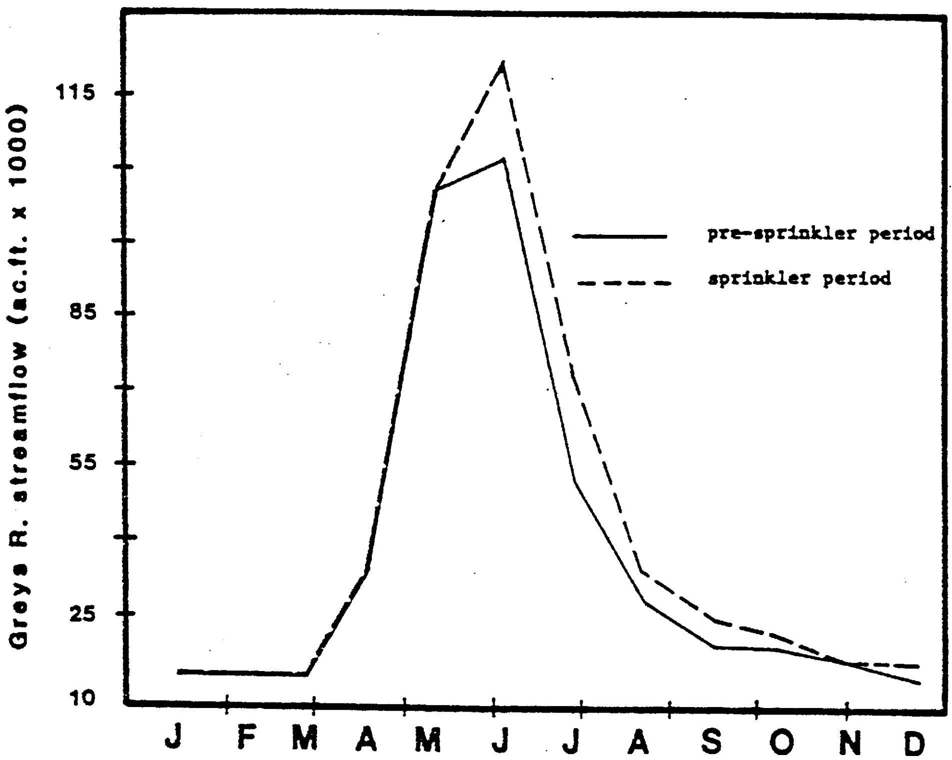

Figure 4. Mean flow duration curves of the Greys River for the pre-sprinkler and sprinkler periods.

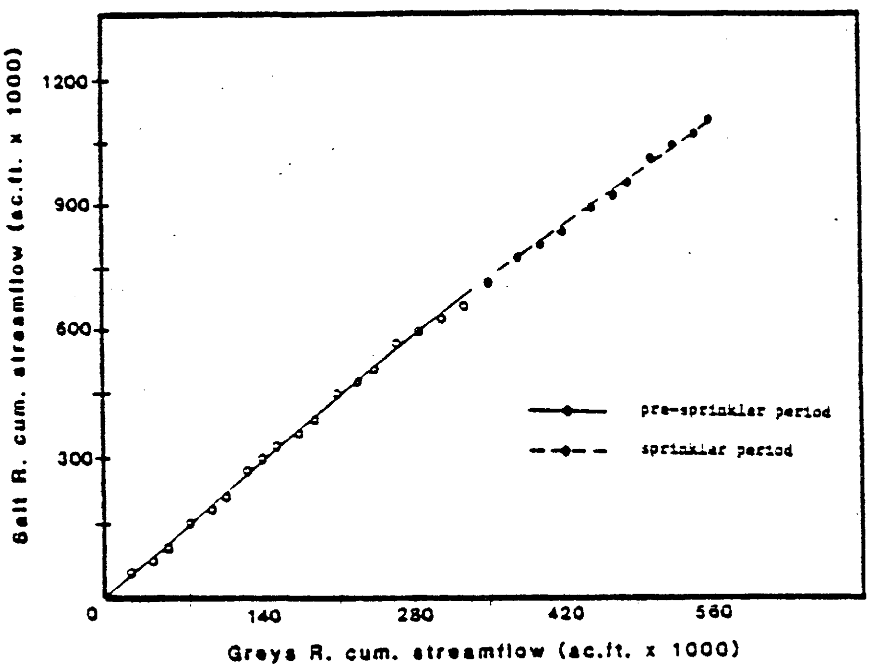

Figure 5. Double mass plot of Salt R. flows versus Greys R. flows for October.

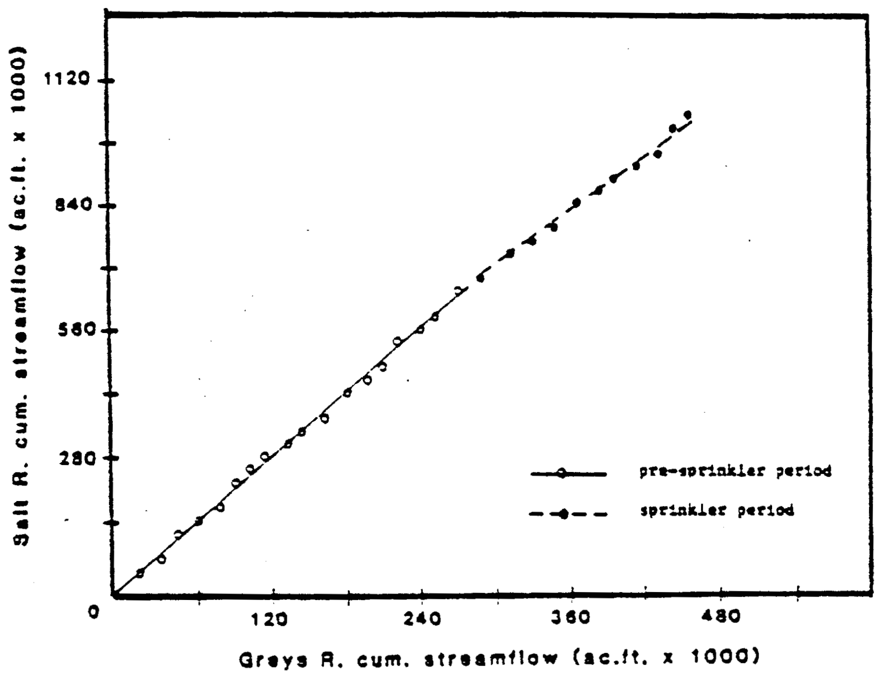

Figure 6. Double mass plot of Salt R. flows versus Greys R. flows for November.

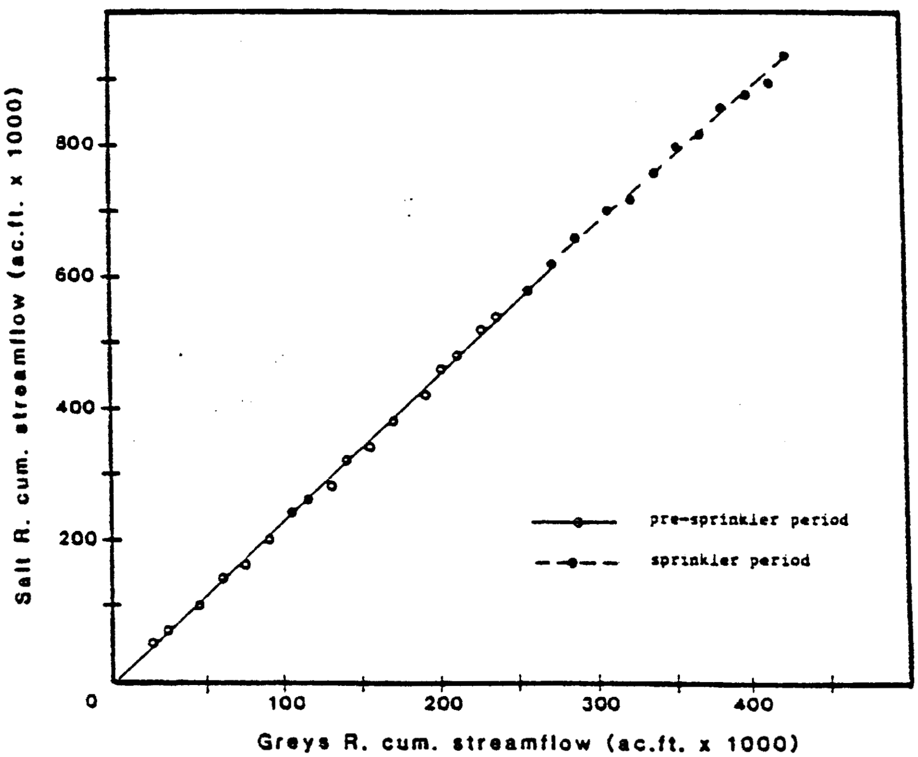

Figure 7. Double mass plot of Salt R. flows versus Greys R. flows for December.

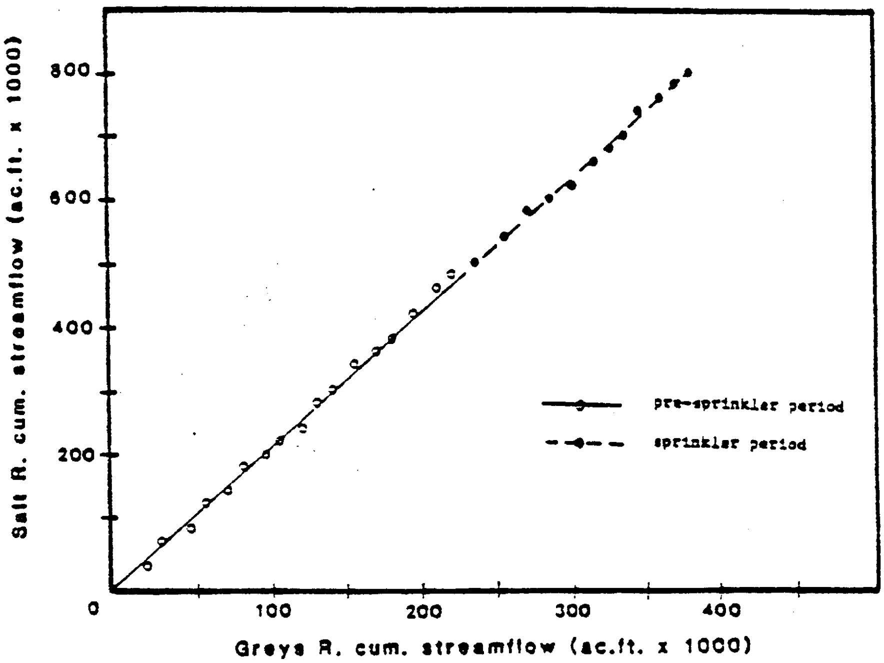

Figure 8. Double mass plot of Salt R. flows versus Greys R. flows for January.

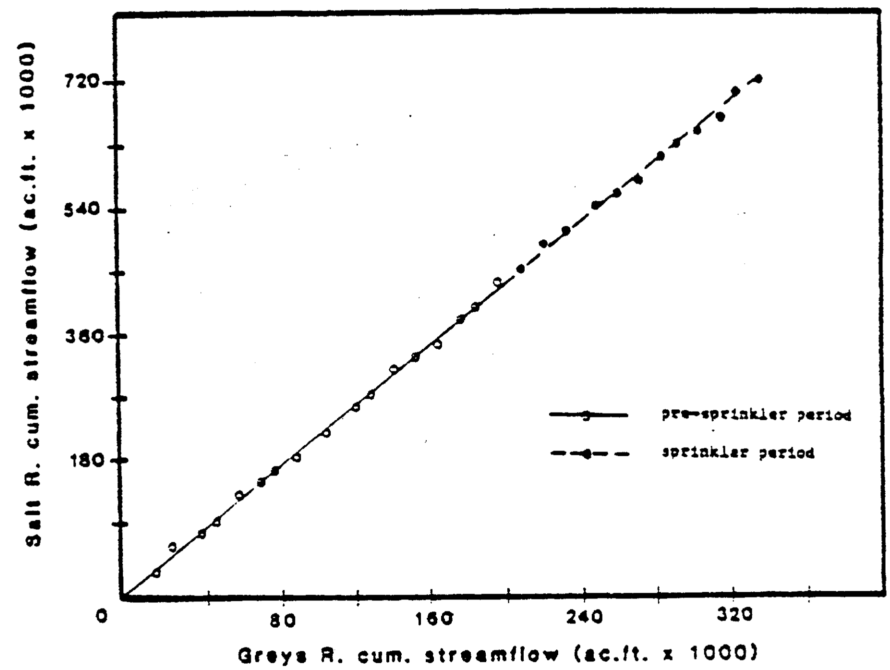

Figure 9. Double mass plot of Salt R. flows versus Greys R. flows for February.

