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Effect of Large-Scale Irrigation on Climate in the Columbia Basin

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For a century or more, irrigation has increased the agricultural productivity of arid lands in the western United States. Slowly at first, through small individual or locally sponsored irrigation projects, dryland farming has given way to irrigated agriculture. Early efforts were concentrated in interior valleys, where simple water distribution systems based on gravity were feasible. Midsummer low flow severely limited the expansion of these projects. With federally sponsored projects much more land became irrigable, an expansion made possible through ample reservoir storage, hydroelectric power for pumping, and efficient regional water distribution systems.

We can easily visualize the hot, parched climate becoming increasingly ameliorated as areas were brought under irrigation. Undoubtedly, some changes in the immediate environment occurred throughout this period, but there are few climatic records to illustrate these changes. Within eastern Washington State, 27 weather stations were in operation at the turn of the century. Unfortunately, only a few of these volunteer stations have been continued, and much information on the dryland climate before 1900 survives only in the historical, nonclimatic record.

Whether there is a major climatic effect due to changes in water use in an area—for example, increased local precipitation caused by evaporated moisture, or the inverse, reduction of precipitation by removal of transpiring crops—has been debated for some time. Holzman (*1*) addressed the latter question in discussing whether forest harvest on the East Coast affected precipitation. More recently, some popular misconceptions about the evaporative effect on widespread climatic change have been corrected (*2*).

Even within an irrigated area, documenting the cause and effect of climatic change is difficult because of the gradual nature of most climatic change; the influence of other factors, notably the cyclic variability of all climates; and the lack of a measurable response from a small area. Therefore, the Columbia Basin Project is particularly interesting. First, a sizable area, about 200,000 hectares, has been irrigated in the relatively short period of about 15 years; and second, some preirrigation climatic data are available for analysis.

In his analysis of this area, Stidd (*3*) indicated not only a local modification in climate, especially an increase in precipitation in July and August, but also an effect extending to several thousand square kilometers around the project. Stidd's conclusions are at variance with most other research, which has shown irrigation to have a minimum influence at distances much beyond the boundaries of even substantial irrigated blocks (40,000 to 50,000 ha) (*4*). His concept of the mechanism for increased precipitation is novel, however, relying on the latent instability created by increased moisture and not strictly an increment of moisture added to the atmosphere's present supply. As McDonald (*2*) noted, the mean precipitable water in the atmosphere in July above the deserts of the Southwest can be equivalent to 3.3 centimeters of available moisture. A mechanism for moisture release appears to be the critical factor, rather than lack of moisture.

The supplement to irrigation provided by natural precipitation during the growing season is a climatic element which often regulates the extension of irrigated agriculture. Areas with inadequate irrigation are found in most projects due to oversubscription of the late season supply or inadequate late season storage. Even small increases in natural precipitation would have tremendous significance at this time. A small supplement to the water economy of the surrounding areas where dryland cropping is practiced in alternate years would also be important.

Other climatic parameters characterizing the irrigated area and its surroundings in the Columbia Basin are examined for trends concomitant with the extension of irrigation. Summer air temperature and open pan evaporation are examined at stations inside and outside the irrigated area.

Certain species of plants are sensitive indicators of levels of atmospheric controls (*5, 6*). The big sagebrush indigenous to this climatic zone is known to respond significantly to seasonal rainfall by radial growth. As a supplement to the meager climatic data, a ring width chronology is examined for this species.

Study Area

The Columbia Basin Project is centrally located within Washington State about midway between the major population centers of Seattle and Spokane. Figure 1 shows the general location of the study area and the data sites.

Historically, the Columbia Basin Project began with construction of Grand Coulee Dam in the early 1930's. Water became available to the irrigated area about 15 years later. Active irri-

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gation throughout the project area began in the early fifties (Table 1). The water supplied to the project in 1966 amounted to 2.737×10^9 cubic meters (*7*). Crops dependent on this supply vary from cereals and vegetables to soft and stone fruits.

The project area is located on a southerly sloping plateau of moderate relief. The irrigated land lies mostly on the western edge of this plateau; expansion is planned to nearly 500,000 ha into the more dissected lands to the east and northeast.

General climate. The central Washington area is characterized by cool, moist winters and hot, droughty summers. Minimum precipitation and maximum tempertures occur during July in most years. Wind flow is generally westerly, and a pronounced rain shadow effect is observed in the lee of the Cascade Range to the west. Precipitation increases rapidly to the west of the Yakima Valley and increases more slowly to the east. The eastern edge of the state receives about twice the annual precipitation of the stations in the irrigated belt (15 to 25 cm).