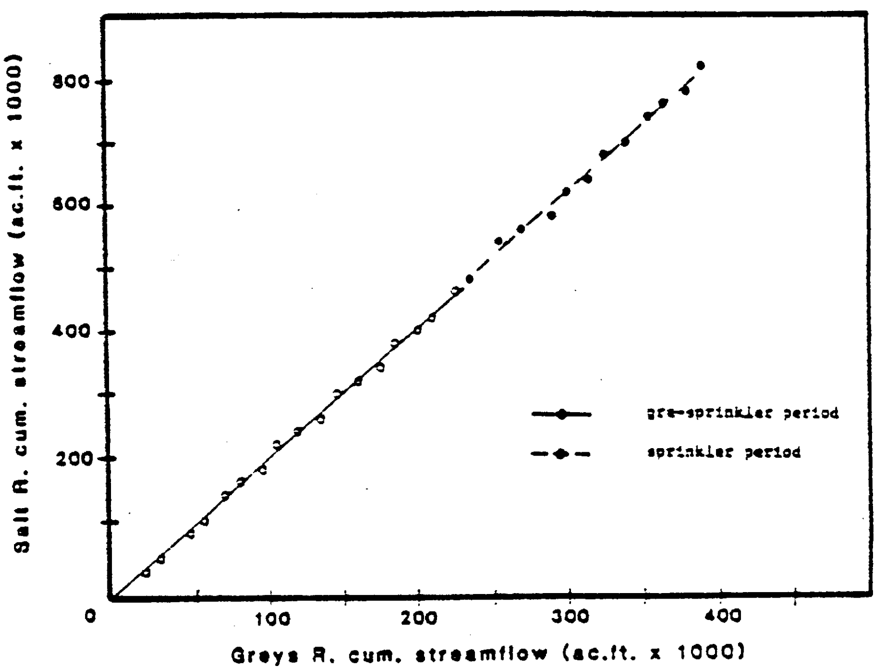

Figure 10. Double mass plot of Salt R. flows versus Greys R. flows for March

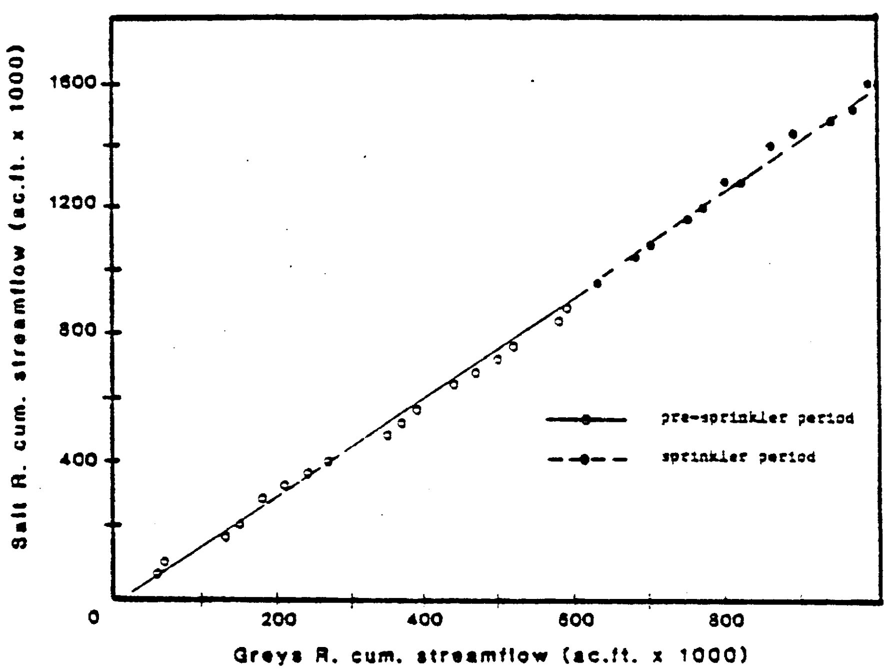

Figure 11. Double mass plot of Salt R. flows versus Greys R. flows for April.

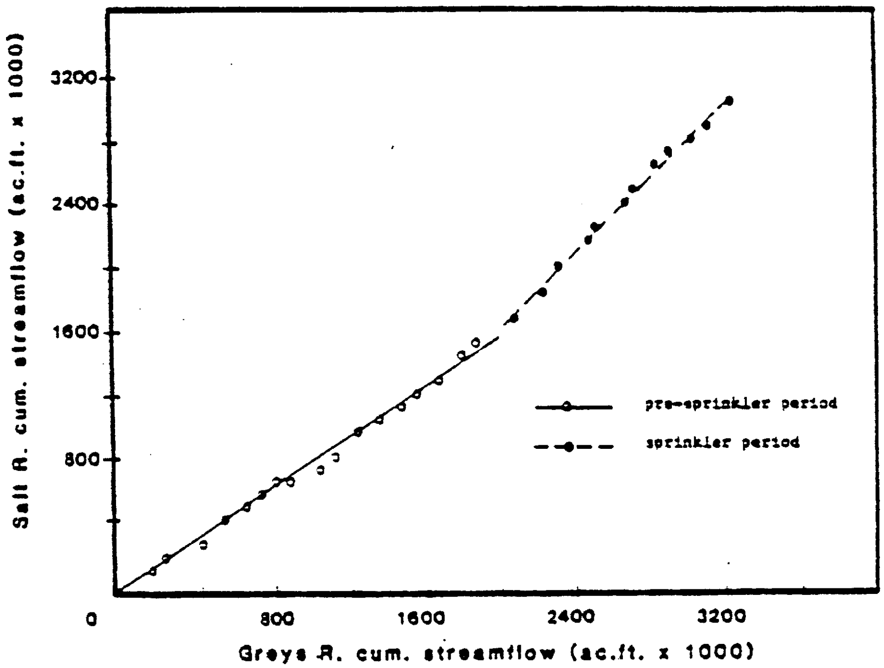

Figure 12. Double mass plot of Salt R. flows versus Greys R. flows for May.

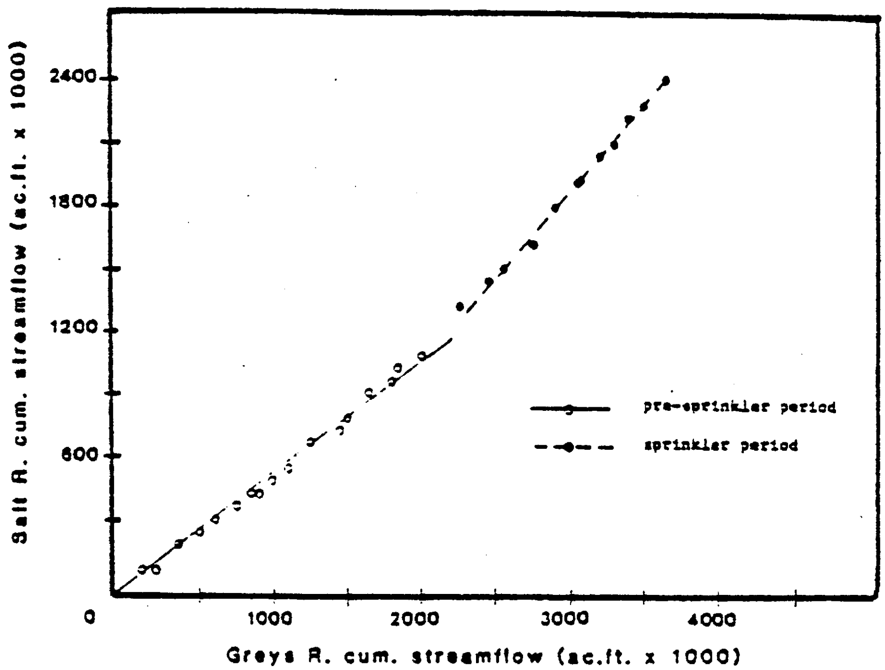

Figure 13. Double mass plot of Salt R. flows versus Greys R. flows for June.

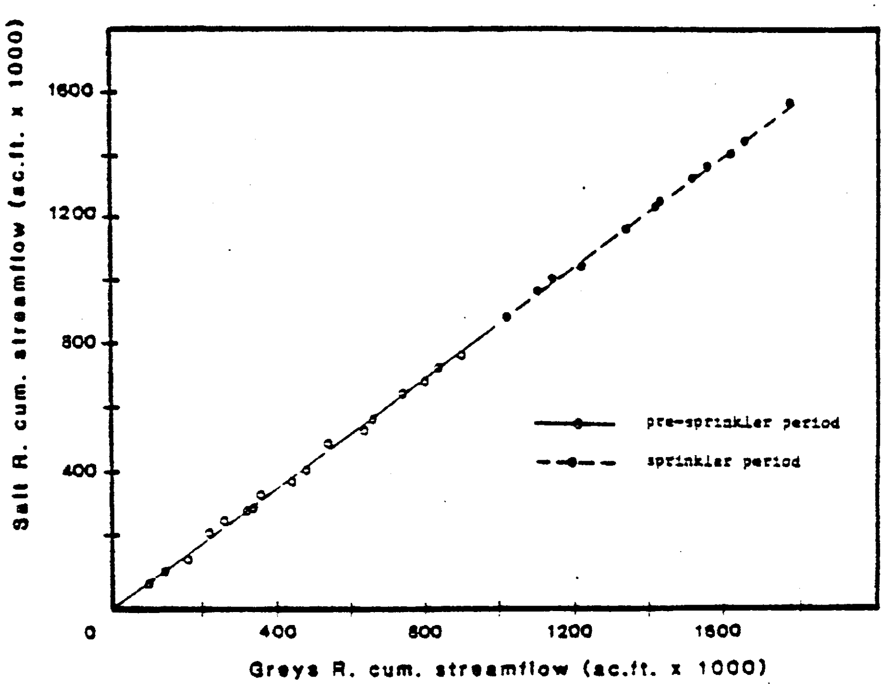

Figure 14. Double mass plot of Salt R. flows versus Greys R. flows for July.

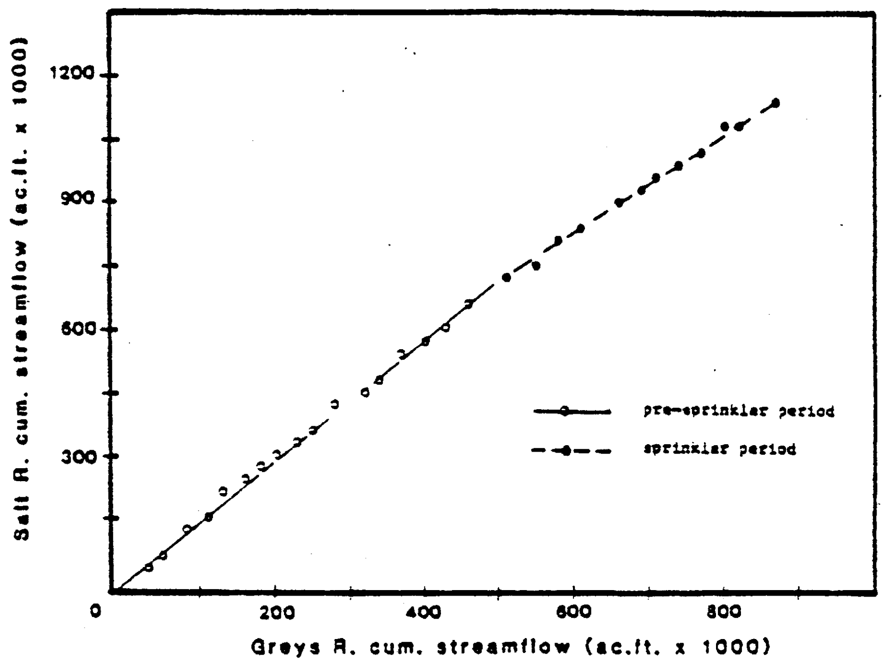

Figure 15. Double mass plot of Salt R. flows versus Greys R. flows for August.

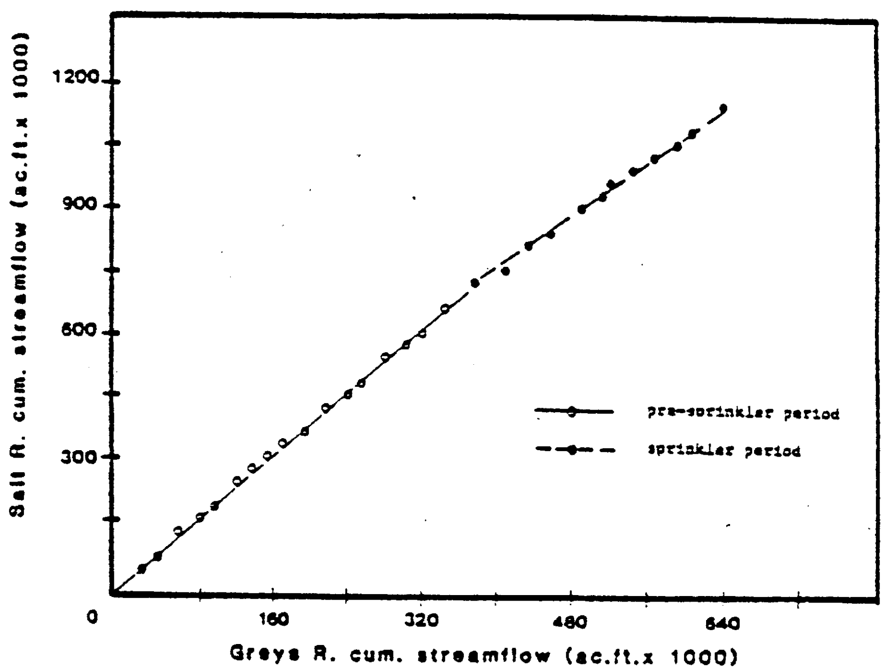

Figure 16. Double mass plot of Salt R. flows versus Greys R. flows for September.

of the Greys River (see Figures 5, 6, 15 and 16). All other months show little change between the two rivers, with relatively constant slopes in the cumulative streamflow plots.

Double mass plots for the Salt River cumulative flows versus the averaged cumulative flows from all five gaging stations are presented in Appendix B (Figures 23-24). The relative increase in Salt River stramflows in May and June starting in 1971 is again shown in Figures 24 and 25. A relative decline in fall flows for the Salt River is present but not as marked in this test as in the Salt River versus Greys River double mass test. In the Salt River versus Greys River double mass test, the degree of relative decline of Salt River streamflow in the fall months was not as great as the degree of relative increase of streamflow in the spring months. Therefore in the double mass test using the averaged data, the relative decline in the fall may have been obscured by differences in other factors, like land use and climatic influences, between the various drainages. The close proximity of the Greys River to the Salt River provides that other factors including climatic influences are most nearly identical between these two drainages. Therefore, the relative trends revealed in these tests are probably most accurate for the Salt River versus the Greys River than for the Salt River versus the averaged streamflow values.

Synthetic Flow Analysis

Results of the regression of Salt River cumulative monthly streamflows versus Greys River cumulative monthly streamflows for each month are presented in Table 2. Results of the tests comparing synthetic monthly streamflows that were generated by these regressions with the actual Salt River streamflows observed in the sprinkler period are presented in Table 3. These tests substantiate the trends shown in the double mass analysis, with the observed Salt River flows in the sprinkler period being significantly higher ($\alpha = 0.05$) in the spring months (May and June) and significantly lower in the fall months (August-November) than the synthesized flows which represent expected Salt River streamflows if the sprinklers were not installed. Steamflows in other months (December-April and July) showed no significant differences.

Annual Flood Peak Analysis

The annual peak discharges for period of record for the Salt River and Greys River are presented in Table 4.

Flood Frequency Distributions

The Log Pearson Type III flood frequency distributions for the pre-sprinkler and sprinkler periods for the Salt River appear in Figure 17. Using the pre-sprinkler Salt River flood frequency distribution the 200 year flood is calculated to be 3020 cfs. This peak discharge was exceeded in 7 out of the 12 years during the sprinkler period. The

Table 2. Results of the regressions employed in the synthetic flow analysis.

MONTH	PERIOD	EQUATION	R-SQUARED
OCT	'54-71	Y = 2097 + 2.08(X)	.99
NOV	'54-71	Y = 812 + 2.34(X)	.99
DEC	'54-71	Y = 5425 + 2.31(X)	.99
JAN	'54=71	Y = 2093 + 2.16(X)	.99
FEB	'54-71	Y = 4855 + 2.19(X)	.99
MAR	'54-71	Y = 4283 + 2.04(X)	.99
APR	'54-70	Y = 4701 + 1.48(X)	.99
MAY	'54-70	Y = 58833 + .815(X)	.99
JUN	'54-70	Y = 34254 + .549(X)	.99
JUL	'54-70	Y = 3254 + .859(X)	.99
AUG	'54-70	Y = 5735 + 1.42(X)	.99
SEP	'54-70	Y = 670 + 1.92(X)	.99

Table 3. Results of the Salt River snythetic flows analysis for the sprinkler period.

MONTH	OBSERVED MEAN FLOW (acft/mo)*	SYNTHETIC MEAN FLOW (acft/mo)	PERCENT DIFFERENCE	T VALUE
OCT	39,188	43,973	10.9	-4.62**
NOV	35,579	39,579	-10.1	-3.11**
DEC	31,987	34,563	-7.5	-1.90
JAN	27,528	28,509	-3.4	-1.01
FEB	24,097	25,393	-5.2	-2.05
MAR	30,293	28,799	+5.2	1.80
APR	36,932	49,620	+14.7	2.03
MAY	130,329	91,149	+42.3	-4.61**
JUN	109,559	74,142	+47.8	5.09**
JUL	64,244	62,341	+3.1	0.95
AUG	41,136	49,117	-16.2	-7.61**
SEP	40,531	47,313	-14.3	-8.30**

* May, 1971 - September, 1982

** Statistically significant at $\alpha = 0.05$.

Table 4. Annual peak discharges for the Salt River and Greys River (1954-1982).

YEAR	SALT RIVER PEAK ANNUAL DISCHARGE (cfs)	GREYS RIVER PEAK ANNUAL DISCHARGE (cfs)
1954	1560	4210
1955	1280	2010
1956	2420	5010
1957	2320	4290
1958	2260	3720
1959	1230	2920
1960	1520	2500
1961	899	2110
1962	2250	3110
1963	1830	2420
1964	2790	4280
1965	2310	3860
1966	2230	3150
1967	2190	4050
1968	1720	3260
1969	2070	2670
1970	2340	4250
1971	3870	7230
1972	3560	5170
1973	2250	2550
1974	3590	5220
1975	3580	3650
1976	3760	3590
1977	914	650
1978	3030	3950
1979	1870	2760
1980	2550	2960
1981	1680	2080
1982	3810	3940

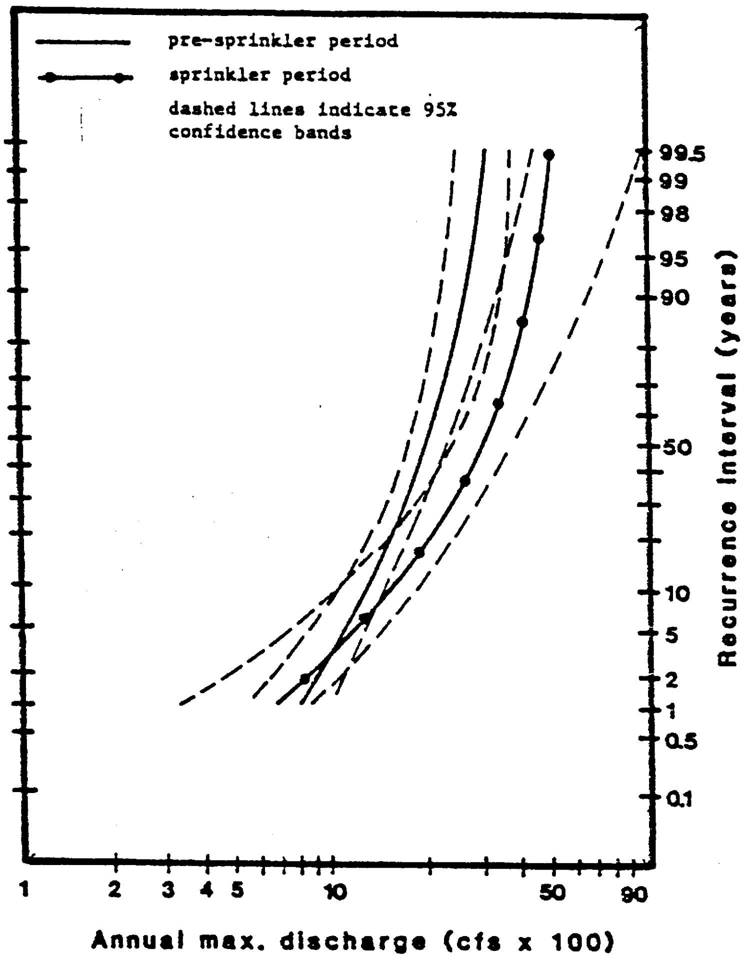

Figure 17. Log Pearson III flood frequency distributions of the Salt River for the pre-sprinkler and sprinkler periods.

hydrologic probability of exceeding the 200 year flood in 7 out of 12 years for an unchanged system is 9.947 x 10>11 or approximately one chance in one trillion. This very remote possibility indicates that a significant change occurred between the two periods. A visual comparison of the flood frequency distributions of the two periods also shows that for all flood estimates greater than the four year flood, the sprinkler period flood estimates were greater. For all floods greater than the 40 year flood the increase in the flood estimates for the sprinkler period are large enough that there is little if any overlap in the 95% confidence limits of the two distributions.

The Log Pearson Type III flood frequency distributions for the same two periods for the Greys River are presented in Figure 18. Using the pre-sprinkler period distribution, the 200 year flood for the Greys River was calculated to be 6069 cfs. This peak discharge was exceeded only once during the sprinkler period in 1971 which was an exceptionally high water year throughout western Wyoming. A visual comparison of the flood frequency distributions for the two periods for the Greys River shows a much greater degree of overlap. The only portion of the two distributions where the 95% confidence limits are separated is between the one and eight year floods where the pre-sprinkler period flood estimates are greater than those of the sprinkler period.

Test for Stationariness

The stastic T for this test was calculated to be 2.62. The critical value t at $\alpha = 0.05$ is 2.05. Since $|T|>T$, we reject $H : b = 0$ and conclude that the slope of the regression line of annual peak flows versus years is significantly different than zero. This means that a long term trend is present in the record of annual peak flows. An examination of the annual peak discharges reveals that this long term trend is due to an increase in the annual peak flows of the Salt River during the sprinkler period.

Test for Independence

The first test for independence, using serial correlation yielded a test statistic $r(1) = 0.1687$. Confidence limits at the 5% level for $r(1)$ were calculated to be -0.399 to 0.238. Since the calculated $r(1)$ is within this range, we do not reject $H : r(1) = 0$ and conclude that successive annual flood peaks are independent of each other.

The second test for independence, using the turning point, showed that the data record of annual peak flows contained 19 turning points or T=19. Confidence limits for T at the 5% level were calculated to be 13.7 to 22.3. Since the number of turning points, T, is within this range we again conclude that successive annual flood peaks are independent of each other.