Table 1. Development of irrigation in the Columbia Basin Project. [Data are from the U.S. Bureau of Land Management]

Year	Area irrigated (ha)
1950	2,876
1955	60,391
1960	117,189
1965	166,182
1970	180,732

The climate of any area is the composite of a number of complex, mostly nonpredictable, fluctuations of the atmospheric elements. Figure 2 illustrates the course of mean annual temperature and precipitation for two of the reference stations, Ellensburg and Sunnyside. These two stations have the longest consecutive records of any in the area and were selected to show the early trends. The plot of 5-year running means smooths the year-to-year variation but exhibits the major trends throughout the 70-year history. On an annual basis, the early two decades to 1920 were generally cool and moist. The twenties became progressively drier, with temperatures rising in the mid-twenties and dropping again around 1930, coincident with a time of minimum precipitation. Temperatures rose again in the early thirties and decreased gradually to a low in the early fifties to rise again in the sixties. Precipitation at these two stations since the drought of the thirties approximates pre-1930 levels with minor peaks and valleys. The running means of precipitation at other stations within the area show similar trends, but temperatures at these stations were cooler, by comparison, in the thirties.

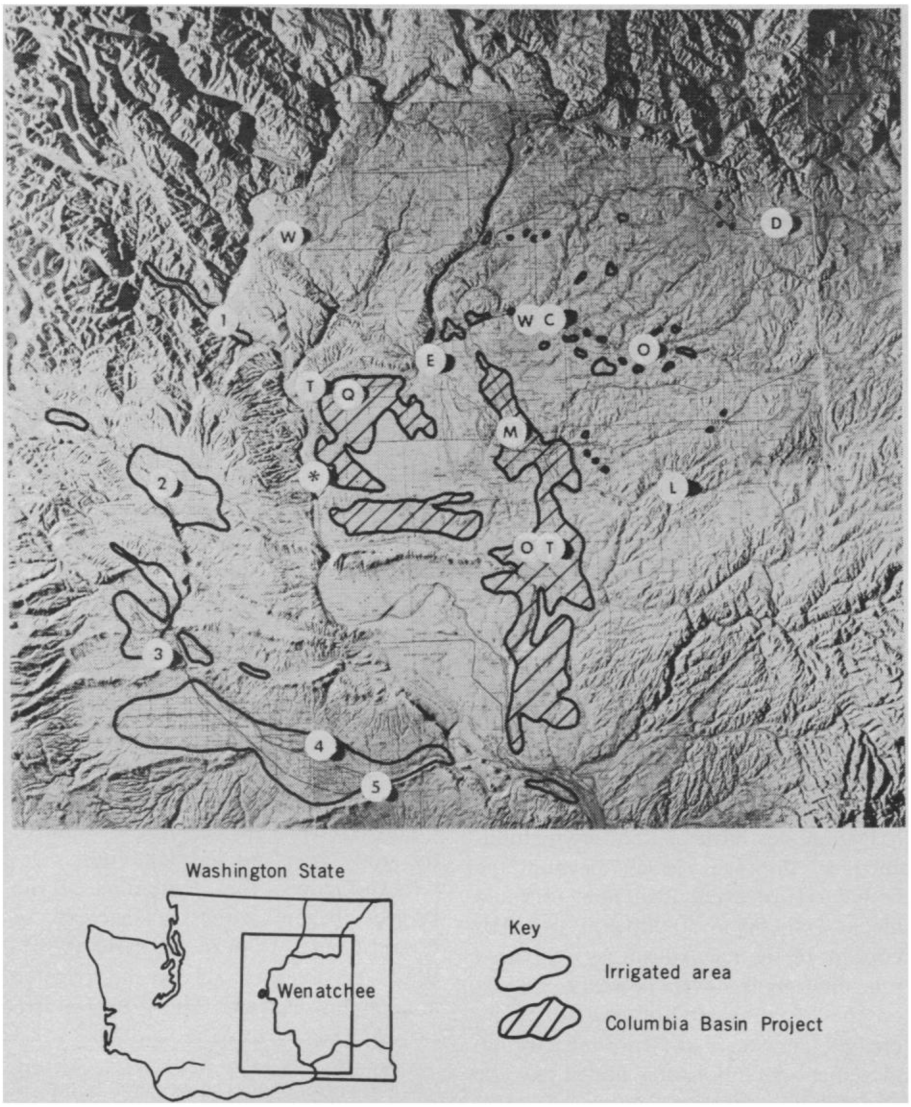


Fig. 1. Central Washington State, showing the locations of the irrigated areas and measurement sites. Symbols are explained in the text.

Stations. Climatic stations in the study area are numbered or lettered in Fig. 1. The numbered stations are outside the basin area proper, in valleys where irrigation has been practiced for many years. They are: 1, Wenatchee; 2, Ellensburg; 3, Yakima; 4, Sunnyside; and 5, Prosser. The letters designate both stations in the irrigated basin area and several other irrigated and dryland sites. The irrigated stations are: Q, Quincy; E, Ephrata; M, Moses Lake; O, Odessa; OT, Othello; and WC, Wilson Creek (*8*). The nonirrigated stations are: L, Lind; W, Waterville; T, Trinidad; and D, Davenport. The asterisk in Fig. 1 indicates the control sagebrush collection site.

Selection of reference stations for comparison was a problem since the stations with long climatic records were also located in irrigated valleys. Several stations had been established by railroad companies and maintained by their employees for years. In the Yakima River Valley, where four or five reference sites are located, irrigation was initiated about 1840. By early 1900 the valley was the most extensively irrigated area in Washington, with 50,000 ha irrigated. The greatest expansion occurred after the Yakima project was completed in 1907, and the area irrigated totaled 204,000 ha in 1966 (*7*). Figure 1 shows that irrigation was concentrated in the Yakima Valley (the control area), which is separated from the Columbia Basin Project (the test area) by a nonirrigable highland.

Results and Discussion

Summer temperature. The temperature in July, normally the warmest summer month at these stations, is expected to be most influenced by enlargement of the irrigated area. The July mean maximum and minimum temperatures, along with the monthly mean temperatures, were examined for all possible stations in the area. Table 2 shows the means for two periods, 1924 to 1950 and 1951 to 1971 (considered to be before and after Columbia Basin irrigation), and the significance of changes in the mean values.

With the exception of Yakima, the mean monthly July temperatures at these stations show no significant change between the two periods. The probability of chance occurrence of the temperature change at Yakima is less than 1 in 100, however, and deserves some note. The most likely influence here was the change in the location of the station in 1948 from within the city to the local airport. Figure 3C shows the change in the mean value.

The temperature depression at Yakima is also reflected in the July maximum and minimum temperatures (Fig. 3, A and B). At the other control stations, both Sunnyside and Wenatchee show a rise in the minimum temperatures, while the maximum temperatures appear lower but not significantly different between the two periods. Urbanization (the inverse of the case at Yakima) and small changes in station location at Wenatchee (1953) and Sunnyside (1947) may be responsible. Stations in the irrigated area show no comparable temperature changes; therefore it is doubtful that the temperature changes at Yakima have been due to irrigation.

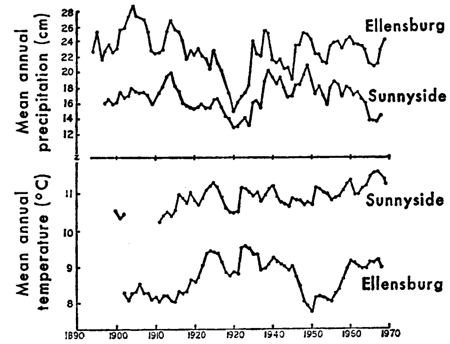
Ephrata shows a significant decrease in minimum temperature in the 1951–1971 period; however here, as at Waterville and Lind in the dryland area, several major and minor locational changes were made during the period of record. The stations at Ephrata and Waterville were moved out of town, and the Ephrata station was closed in 1970.

Minimum and maximum temperatures responded to locational changes, as seen in these examples. Where some constancy of location was maintained, the slight changes in temperature are nonsignificant. Consequently, there is little or no change in July temperatures attributable to the development of Columbia Basin irrigation.

July-August precipitation. Stidd (*3*) suggested that precipitation in this area in July and August is sensitive to increased moisture from local evapotranspiration. Using a *t*-test, he determined that the difference in mean precipitation between a selected period, 1959 to 1966, and a base period, 1931 to 1950, was significant.

We have reexamined the topic by an alternate procedure, using all available data. Double-mass plotting is an analytical method commonly used in several fields. Its applications include testing the efficiency of rain gage catch as influenced by changes in site or exposure, and testing for seepage leaks at stream gaging stations. The method compares the cumulative values of a parameter measured at two locations (such as rain gage catch) by plotting the accumulated catch at one station against the accumulated catch at the second during the period of record. If the rainfall at the two stations bears a constant relationship, the slope of the plotted line will remain constant. A variation in slope indicates some change in catch efficiency, the significance of the change in slope can be tested (*9*). Although the number of points in the curve influences the test sensitivity, the period of record is not important.

We compare July-August precipitation data from two periods, 1924 to 1951 and 1952 to 1971. Stidd terminated his base period at 1950 since irrigation development was minimal before 1951. The year 1924 is the earliest date for complete records for all five control stations. Baseline data on the July-August precipitation averaged over the five control stations are the independent variable in these plots. All these base stations have a long history



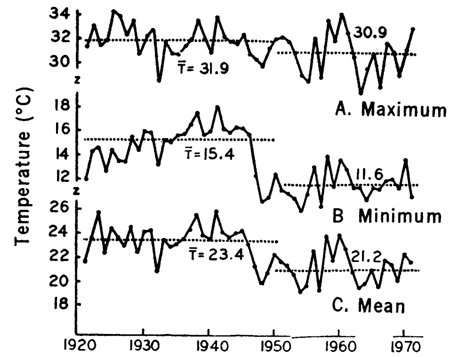
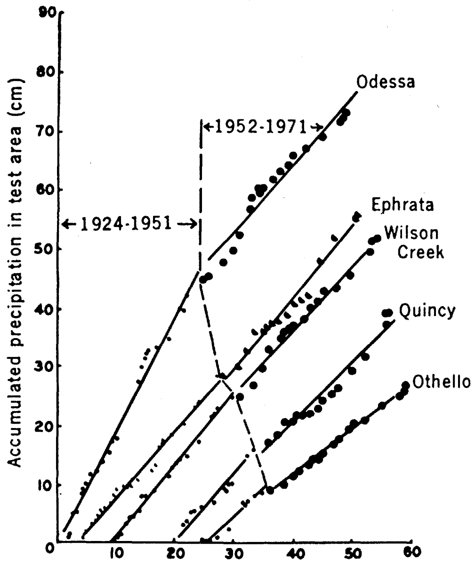