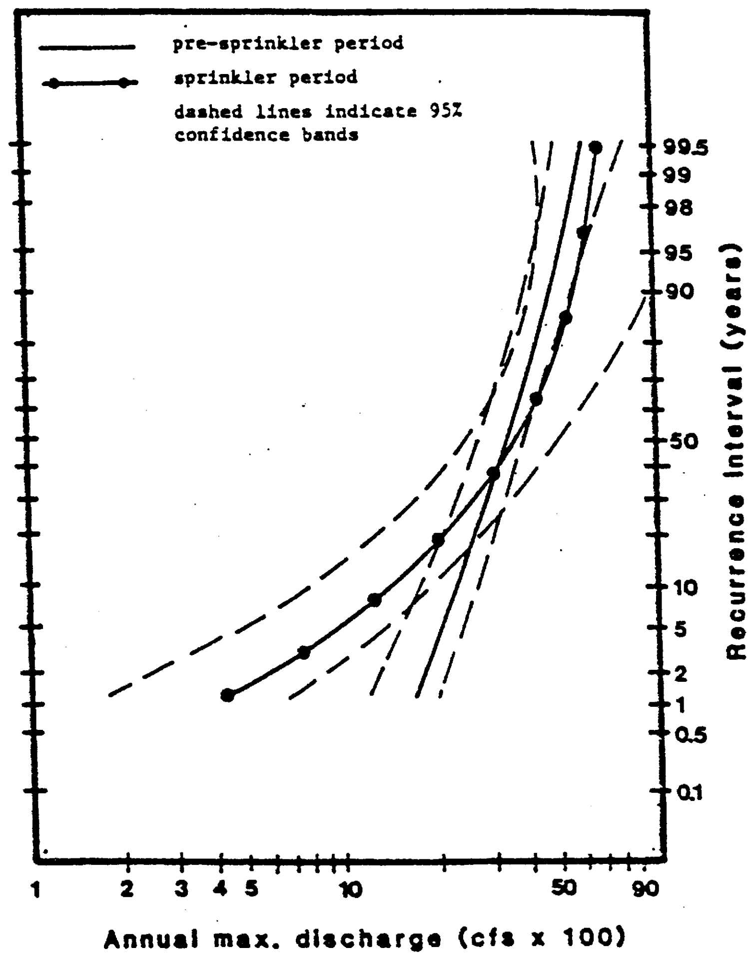

Figure 18. Log Pearson III flood frequency distributions of the Greys River for pre-sprinkler and sprinkler periods.

Test for Homogeneity

In the Mann-Whitney U test of homogeneity, the test statistic T was calculated to be -4.18. The critical value was found to be: z [1 - (α/2)] = 1.96 at α = 0.05. Since $|T|<z$, we reject the hypothesis that both the pre-sprinkler period and sprinkler period annual peak flows are from the same population. An examination of the peak flows again reveals that the sprinkler period annual peak flows are significantly higher than those of the pre-sprinkler period.

The Moving Average

The plots of peak flows and peak flow moving average versus time in years for both the Salt River and the Greys River appear in Figure 19. During the pre-sprinkler period, the difference betwen the Salt River moving average plot and the Greys River moving average plot is large and relatively constant. Recall that the Greys River drainage is largely undeveloped agriculturally or otherwise and therefore the Greys River flow represents a natural flow regime. The large difference between the Salt River moving average plot and the Greys River moving average plot during the pre-sprinkler period can be partially attributed to the flood irrigation practices in the Salt River drainage. With the flood irrigation systems, a large portiion of the spring flows are diverted into the canal systems and onto the cultivated land. Therefore, decreased peak flows are expected under such a system. There are, of course, other factors such as drainage basin area and climatic influences which also contribute to the differences in peak flows for the two rivers. Starting in 1974, the Salt River moving average plot begins to converge toward the Greys River moving average plot and from 1977 on the two plots stay consistently close to each other. The most probable explanation for this is that following the conversion to sprinkler systems, a much smaller portion of the flows of the Salt River and its tributaries were diverted for irrigation purposes, therefore there was a relative increase in peak annual discharges. The fact that this trend isn't visible until 1974 (construction of the sprinkler systems was completed in 1971) is most likely due to the method of calculation of the moving average. Since the moving average in 1971 is calculated by averaging the peak annual discharges of 1967-1971, it is clear that this value is still most representative of pre-sprinkler conditions. Not until 1973 or 1974 would the moving average plot begin to mostly show the influence of the sprinkler systems upon the peak annual flows.

New Log Pearson Type III Flood Frequency Distribution

The new Log Pearson Type III flood frequency distribution for the Salt River is presented in Figure 20 and in tabular form in Table 5. This distribution was developed using data from the period 1975-1982 and is intended to represent current hydrologic conditions for the Salt River.

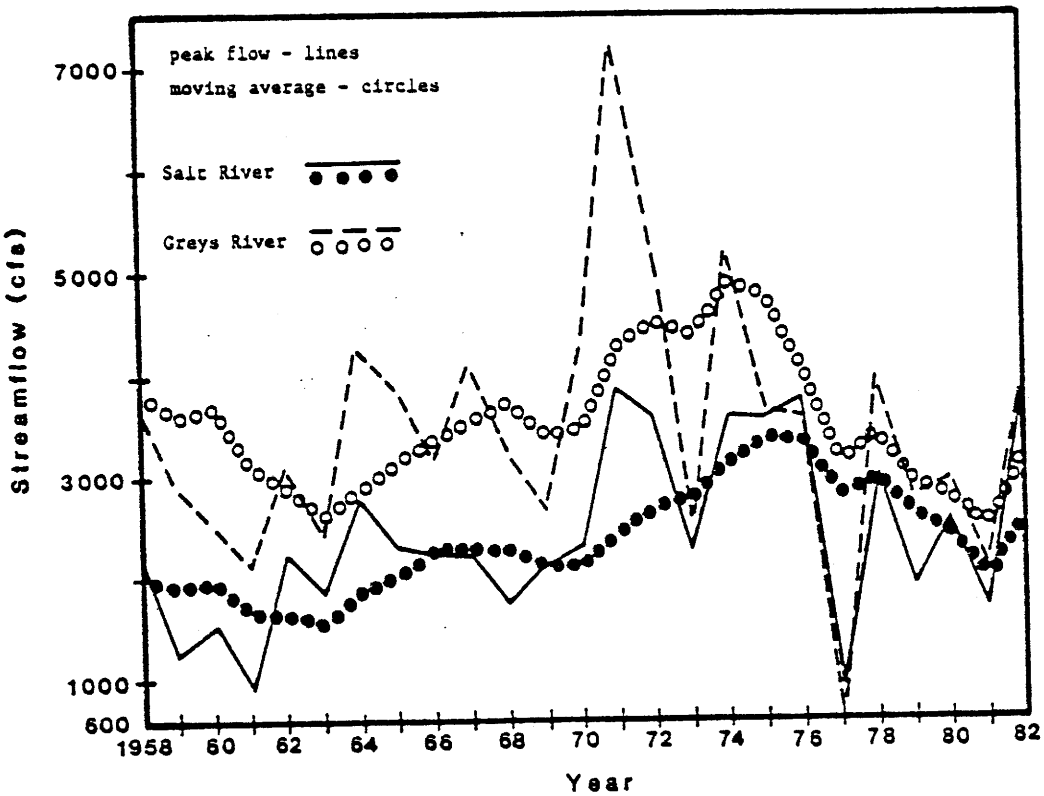

Figure 19. Peak flows and peak flow moving averages of the Salt River and Greys River.

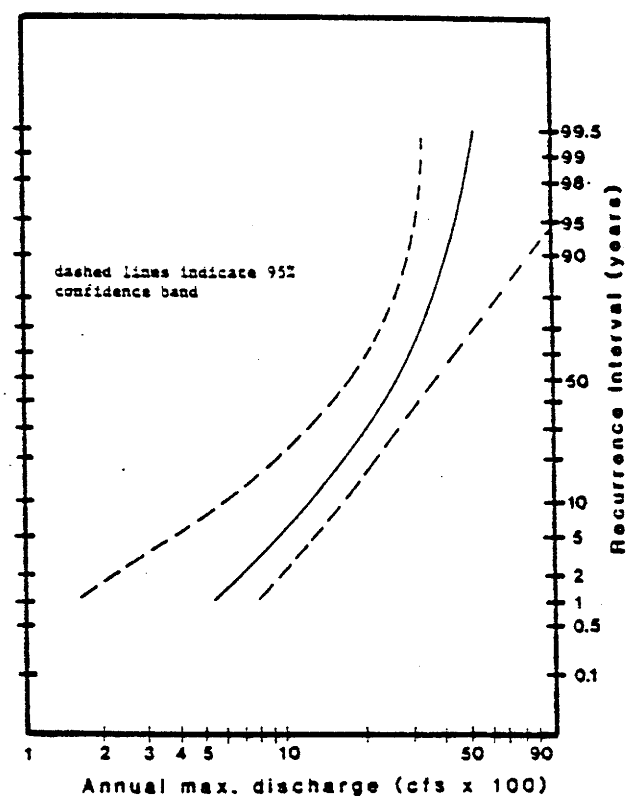

Figure 20. Current log Pearson III flood frequency distribution for the Salt River.

Table 5. Results of the new Log Pearson TYPE III flood frequency distribution for the Salt River.

Data Record: 1975-1982
Equation: Log Q = 3.39201 + K(0.217420)

RECURRENCE INTERVAL	K	LOG Q	CFS
1.01	-3.079	2.713	316
1.05	-1.892	2.971	935
1.11	1.341	3.091	1232
1.25	-0.747	3.220	1658
2	0.178	3.421	2635
5	0.849	3.567	3686
10	1.110	3.623	4200
25	1.329	3.671	4689
50	1.442	3.696	4962
100	1.527	3.714	5177
200	1.592	3.728	5347

95% CONFIDENCE INTERVAL
Log Q = Log Q + (err. fac.)(0.217420)

RECURR INT.	UPPER ERR. FAC.	LOWER ERR. FAC.	UPPER LOG Q	LOWER LOG Q
1.01	0.856	2.354	2.899	2.201
1.11	0.646	1.49	3.231	2.767
2	0.728	0.728	3.679	3.262
10	1.470	0.646	3.947	3.483
100	2.354	0.856	4.226	3.528

Analysis of NOAA Climatic Data

The purpose for analyzing climatic data is to determine if climatic changes could have potentially caused the observed streamflow changes. Presented below are the results of those analyses.

Comparison of Means and Variances

Results of the T-tests and F-tests for the comparison of mean monthly precipitation at Afton for the pre-sprinkler and sprinkler periods are presented in Table 6. The only month that showed a significant difference ($\alpha = 0.05$) was June, where precipitation decreased by 40.5% in the sprinkler period. Although monthly precipitation and monthly streamflow are often poorly correlated (Branson et al., 1981) the variation in monthly precipitation trends for the pre-sprinkler period versus the sprinkler period indicates that there are no patterns of precipitation changes that would explain the significant changes in streamflow. Even in the month of June where a significant change in mean precipitation did occur the trend was opposite (a decrease in precipitation) to that which would have been expected given the significant increasee in streamflow during that month. It is also of note that mean precipitation during the months of July-November increased by an average of 22.7% in the sprinkler period when compared to the pre-sprinkler period. While this increase was not statistically significant, it probably tended to offset some of the late season declines in streamflow that would be expected as a result of the switch to sprinklers. These observations lead to the conclusion that precipitation trends in the Star Valley had a negligible effect upon the observed streamflow changes after the switch to sprinklers and, in fact, the precipitation trends may have served to attenuate the effects of the sprinklers, especially in the fall months.

Results of the T-test and F-test for the comparison of mean monthly temperatures for the pre-sprinkler period and sprinkler period at Afton are presented in Table 7. Two months showed significant differences at ($\alpha = 0.05$). In March, mean temperatures increased from 25.13 degrees F during ther pre-sprinkler period to 29.15 degrees F during the sprinkler period, a change of 12.1%. May mean temperatures decreased from 48.11 degree F during the pre-sprinkler period to 46.29 during the sprinkler period, a change of 3.8%. Temperature changes could possibly contribute to changes in streamflow if the temperature trends were large enough to appreciably alter evapotranspitation in an area and thereby affect surface water interactions. It is unlikely, however, that the temperature changes observed between the two periods in this study are sufficiently large or of a consistent pattern to significantly contribute to the observed streamflow changes between the two periods.

Table 6. Results of the T-test and F-test of mean monthly precipitation for the pre-sprinkler and sprinkler periods at Afton, Wyoming.

MONTH	MEAN PRECIPITATION (in.) PRE-SPRINKLER*	SPRINKLER**	PERCENT DIFFERENCE	T VALUE	F RATIO
JAN	1.55	1.78	+15.1	-0.76	0.66
FEB	1.39	1.17	-16.4	1.04	0.96
MAR	1.20	1.38	+8.7	-0.38	0.13
APR	1.68	1.70	+1.0	-0.05	0.00
MAY	1.90	2.27	+19.5	-0.77	0.64
JUN	2.31	1.38	-40.5	2.35***	4.58***
JUL	0.99	1.31	+32.1	-0.88	0.90
AUG	1.11	1.34	+21.0	-0.82	0.67
SEP	1.33	1.53	+15.0	-0.43	0.20
OCT	1.26	1.60	+33.1	-1.25	1.78
NOV	1.55	1.37	-12.1	0.73	0.48
DEC	1.65	1.79	+8.6	-0.32	0.12
ANNUAL	17.88	18.90	+5.7	0.75	0.62

* October, 1953 - April, 1971

** May, 1971 - September, 1982

*** Statistically significant at $\alpha = 0.05$

Table 7. Results of the T-test and F-test of mean monthly temperature for the pre-sprinkler and sprinkler periods at Afton, Wyoming.

MONTH	MEAN TEMPERATURE (F) PRE-SPRINKLER*	SPRINKLER**	PERCENT DIFFERENCE	T VALUE	F RATIO
JAN	15.96	15.92	-0.3	0.02	0.00
FEB	20.38	20.54	+0.8	-0.10	0.01
MAR	25.13	28.15	+12.0	-2.29***	3.50***
APR	36.76	36.77	0.0	-0.01	0.00
MAY	48.11	46.29	-3.8	2.19***	4.38***
JUN	54.23	54.20	+0.5	0.34	0.14
JUL	61.40	61.16	-0.4	0.36	0.13
AUG	59.87	59.58	-0.5	0.33	0.11
SEP	52.34	51.43	-1.8	1.07	0.93
OCT	42.12	41.47	-1.5	0.73	0.45
NOV	28.81	28.05	-2.7	0.53	0.25
DEC	17.95	18.92	+5.4	-0.77	0.56
ANNUAL	38.57	38.58	0.0	-0.00	0.00

* October, 1953 - April, 1971
** May, 1971 - September, 1982
*** Statistically significant at $\alpha = 0.05$

Correlation Analysis and Double Mass Analysis

Results of the correlation analysis between the Afton climatic data and the Bondurant and Big Piney data are presented in Table 8. The T-ratio values for these correlations showed that both yearly precipitation and mean annual temperature values at Afton were significantly ($\alpha = 0.05$) correlated with those from the Bondurant and Big Piney stations. This indicates that climatic trends in the Salt River drainage are similar to those of the surrounding areas. This leads to the conclusion that the relative changes in streamflow between the Salt River and the adjacent Greys River were not due to differences in climatic trends between the two drainage basins.

The results of the double mass analysis of Afton cumulative climatic data versus cumulative averaged values of the other stations also confirm the similarity in climatic trends in the region. The double mass plots for total annual precipitation and mean annual temperature are presented in Figures 21 and 22. These plots show relatively straight lines throughout the period of record and confirm that climatic trends in Star Valley were similar to those of surrounding areas and this probably did not contribute to the differences in streamflow observed between the Salt River and the Greys River.

Crop Water Analysis

Average alfalfa yields for Lincoln County during the pre-sprinkler and sprinkler periods were 1.60 and 2.11 tons per acre, respectively. Using the crop water function derived at Logan, Utah average seasonal consumptive use during the pre-sprinkler period was calculated to be 7.56 inches. For the 60,464 irrigated acres in Star Valley, this resulted in a mean seasonal consumptive use of 38,092 acft during the pre-sprinkler period. Using the monthly ratios reported by Trelease et al. (1970), mean monthly consumptive use values during the pre-sprinkler period for August, September and October were calculated and appear in Table 9.

For the least impact case where yield increases during the sprinkler period were assumed to be equal to Lincoln County yield increases, seasonal consumptive use during the sprinkler period was calculated to be 9.13 inches which resulted in a total of 45,999 acft for the Star Valley. The portions of this seasonal consumptive use calculated to have occurred in the months August, September and October appear in Table 9.

The maximum impact case assumed that average yields doubled in the Star Valley after the sprinklers were installed. Using this assumption, season consumptive use was calculated to be 12.5 inches which resulted in a total of 62,898 acft for the Star Valley. The portions of this seasonal consumptive use calculated to have occurred in the months August, September and October appear in Table 9.

Some of the hydrologic impacts of the increased yields can be

Table 8. Correlations between climatic stations.

STATIONS	PRECIPITATION CORRELATIONS (R)	T RATIO	TEMPERATURE CORRELATION (R)	T RATIO
Afton/ Big Piney	61.6%	4.06*	60.1%	3.90*
Afton/ Bondurant	59.7%	3.87*	21.2%	2.70*

* Statistically significant at $\alpha = 0.05$

Table 9. Results of Crop Water Use Analysis.

	ANALYSIS PERIOD		
	PRE-SPRINKLER	SPRINKLER (LEAST IMPACT)	SPRINKLER (MAXIMUM IMPACT)
ALFALFA YIELD (tons/Ac.)	1.60	2.11	3.20
SEASONAL E. T. (in.)	7.56	9.13	12.48
STAR VALLEY E. T. (acft)	38092.3	45999.2	62898.1
AUGUST E. T. (acft)	8227.9	9935.8	13586.0
SEPTEMBER E. T. (acft)	4799.6	5795.9	7925.2

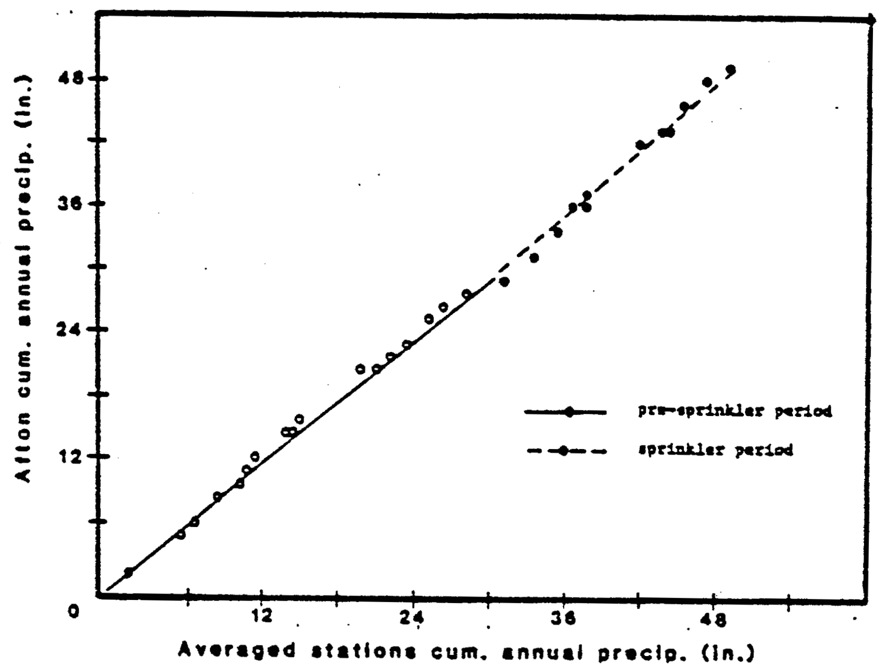

Figure 21. Double mass plot of Afton mean annual precipitation versus averaged mean annual precipitation of Bondurant and Big Piney.

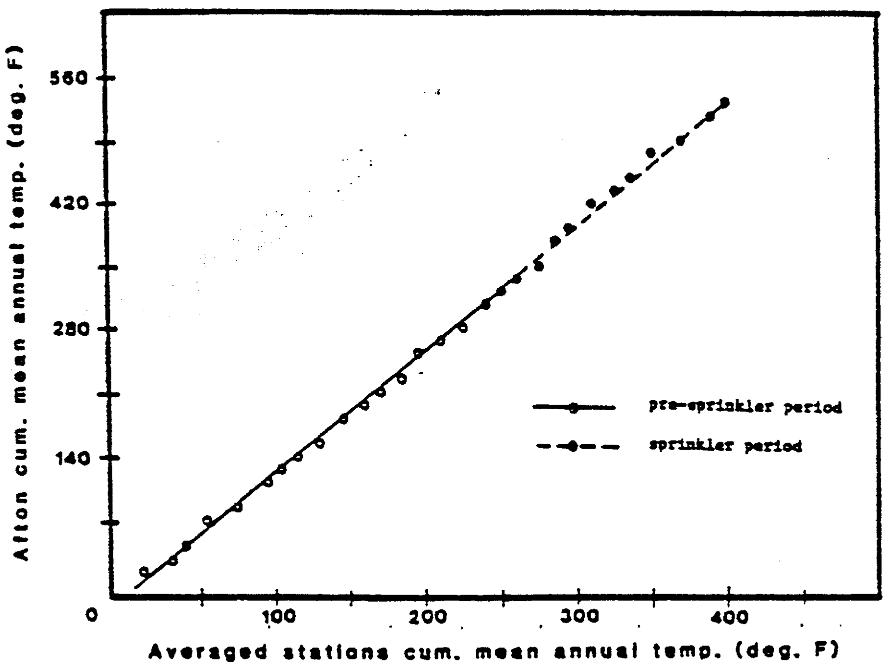

Figure 22. Double mass plot of Afton mean annual temperature versus averaged mean annual temperature of Bondurant and Big Piney.

assessed from the results of this crop water analysis. Firstly, for the least impact case, mean consumptive use increased by 1,709 acft in August during the sprinkler period. From the synthetic flows analysis (Table 3) August streamflows during the sprinkler period decreased by 7,981 acft from expected flows. Therefore, for the least impact the estimated increased consumptive use accounted for 21.4% of the decline in streamflow in August. September mean consumptive use increased by 996 acft during the sprinkler period and mean streamflows were 6,782 acft less than expected. Increased consumptive use thus accounted for 14.7% of the mean streamflow decline. October mean consumptive use increased 308 acft during the sprinkler period and mean streamflows declined 4,785 acft from the expected. This consumptive use was 6.4% of the streamflow decline. Therefore, under the least impact case the hydrologic impact of the increases in consumptive use was small in (a maximum of 21.4% during August) with reference to declines in Salt River streamflow during the late summer and fall months.

For the maximum impact case, mean August consumptive use increased by 5,357 acft during the sprinkler period which was 67.1% of the decline of observed streamflows from expected streamflows. In September, the increase in mean consumptive use (3,125 acft) accounted for 46.1% of the streamflow decline. In October, the increase in mean consumptive use (967 acft) accounted for 20.2% of the streamflow decline. Therefore, for the maximum impact situation the increase in consumptive use had a larger impact upon Salt River late summer and fall streamflows, accounting for up to 67% of the streamflow declines.

The actual increase in crop yield for Star Valley during the sprinkler period was probably intermediate between the least impact and the maximum impact cases. The contribution of increased consumptive use to the decline in streamflow probably approached 50% for the month of August and considerably lower values for September and October. Therefore, increased consumptive use did not account for a substantial portion of the decreases in streamflow. However, consumptive use increases did not account for most or all of the streamflow decreases during the late summer and fall months. The largest factor contributing to the decline in streamflow in late summer and fall was probably a reduction in groundwater inflow during this period. The groundwater inflow would be expected to decline because of less groundwater recharge in the spring and early summer with the sprinkler systems than with flood irrigation systems.