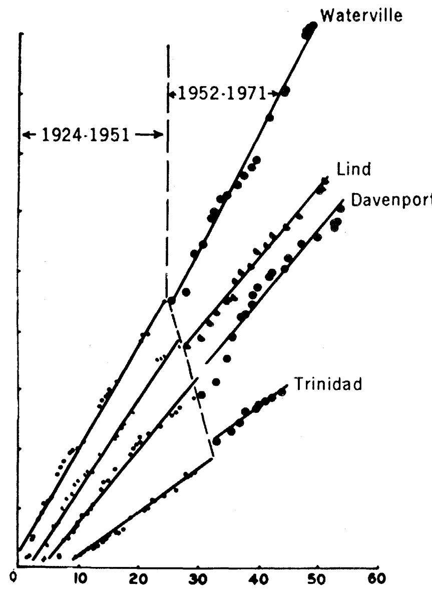
Fig. 2 (left). Running 5-year means of annual temperature and precipitation for two locations in central Washington State. Fig. 3 (right). July temperatures at the control station at Yakima for the period 1921 to 1971. The change in the mean temperature ($\overline{T}$) between the periods 1921 to 1950 and 1951 to 1971 is significant at (A) $P = .05$, (B) $P = .001$, and (C) $P = .01$.

Table 2. Significance of changes in July mean temperatures for the periods 1924 to 1950 (before irrigation) and 1951 to 1971 (after irrigation). The probability (*P*) values give the significance of the change, determined by Student's *t*-test. Abbreviations: N.S., not significant at $P = .05$; N.T., not tested.

Station	Mean maximum temperature (°C)		P	Mean minimum temperature (°C)		P	Mean temperature (°C)		P
	1924–1950	1951–1971		1924–1950	1951 1971		1924–1950	1951–1971	
				Control stations					
Ellensburg	29.5	29.1	N.S.	12.1	11.8	N.S.	20.7	20.5	N.S.
Sunnyside*	32.8	32.2	N.S.	11.6	12.7	.001	22.3	22.2	N.S.
Wenatchee	31.3	30.7	N.S.	14.7	15.4	.05	23.1	23.1	N.S.
Yakima	31.9	30.9	.05	15.4	11.6	.001	23.4	21.2	.01
				Irrigated stations					
Ephrata	32.7	32.2	N.S.	17.1	16.0	.05	24.7	24.1	N.S.
Odessa	31.8	32.6	N.S.	11.2	11.6	N.S.	21.5	22.1	N.S.
Quincy							23.4	22.0	N.T.‡
				Dryland stations					
Waterville	27.2	28.6	.05	11.9	10.6	.01	19.6	19.5	N.S.
Davenport							19.7	19.7	N.S.
Lind	32.1	32.5	N.S.	12.4	11.5	.05	22.2	22.0	N.S.
Trinidad	33.6	34.7	N.T.†	16.3	16.3	N.T.†	24.5	25.5	N.T.§

* Seven years are missing in the maximum and minimum records. † Seventeen years are missing in the pre-1950 record. ‡ Thirteen years are missing in the pre-1950 record. § Record complete but ends in 1961.





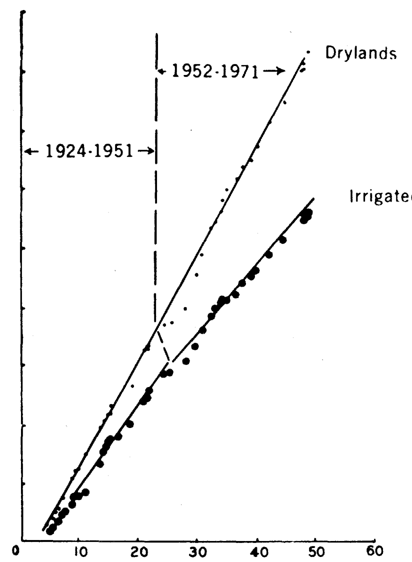


Fig. 4 (left). Double-mass plot of July-August precipitation for irrigated locations in Fig. 1. Fig. 5 (center). Double-mass plot of July-August precipitation for nonirrigated locations in Fig. 1. Davenport is plotted at one-half scale. Fig. 6 (right). Double-mass plot of July-August precipitation for grouped sites.

of irrigation and lie to the west, generally upwind from the basin area.