Rancher Survey and Interviews

Thirty-two ranchers responded to the survey. The mean number of years that these ranchers farmed in Star Valley was 42.4 years. The total irrigated acreage farmed by these 32 ranchers was 7,986 acres (5,895 acres in sprinkler irrigation and 2,091 acres in flood irrigation). The average number of irrigated acres per farm for those surveyed was 225.2 acres. The average date of the first irrigation of the season was June 1st. For the irrigators who switched to sprinklers, the mean date of first irrigation did not change appreciably following the switch to sprinklers. The average date of the last irrigation of the season was the first week in September. Many irrigators who switched to sprinklers were able to irrigate later following the switch to sprinklers due to greater availability of late season water after the sprinklers were installed. Most of the irrigators that switched to sprinklers estimated that the total water applied decreased after the sprinklers were installed. A small number (6 out of 26) of the ranchers that switched to sprinklers estimated that the total water applied increased after the switch to sprinklers. This estimated increase was probably due to the fact that the ranchers were able to irrigate later into the season with the sprinklers and therefore they felt that the total water applied may have increased even though the water applied per application had declined. Most of the ranchers that switched to sprinklers estimated a slight increase in the number of acres they irrigated, mainly due to cultivation of areas previously occupied by flood system canals. The ranchers that switched to sprinklers estimated that their crop yield increased by an average of 120% with the sprinkler systems.

From the personal interviews with SCS, Wyoming Game and Fish Department, Wyoming Highway Department and Lincoln County personnel, the following information relevant to this study was determined:

1. In the early 1960's the ASCS sponsored a cost sharing program to encourage Star Valley ranchers to clear portions of their land of willows. This program as well as ranchers acting independently resulted in the removal of willows from the stream bank along 19.1 miles of the Salt River (Erickson, 1981).

2. There were no significant increases in urban or road construction in the Star Valley to account for changes in Salt River streamflow.

3. The average date for filling the flood system canals and the sprinkler system pipelines was May 1st. These conveyance systems were generally emptied around October 15th.

4. Prior to sprinkler installation the Dry Creek channel was usually dry during the growing season due to irrigation diversions. Following the installation of sprinklers, flow has always been present in the Dry Creek channel and flooding has been common.

5. In recent years, there has been a major problem with bank erosion along the Salt River channel. A Wyoming Game and Fish Department and SCS tree revettment program aimed at stabilizing the stream bank in problem areas has been moderately successful. In some years, Salt River flows have been high enough to wash out the tree revettment structures.

SUMMARY AND CONCLUSIONS

The switch from flood irrigation systems to sprinkler irrigation systems over a large portion of Salt River drainage area has offered a unique opportunity to study some of the hydrologic effects of increased irrigation efficiencies. The major results of this study can be summarized as follows:

1. Following the switch to sprinklers mean monthly flows of the Salt River increased by an average of 58.7% during the months of May and June.

2. Peak annual discharges also increased significantly (47%) following the installation of the sprinklers. For this reason, a new Log Pearson Type III flood frequency distribution was developed to represent current hydrologic conditions for the Salt River.

3. Fall flows (August - November) increased slightly during the sprinkler period (4.5%). However, this was attributed primarily to increased precipitation in the fall months during the sprinkler period. The synthetic flows analysis which attempted to compensate for climatic variations between the pre-sprinkler and sprinkler periods indicated that Salt River flows during the fall months declined an average of 12.9% in the sprinkler period.

4. The analysis of climatic data indicated that precipitation and temperature trends did not significantly contribute to the observed changes in streamflow for the Salt River during the sprinkler period. In fact, where changes in precipitation and temperature patterns were observed between the two periods, they tended to be opposite to that expected from the streamflow changes. This may have served to obscure some of the hydrologic effects of the sprinklers.

5. The crop water analysis showed that increases in crop water use due to yield increases following installation of the sprinklers did contribute to the declines in Salt River streamflows during August and September in the sprinkler period. While the contribution of this increased crop water use may have accounted for up to 50-60% of the decline in flow, it is clear that decreased groundwater recharge also contributed significantly to and probably was responsible for the majority of the decline in late season flows.

6. Interviews with Star Valley residents indicated that no significant increases in urban construction or other possible influential factors contributed to the observed changes in streamflow.

In recent years, the Star Valley has had considerable problems with flooding and erosion on the Salt River. The results of this study indicates that the switch to sprinklers has certainly contributed to these problems. The removal of willows from the Salt River streambank in the early 1960's has probably also contributed to these problems especially with respect to the erosion of the banks of the Salt River. The tree revettment program sponsored by the Game and Fish Department and the SCS and other bank stabilization projects (e.g., reestablishment of willows) may help to alleviate the erosion problems. However, presently the Salt River channel is in the process of ajusting to new hydrologic conditions following the switch to sprinklers. This may make bank stabilization programs even more difficult. Some type of surface storage may be desirable to help alleviate the flood and erosion problems of the Salt River.

This study has described some of the hydrologic effects of increased irrigation efficiencies. As hypothesized, the primary effects of increasing irrigation efficiencies are higher flows in the spring months, higher peak annual discharges and lower fall flows due to decreases in groundwater recharge. Due to variations in the physical, geologic, hydrologic and climatic characteristics of drainage basins, it is impossible to use the results of this study to quantitatively predict how increases in irrigation efficiencies will affect streamflows in other drainage basins. However, this study has documented irrigation efficiencies which can be valuable in planning future irrigation projects.

Increasing irrigation efficiencies will be necessary in dealing with salinity and water supply problems in the future. The possibility that increased spring streamflows and decreased fall streamflows may result from projects designed to increase irrigation efficiencies should be considered in irrigation project design. Where these effects appear likely to occur to a degree where problems may result, procedures to alleviate the problems can be incorporated into the project design. Where applicable, surface storage and artificial groundwater recharge may be used to offset the effects of higher spring flows and lower fall flows.

REFERENCES

Benz, L. C. and E. J. Doering. 1975. Pump drainage effects on Red River Valley (North). In Symposium on Watershed Management. Irrigation and Drainage Division of American Society of Civil Engineers. Logan, Utah.

Branson, F. A., G. F. Gifford, K. G. Rechard and R. F. Hadley, 1981. Rangeland Hydrology. Randall Hunt Publishing Co. Dubuque, Iowa.

Brosz, D. J. 1980. Current status of Irrigation in the United States. In Proceedings of the American Society of Agricultural Engineers. Second Nat. Irrigation Symposium. Lincoln, Nebraska..

Buchberger, S. R. 1981. Flood frequency analysis for regulated rivers. In Erosion, Sedimentation, Flood Frequency and Bridge Testing. Transportation Research Board Report #832. National Academy Science. Washington, D. C.

Bulavko, A. G. 1977. Errors of estimates of post reclamation streamflow changes following land reclamation by drainage. Sov. Meteorol. Hydrol. (6):56-63.

Dahms, W. G. 1971. Growth and soil moisture in thinned lodgepole pins. Forest Service Research Paper FNBW-127. Pacific Northwest Forest and Range Experiment Station. U. S. Forest Service.

Food and Agriculture Organization of United Nations. 1973. Man's influence on the hydrologic cycle. Irrigation and Drainage Paper #17. FAO, Rome.

Frederick, K. D. 1982. Water for Western Agriculture. The Johns Hopkins University Press. Baltimore, Maryland.

Gasseling. D. 1984. Personal communications. SCS. Afton, Wyoming.

Geraud, J. D. 1977. A potential impact of P. L. 92-500 on apparent irrigation flow contribution to late season streamflow in Wyoming. M.S. Thesis, Dept. Agr. Engr., University of Wyoming, Laramie, Wyoming.

Harr, R. D. 1979. Effects of timber harvest on streamflow in the rain-dominated portion of the Pacific Northwest. In Proceedings of Workshop on Scheduling Timber Harvest for Hydrologic Concerns. U.S. Department Agriculture Forest Service. Pacific Northwest Region, Portland, Oregon.

Harr, R. D., W. C. Harper, J. T. Krygler and F. S. Hsieh. 1975. Changes in storm hydrographs after road building and clear cutting in the Oregon Coast Range. Water Resources Research. (11):436-444.

Harr, R. D., R. L. Frederiksen and J. Rothacher. 1979. Changes in streamflow following timber harvest in southwestern Oregon. U. S. Department Agriculture Forest Service Research Paper PNW-249.

Harr, R. D., A. Levno and R. Mersereau. 1982. Streamflow changes after logging 130 year old Douglas Fir in two small watersheds. Water Resources Research 18(3):637-644.

Hornbeck, J., W. R. S. Pierce and C. A. Federere. 1970. Streamflow changes after forest clearing in New England. Water Resources Research. 6(4):1124-1132.

Interagency Task Force on Irrigation Efficiencies (IATF). 1978. Irrigation Water Use and Management. U. S. Bureau Reclamation, Denver, Colorado.

Kohler, M. A. 1949. On the use of double mass analysis for testing the consistency of meteorological records and for making required adjustments. Bulletin Am. Meteor. Soc. 30(5):188-189.

Moore, W. L. and C. W. Morgan. 1969. Effects of Watershed Changes on Streamflow. University of Texas Press, Austin, Texas.

Novikov, S. M. and Y. N. Polimeiko. 1980. Impact of drainage on streamflow. In Casebook of Methods of Computation of Quantitative Changes in the Hydrological Regime of River Basins due to Human Activities. United National Educational, Scientific and Cultural Organization. Project #51. Paris, France.

Pitman, W. V. 1978. Trends in streamflow due to upstream land use changes. Journal of Hydrology. Amsterdam. 39(3/4):227-337.

Robinson, F. E. O. D. McCoy, G. F. Worker and W. F. Lehman. 1968. Sprinkler and surface irrigation of vegetable and field crops in an arid environment. Agronomy Journal 60(6):696-700.

Rotacher, J. 1971. Increases in water yield following clearcut logging in the Pacific Northwest. Water Resources Research. 6:653-658.

Snedecor, G. W. and W. E. Cochran. 1974. Statistical Methods. The Iowa State University Press. Ames, Iowa.

Sterosolzky, D. 1980. Impact of drainage. In Casebook of Methods of Computation of Quantitative Changes in the Hydrological Regime of River Basins due to Human Actiities. United Nations Scientific and Cultural Organization. Project #51. Paris, France.

Trelease, F. J., R. D. Burman, P. A. Rechard and T. J. Swartz. 1970. Consumptive use of irrigation water in Wyoming. Wyoming Water Resources Research Institute Report #19. University of Wyoming. Laramie, Wyoming.

Viesssman, W. J., J. W. Knapp, G. L. Lewis, T. E. Harbaugh. 1977. Introduction to Hydrology. Harper and Row Publishers. New York.

APPENDIX A

RANCHER SURVEY

1) Your name ___________________________

2) How long have you farmed in Star Valley? ____________

3) How large is your ranch? _______

4) What type of irrigation do you now use? (check one)

   ___ gravity sprinkler irrigation
   ___ pump sprinkler irrigation
   ___ flood irrigation

5) When do you generally first irrigate in the spring? (check one)
   ___ mid-May
   ___ late May
   ___ early June

6) Do you ever start irrigating in May? Yes___No___

7) When do you generally stop irrigating in the fall? __________

8) If you now use sprinkler irrigation, please answer these questions:

   a) Do you now start irrigating? (check one)
      ___ earlier than
      ___ later than
      ___ about the same time as when you flood irrigated.

   b) Do you now stop irrigating in the fall? (check one)
      ___ earlier than
      ___ later than
      ___ about the same as when you flood irrigated.

   c) Have you changed your crops since switching to sprinklers?

      Yes___No___

   d) Since you switched to sprinklers would you say the number of acres that you irrigate has (check one)

      ___ increased
      ___ decreased
      ___ remained the same

   e) Since you switched to sprinklers would you say your crop yield has
      ___ increased
      ___ decreased
      ___ remained the same

f) Since you switched to sprinklers would you say you apply (check one)

___ more
___ less
___ the same amount of water as when you flood irrigate

9) Were you involved in the willow removal program? Yes___No___
If yes, please estimate how many acres you cleared ___

10) Are you involved in any erosion control programs? Yes___No___
If yes, please answer these questions:

a) What erosion control practices are you doing?

____

____

b) Would you say these practices are (check one)

___ very effective
___ somewhat effective
___ not effective

APPENDIX B

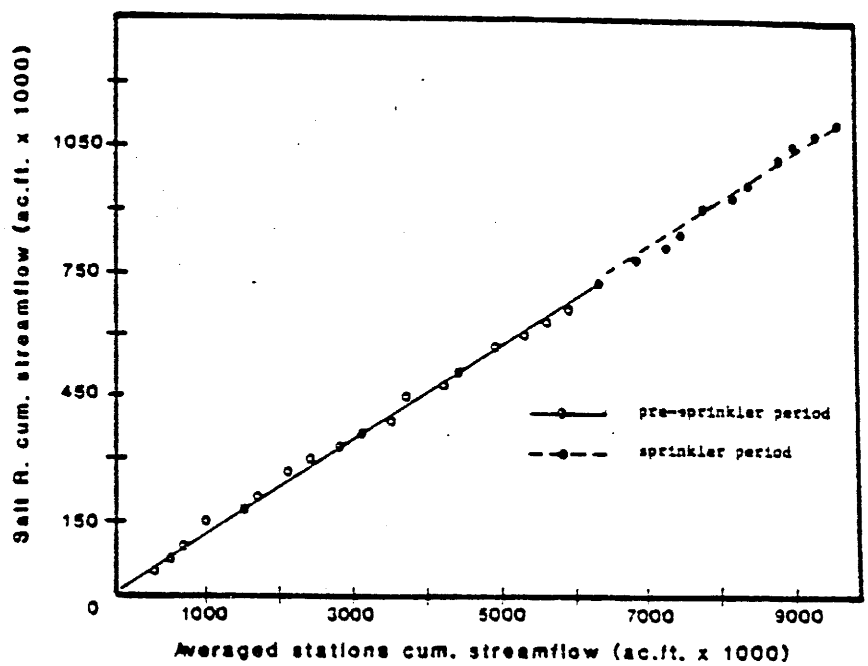

Figure 23. Double mass plot of Salt River flows versus averaged stations flows for October.

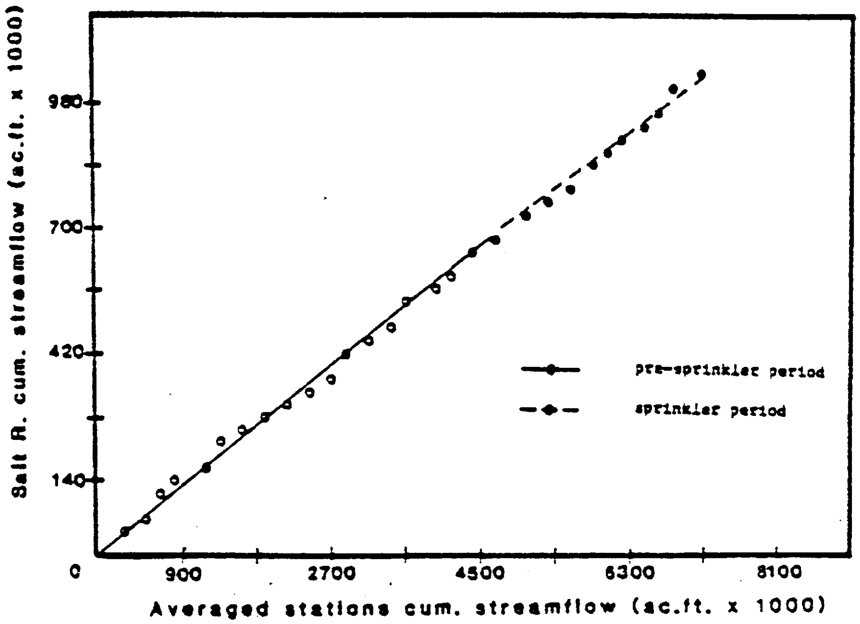

Figure 24. Double mass plot of Salt River flows versus averaged stations flows for November.

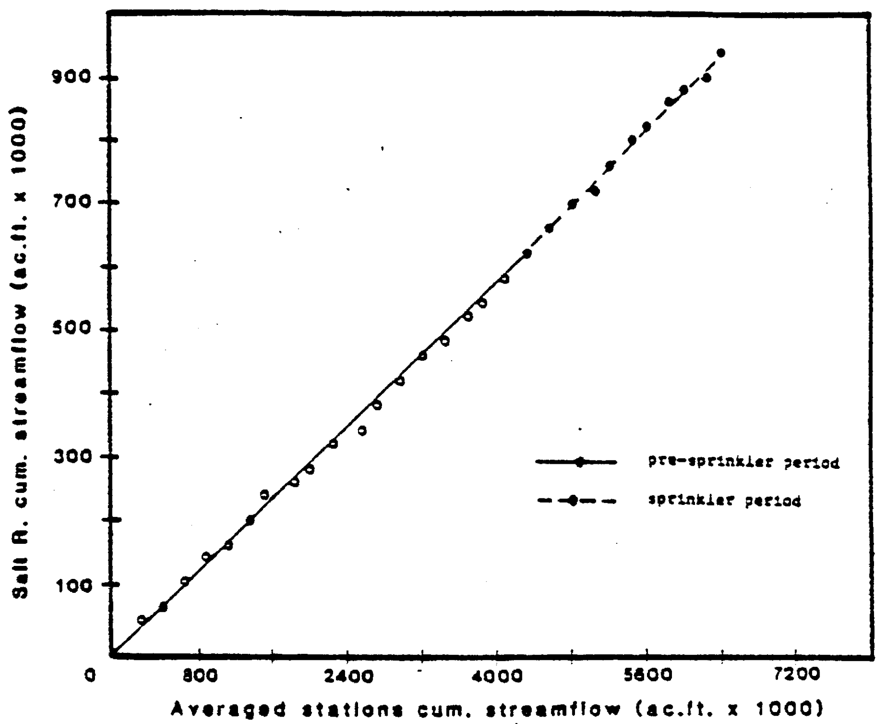

Figure 25. Double mass plot of Salt River flows versus averaged stations flows for December.

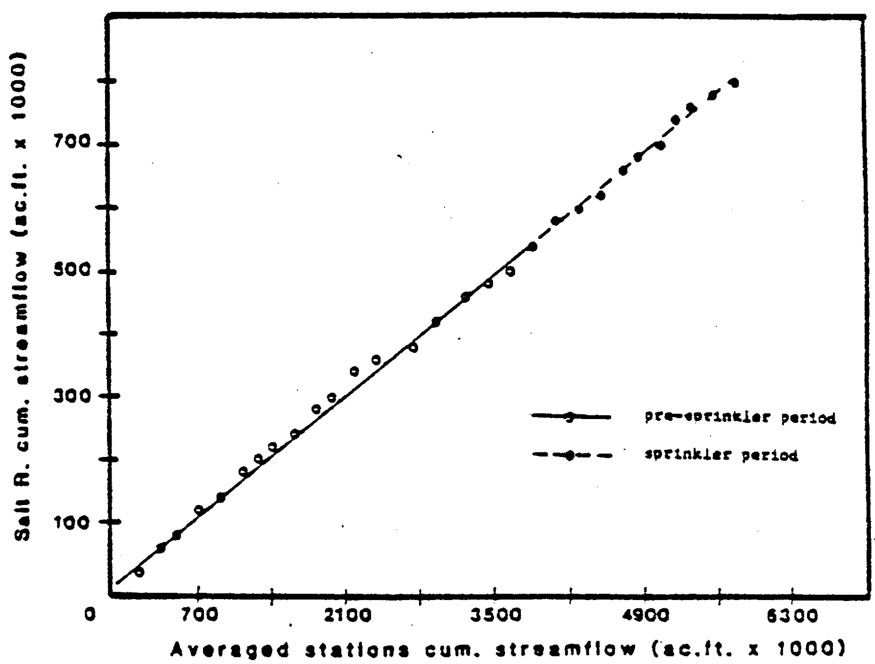

Figure 26. Double mass plot of Salt River flows versus averaged stations flows for January.

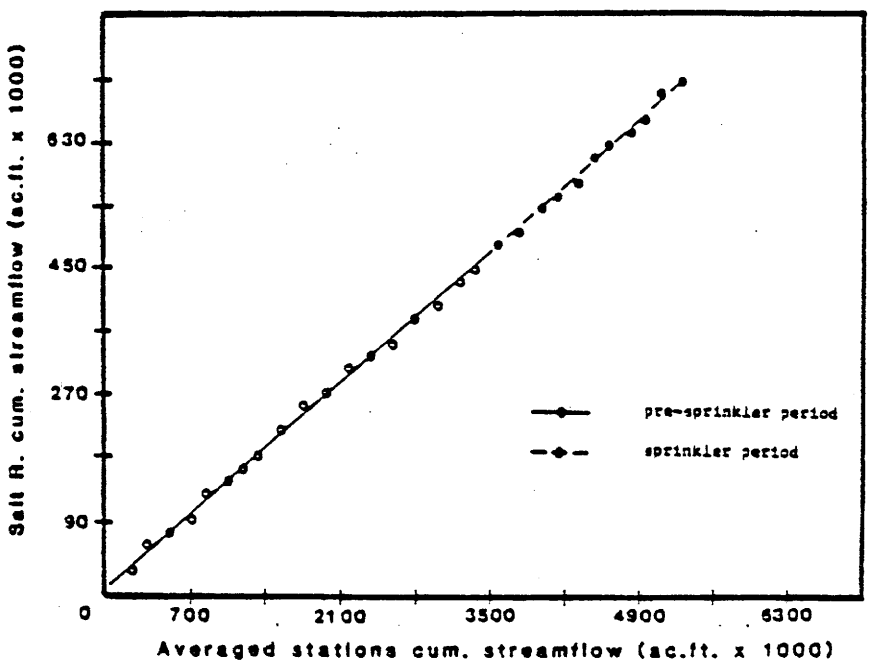

Figure 27. Double mass plot of Salt River flows versus averaged stations flows for February.

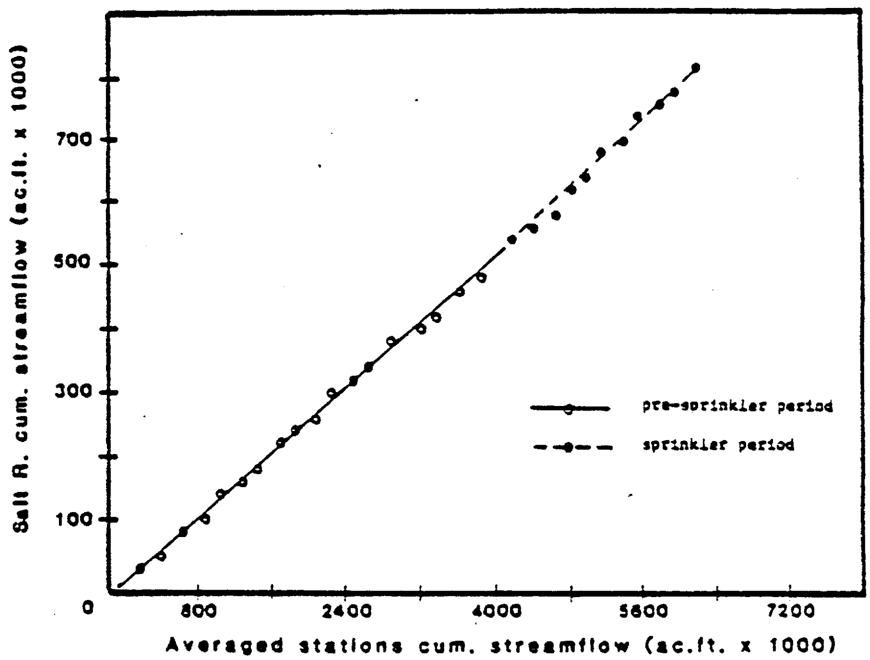

Figure 28. Double mass plot of Salt River flows versus averaged stations flows for March.