Double-mass plots are shown in Figs. 4, 5, and 6. Data points and regression lines for the two periods are included. To separate the curves at the origin, we have displaced them 2.54 units on the x-axis in addition to the offset due to variable record length. Some station records begin later, in the thirties and forties.

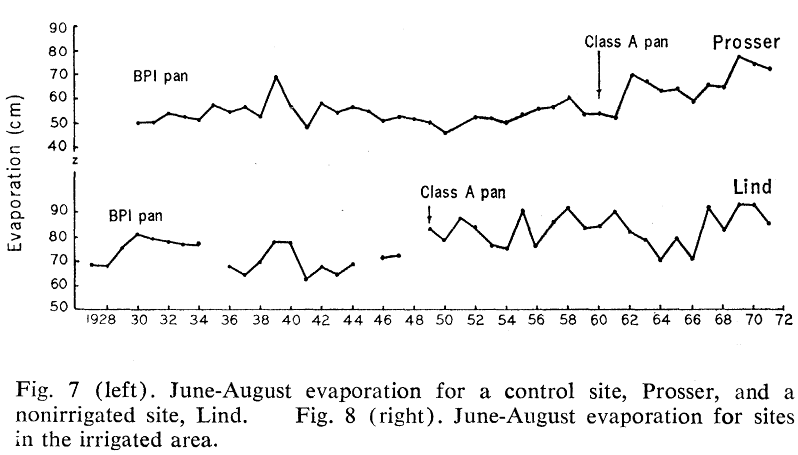
If July-August rainfall at any station increases compared to the baseline, the curve will rise; conversely, it will fall if rainfall decreases with time. The normal variability of convective summer rainfall causes the scatter about the curves.

Table 3 summarizes the analysis. With the exception of Ephrata, the slope of the curve decreases in the period after irrigation at all irrigated locations (Fig. 4). Ephrata shows a nonsignificant increase in slope in the postirrigation period. Among nonirrigated dryland stations (Fig. 5), Davenport and Waterville show nonsignificant increases in slope, while Lind shows a significant decrease in slope.

The averages for stations in both nonirrigated and irrigated areas are shown in Fig. 6. The increasing slope in the nonirrigated areas is not significant; irrigated areas show a decrease in slope significant at $P = .01$.

The test periods were shortened at both Waterville (to 1965) and Ephrata (to 1968) to eliminate some rainfall data taken after the station was last moved. Both stations now appear to have an increased rainfall catch. Inclusion of the later data makes the positive slopes for Ephrata and Waterville significant at $P = .05$ and $P = .01$. The precipitation response at these two stations, if due to basin irrigation, is an anomaly and has been slow to appear.

A question not answered by this analysis is whether all stations had increased July-August rainfall in 1952 to 1971 compared with the nonirrigated period, 1924 to 1951. For all stations used for the baseline, t-tests of the means for these periods were made. The results showed nonsignificant changes (even at $P = .1$) in the means for individual stations for these periods. The average July-August precipitation in 1952 to 1971 for all the base stations, however, increased by amounts ranging from 0.13 cm at Sunnyside to 0.63 cm at Wenatchee. The change in the average baseline values including all stations collectively was also nonsignificant.



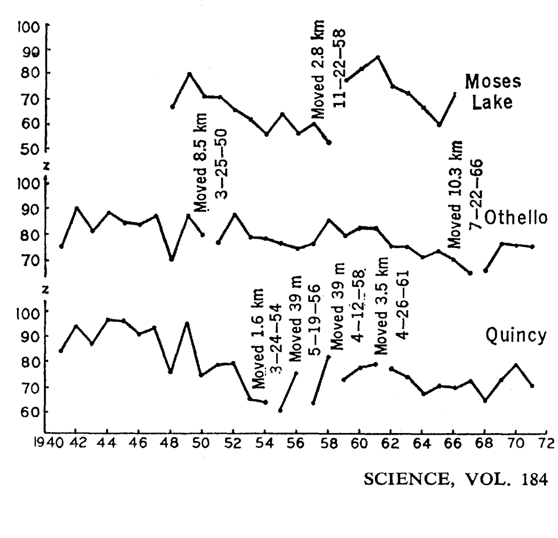


Fig. 7 (left). June-August evaporation for a control site, Prosser, and a nonirrigated site, Lind. Fig. 8 (right). June-August evaporation for sites in the irrigated area.

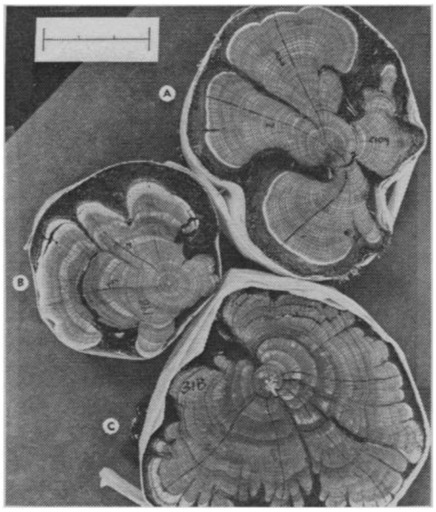


Fig. 9. Sections of sagebrush: (A) section C104 from a control site, (B) section 19B from an irrigated site, and (C) section 31B from an irrigated site. Scale bar, 3 cm.