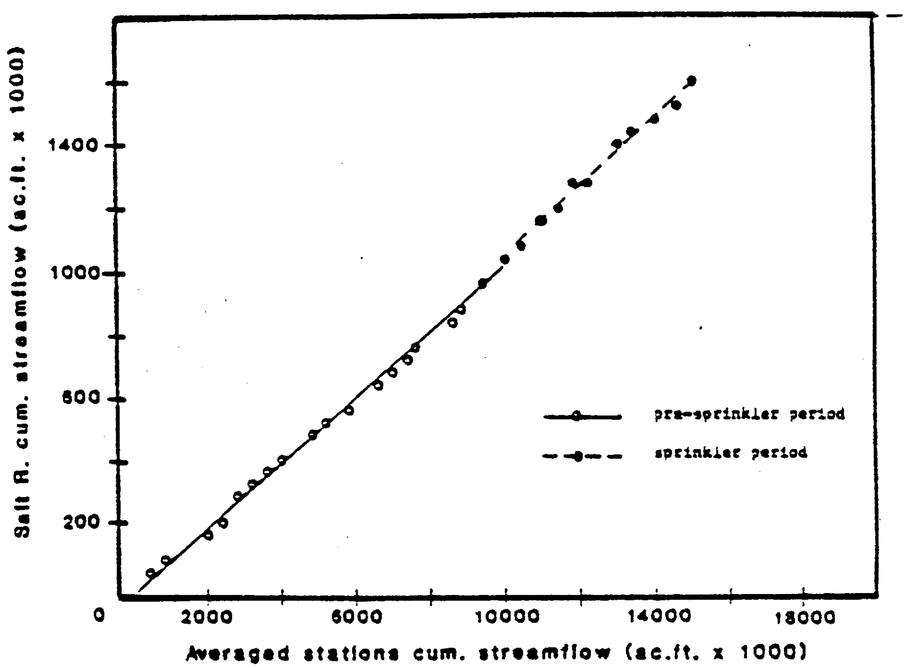

Figure 29. Double mass plot of Salt River flows versus averaged stations flows for April.

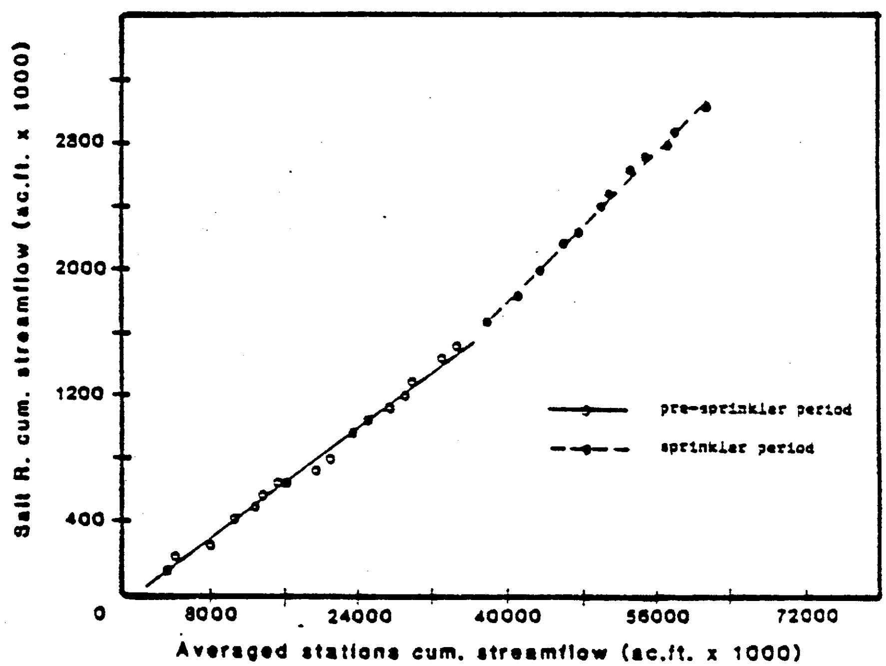

Figure 30. Double mass plot of Salt River flows versus averaged stations flows for May.

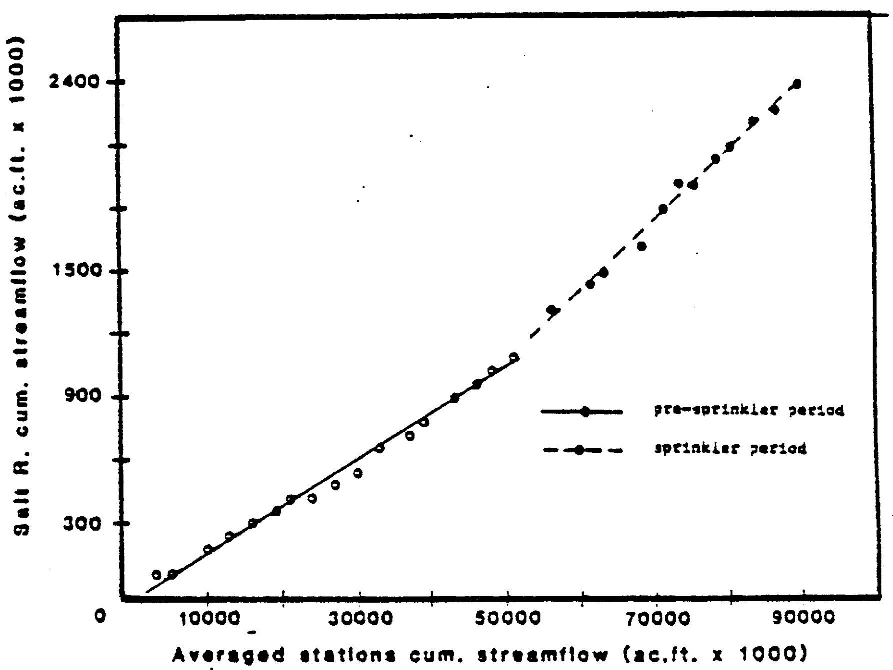

Figure 31. Double mass plot of Salt River flows versus averaged stations flows for June.

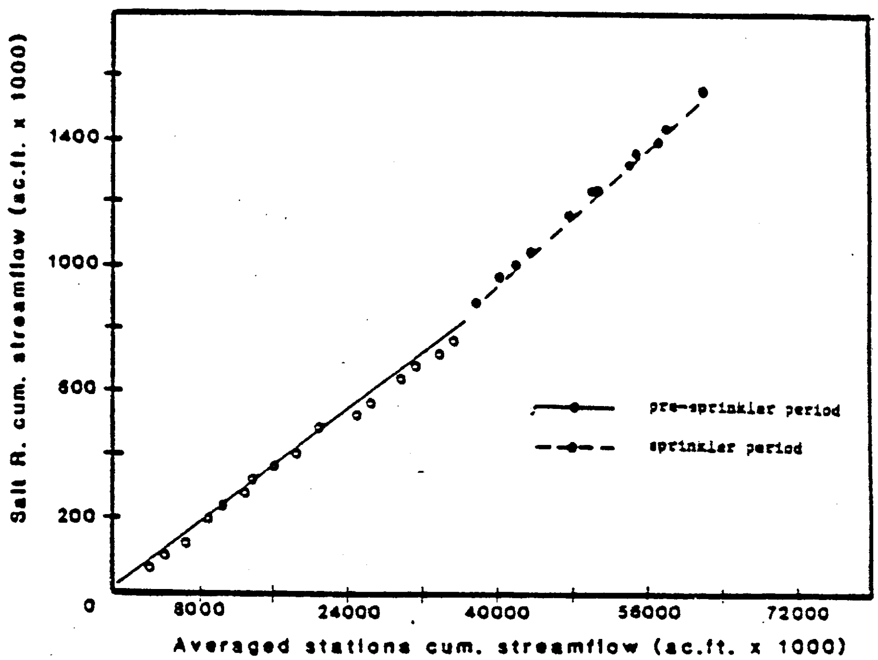

Figure 32. Double mass plot of Salt River flows versus averaged stations flows for July.

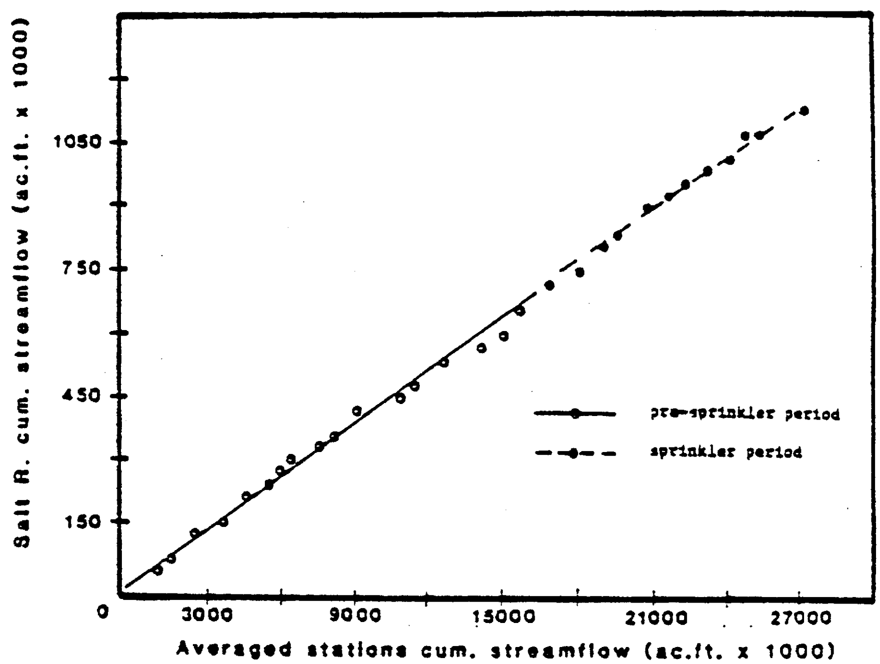

Figure 33. Double mass plot of Salt River flows versus averaged stations flows for August.

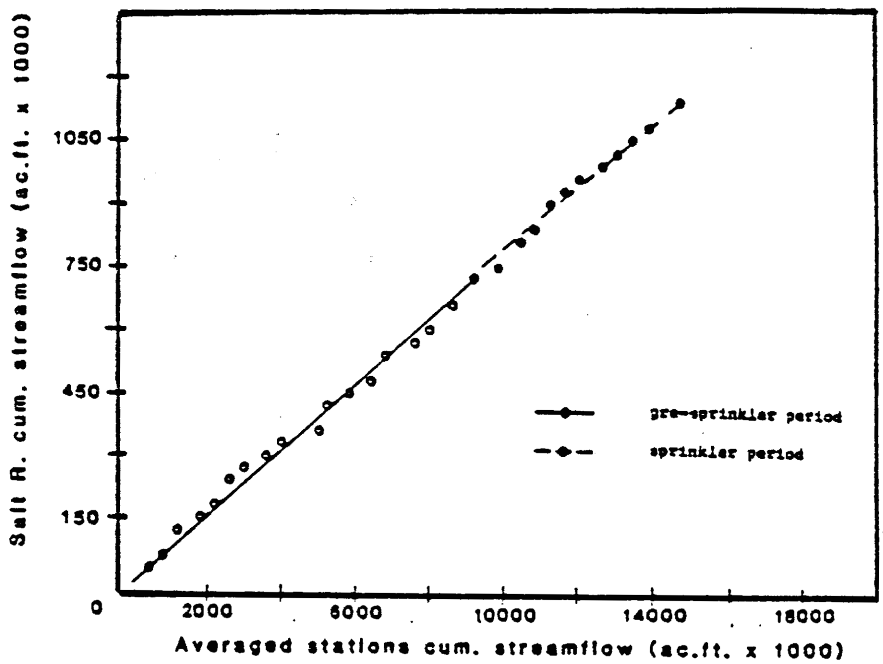

Figure 34. Double mass plot of Salt River flows versus averaged stations flows for September.