The year 1951 was notably wetter at Wenatchee and Ellensburg, with July-August rainfalls of 5.99 and 3.17 cm, respectively. The selection of a time period may cause relations of these types (comparison of means between periods) to become statistically significant, or not, depending on the inclusion or exclusion of 1 year in the test periods. Therefore, we retested the significance of the means of July-August rainfall for the base stations with 1951 in the latter, wetter period; the periods became 1924 to 1950 and 1951 to 1971.

At Sunnyside, Yakima, and Prosser no significant change was observed; and again, this was the case in using the averages for all five stations. For Wenatchee and Ellensburg, the shift in periods caused the means to differ significantly at $P = .05$.

Wenatchee		
1951–1971	1.83 cm	$t = 2.58$*
1924–1950	0.79	
Ellensburg		
1951–1971	1.39 cm	$t = 2.12$*
1924–1950	0.74	

* Significant at $P = .05$.

A comparison between the record for 1924 to 1950 and the earlier segment of the available record at these stations shows

Wenatchee		
1924–1950	0.79 cm	$t = 2.66$*
1912–1923	1.85	
Ellensburg		
1924–1950	0.74 cm	$t = 2.94$**
1901–1923	1.70	

* Significant at $P = .05$. ** Significant at $P = .01$.

Therefore, the claim of a significant increase in July-August precipitation because of basin irrigation does not appear sound.

Evaporation. Open pan evaporation integrates the effects of a number of atmospheric elements, including radiative exchange, temperature of water and air, vapor pressure deficits, and wind movements. The size, condition, and overall exposure of the plan also affect the results. No exhaustive examination of this type of measurement is attempted here because of the paucity of data.

The June-August evaporation for Prosser (control) and Lind (dryland) is shown in Fig. 7. At Prosser, for the period 1930 to 1959 when the BPI (Bureau of Plant Industry) evaporation pan was used, the slope of the curve does not differ significantly from zero. After 1960, when the U.S. Weather Bureau class A pan was used, the slope is positive and significant at $P = .01$. The evaporation rate at Lind from 1949 to 1971 does not show a significant change in slope.

During this period, when pan evaporation was fairly constant or increased at sites outside the irrigated basin area, evaporation at basin locations generally decreased with time (Fig. 8). At Moses Lake, a decrease in evaporation rate for the two segments of record is noted. At Othello, the segment of record from 1951 to the present shows a negative slope significant at $P = .01$. At Quincy, the slope is constant after the last move in 1961; however, the mean value of June-August evaporation for 1941 to 1950, before irrigation, is significantly higher ($P = .01$) than the mean value for 1962 to 1971.

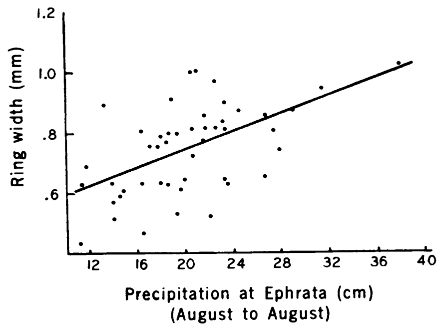


Fig. 10. Regression line for sagebrush ring width at the control site plotted against annual precipitation at Ephrata. The regression equation is $y = 0.454 + 0.0145x$. The correlation coefficient $r = .55$ ($P = .01$); 47 points are used.

Locational changes of the pan itself and changes in pan types (BPI to class A) interrupt the continuity of these records. Trends, however, are consistent and in the expected direction for the irrigated area.

Most stations within the basin area do not report measurements of atmospheric moisture. Only incomplete records of weather observations at the Ephrata airport were available for analysis and are not discussed. An examination of the complete record from Ephrata and Grant County Municipal Airport (formerly Larsen Air Force Base) would be rewarding.

Sagebrush ring indications. Plant growth is often the most sensitive indicator of the total climate of an area; like open pan evaporation, it is the synthesis of a number of both isolated and related factors. The radial growth of plant stems is often used to establish chronologies for historical events. Radial

Table 3. Regression coefficient relating average summer precipitation at five control stations to summer precipitation at irrigated and dryland stations in the Columbia Basin. The period before irrigation is 1924 to 1950; the period after irrigation is 1951 to 1971, except at Ephrata (1968) and Waterville (1965). The F value is a statistical parameter; N.S., not significant at $P = .05$.

Station	Slope of regression line			F value
	Before irrigation	After irrigation	Change	
Irrigated				
Quincy	1.0219	0.8837	−	1.41 (N.S.)
Othello	0.9779	0.7820	−	11.28*
Wilson Creek	1.2429	1.0980	−	10.57*
Odessa	1.9880	1.1463	−	118.86*
Ephrata	1.1610	1.2352	+	2.65 (N.S.)
Dryland				
Trinidad	0.7875	0.7862	−	0.01 (N.S.)
Davenport	2.4725	2.4953	+	0.02 (N.S.)
Lind	1.5909	1.2360	−	44.86*
Waterville	1.8114	1.8587	+	0.31 (N.S.)
Averages				
All stations	1.6472	1.5279	−	7.94*
Irrigated area	1.4522	1.1661	−	63.06*
Nonirrigated area	1.8513	1.9249	+	1.32 (N.S.)

* Significant at $P = .01$.

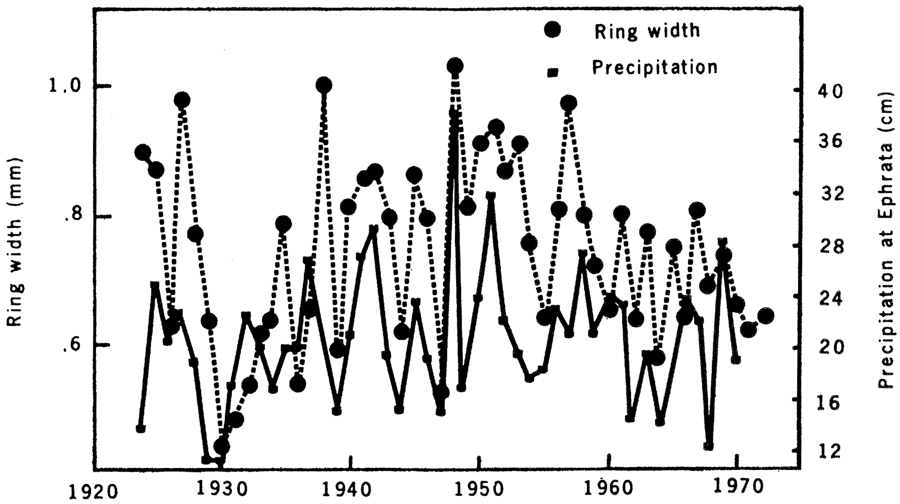


Fig. 11. Ring width chronology (dotted line) and yearly (August to August) precipitation (solid line) at Ephrata.

growth is also a sensitive indication of the moisture levels occurring throughout the plant's development, especially if the levels are at or near the limits of the plant's ability to exist (*6*). The big sagebrush (*Artemisia tridentata*) is a moisture-sensitive plant.

For plants in our area, examples of the growth response and sensitivity can be seen in Fig. 9. The section marked 31B (Fig. 9C) is from a plant growing under optimum moisture conditions because of the elevation of groundwater by irrigation nearby (25 to 50 m away). The plant 19B (Fig. 9B) is older than 31B and had an improved environment for a shorter period of its life. Plant C104 (Fig. 9A) is from the control plot several kilometers from the project boundary. The average ring width of this plant was 0.65 mm compared with 2.2 mm for 31B. Control section C104 was 55 years old and section 31B was 18 years old.

From three plants in the control location, 11 radii were measured. Their yearly average gives the ring width chronology for the control piot. (Control plants were 55, 59, and 72 years old; only the record to 1924 is used.)

The relation between radial growth and yearly precipitation, based on the record from August to August for Ephrata, is shown in Fig. 10. The goodness of fit of this simple relation probably would be better if precipitation data were available at a location nearer the sagebrush control site, or if additional climatic elements were available for inclusion in the regression. Figure 11, comparing the ring width chronology and the annual rainfall at Ephrata, shows several noticeable mismatches. Peaks of growth at 1924, 1927, 1938, and 1957, for example, appear at times of low annual precipitation. A search of the records revealed that in these years the spring (February to March) temperatures or amounts of precipitation, or both, were above normal for these months. The datum from 1948, a generally wet year, fits the regression line shown in Fig. 10. The evergreen nature of the precocious sagebrush allows it to capitalize on isolated weather events to which many deciduous plants could not respond. Of particular importance in Fig. 11 is the general synchronization of the sagebrush ring width with yearly precipitation after 1950.

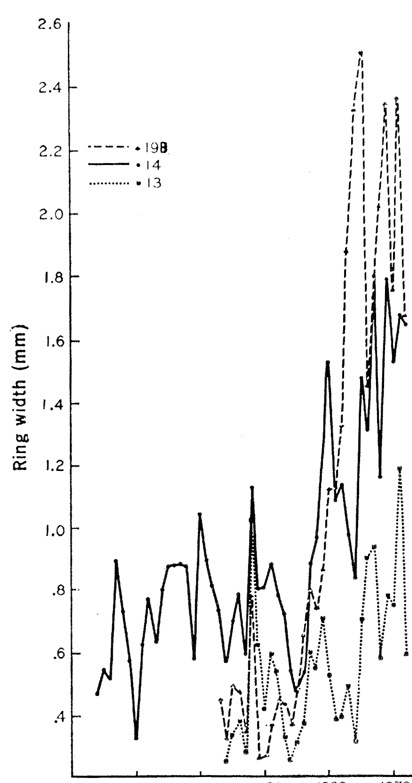


Fig. 12. Ring width chronology for three plants (19B, 14, and 13) in the irrigated area. Irrigation started in the middle to late 1950's.

Attempts to form a simple relation between radial growth and precipitation in other periods were not sucessful. Although early season rainfall is clearly important to the radial growth of these plants, a regression based on precipitation from February to June showed that it was highly significant (correlation coefficient $r = .39$) but not as indicative of the growth process as the yearly precipitation.

Figure 12 portrays the radial growth of three plants in the irrigated area. Plant 19B has a growth record from considerably before the start of irrigation and exhibits the same basic chronology as the control plants (peaks of growth at 1927 and 1938, higher in the early 1940's, the major peak in 1948, and the depression of growth during the drought years around 1930). At some time near the late 1950's, this plant departs from the trend established by the control plants (Figs. 10 and 11). Similarly, plants 13 and 14 show increased radial growth after the late 1950's, an effect undoubtedly related to local irrigation. The opportunistic nature of these plants, even in the juvenile stage, is shown in the 1948 data: plants only several years old developed greatly enlarged ring widths that year.

Summary and Conclusions

Examination of the available records for July air temperature and July-August rainfall shows a minimum response during the postirrigation years, which could be attributed to the development of irrigation in the Columbia Basin Project. Open pan evaporation appears to give the most sensitive measurement of the small integrated effect of irrigation on the environment of the area. Admittedly, we looked for changes in the climate where they might easily be found and at a time when they would be logically expected to be a consequence of irrigation. The effects during the other season, when water is not actually supplied to the land, was beyond the scope of this article. Rosenan (*10*) found that fall precipitation was greater at Tel Aviv, Israel, during the period after irrigation of that area. He suggested that increased turbulence due to higher vegetation assisted in the development of convective precipitation.

The big sagebrush is a particularly valuable plant for detecting change in the environment, especially an improved water economy. Precipitation increases at almost any time of the year influence the radial growth of this long-lived sensitive plant. The ring width of sagebrush from the control site has remained stable throughout the development of the irrigated area, emphasizing the improbability of large increases in precipitation due to nearby irrigation.

In several cases—for the minimum temperature at Waterville and Sunnyside, particularly, and for the rainfall records of Waterville and Ephrata—judgments based on the quality of a record or its constancy were made. Changes in the location and exposure of these sites defeat a rigorous analysis of climatic modification in their areas. Even with an increased number of stations now providing weather records, the variety of elements measured is poor. A number of volunteer weather stations initiated during the early, wetter part of the century, when dryland agriculture flourished, were lost during the widespread abandonment of farms in the dry years. Reestablishment of several of these measuring stations, for even several years, would assist in future investigations.

The question of climatic change due to man's activities is currently quite popular. Both planned and inadvertent modifications of the environment, for better or worse, have occurred and will continue to do so. We consider our generally negative results particularly of interest relative to the application of water to an area on a smaller but more intensive scale; for example, in disposition of sewage effluent on forest or dryland watersheds, power plant cooling, or warm water irrigation at the sites of future nuclear plants. Site changes understandably will occur, but the widespread climatic effects may well be minimal.

The sensitive nature of an ecosystem, including the behavior and distribution of plants and animals, offers a unique opportunity to document climatic changes that continue to occur (*11*). Along with improved weather records, an increasing emphasis on identification and protection of relic areas, further identification of sensitive plants through ring width chronology, and correlation of these plant responses to past and present climate would be valuable tools in research on arid lands.

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Polymorphism of the Somatic Antigen of Yeast

Yeast mannans exhibit species specific structures that are analogous to animal and bacterial antigens.

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A characteristic feature of bacterial and animal cell surfaces is the presence of a variety of specific somatic antigens, many of which involve the carbohydrate components of glycoproteins, glycolipids, lipopolysaccharides, and polysaccharide-protein complexes. Particularly well characterized are the lipopolysaccharide O antigens of enteric bacteria (*1*) and the blood group substances of animal cells (*2*). Although most readily detected by immunochemical methods, these carbohydrate-containing macromolecules may function as virus receptors and as sites for specific cell-cell interaction. They are species specific and may undergo transformation (*3*). It has been speculated that the numerous bacterial viruses, which infect enteric bacteria and bring about the transformation of their O antigens, provide the bacterium with a multitude of disguises that may assist it in surviving attack by the immune system of the animal host (*4*). Over 60 different antigens have been detected on the erythrocyte surface. It is generally thought, although there is little experimental support for the notion, that the many antigens of animal cell surfaces are involved in processes requiring contact informational exchange, such processes being presumed to occur in development, specific cellular adhesion, "homing," and self-recognition.

Specific surface antigens have not been shown to play an important role in yeast physiology except, possibly, in the sexual agglutination reaction (*5*). Nevertheless, yeasts do possess a similar system of such antigens and, as with animal and bacterial cells, the evidence for species specificity in the surface

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