# DRAFT REPORT

# Augmented Flows in Silver Creek

**submitted to**

***The Nature Conservancy of Idaho***

**by**
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# *PREFACE*

This report centers upon assessing just how much stream flow in Silver Creek is augmented by irrigation diversion. Originally, I was asked to investigate this issue and try to make some evaluation of two propositions put forth in Phases I and II of ***Hydrologic Analyses of the Big Wood River and Silver Creek Watersheds***. Essentially these two assertions stated: (1) if irrigation diversions were to cease then Silver Creek flows would probably drop by about 67 percent; and (2) the long term trend for irrigation diversions was downward and this was probably due to the introduction of sprinklers and other more efficient agricultural practices. What follows in this draft is the culmination of work over the past year and a half trying to assess the validity of those propositions.

Since the original contract did not call for a written report such as this one, my findings were more often than not discussed orally with people willing to listen. Sensing the need to amalgamate my ideas into a more organized fashion, however, I elected to produce a report in the effort to summarize the work and observations made over the past 16 months. Be forewarned, this draft has not been footnoted, proof read, or reviewed by either peers or my wife. As a result the following pages may at times appear turgid, repetitious or downright stupid. It does take a whack at trying to explain some rather complex issues and represents a lot of work. I hope it will provide a basis for thinking, debate, and discussion about the future of Silver Creek.

***THE CONCEPT OF AUGMENTED WATER***

The search for understanding the structure of Silver Creek's hydrology has been both difficult and elusive. Some answers to this question were provided by studies as ***The Hydrological Evaluation of the Big Wood River and Silver Creek Watersheds*** and others. By general accord, however, major questions still exist. Near the top of the heap is the issue centering upon quantifying just how much of the creek's flow is from "natural" sources (underflow, precipitation, and river seepage) versus human activity (irrigation diversions). But before proceeding to address this question, perhaps it is best to try and define what we mean by the very term "augmented water."

Certainly, the notion of augmented means something added, something that would otherwise not be there. With this in mind we can see water flowing through Silver Creek comes from four distinct yet related sources. In no special order these sources are: (1) precipitation; (2) underflow moving as ground water from the upper valley; (3) seepage from the Big Wood River; and (4) water diverted from the Big Wood River and laid on as irrigation in Silver Creek's recharge zone.

The term, augmented water, becomes meaningful when considered within the context of Silver Creek's headwaters. Generally speaking, the notion of augmented water is usually characterized as the "un-natural" portion of the creek's flow or what is added by the human wellspring of irrigation diversions. Conversely, precipitation, river seepage, and underflow is said to comport the creek's natural headwaters. Thus water added by human action supplements or ***augments*** the otherwise natural springs which contibute are the base of the Silver Creek system. In the argot of the scientist, the stream flow (Q) of Silver Creek is the dependent (Y) variable while its independent (x) variables are river seepage, underflow, irrigation, and precipitation. The task is then to isolate and identify how much of the variability in the creek's flow is explained by the four independent variables.

In actuality, our purpose here is more specific. What we want to understand is the connection between irrigation diversions on one hand and flows in Silver Creek on the other hand. Said differently, how much of the variability in Silver Creek's flow regime is explained by variability in irrigation diversions. Of course in order to focus on this relationship cannot be done without also looking at the bridges formed with the other factors. Basically two paths exist to solving this problem: one is empirical the other analytical.

Method 1 – Empirical Field Analysis

An empirical approach to the problem of augmented water would use accepted field techniques to take careful measurements of physical properties over a substantial period of time. Adopting this approach would involve, for example, seismic studies to probe the geological boundaries of the aquifer; soil sampling so laboratories could determine porosities and hydraulic conductances; and the installation of piezometers to measure hydrogeologic factors. Of course the obvious drawback of the empirical approach is its enormous cost; a project which could easily exceed several hundred thousand dollars over several years. The benefit inheres in the acquisition of accurate, defined data capable of shedding light on the problem.

Method 2 – Aggregate Data Analysis

An alternate approach to the augmented water problem rests upon what is known as aggregate data analysis. Following this path means the collection of existing databases, public records, and prior studies. Once the data are aggregated and integrated the analyst then applies carefully chosen multivariate statistical analyses in the attempt to convert data into information. The clear advantage of aggregate data analysis is economic, it is far cheaper than its empirical cousin. As one could guess, however, the obstacles strewn in its path are substantial and pose significant barriers.

## *AGGREGATE DATA ANALYSIS: **Proportionality & Limitations***

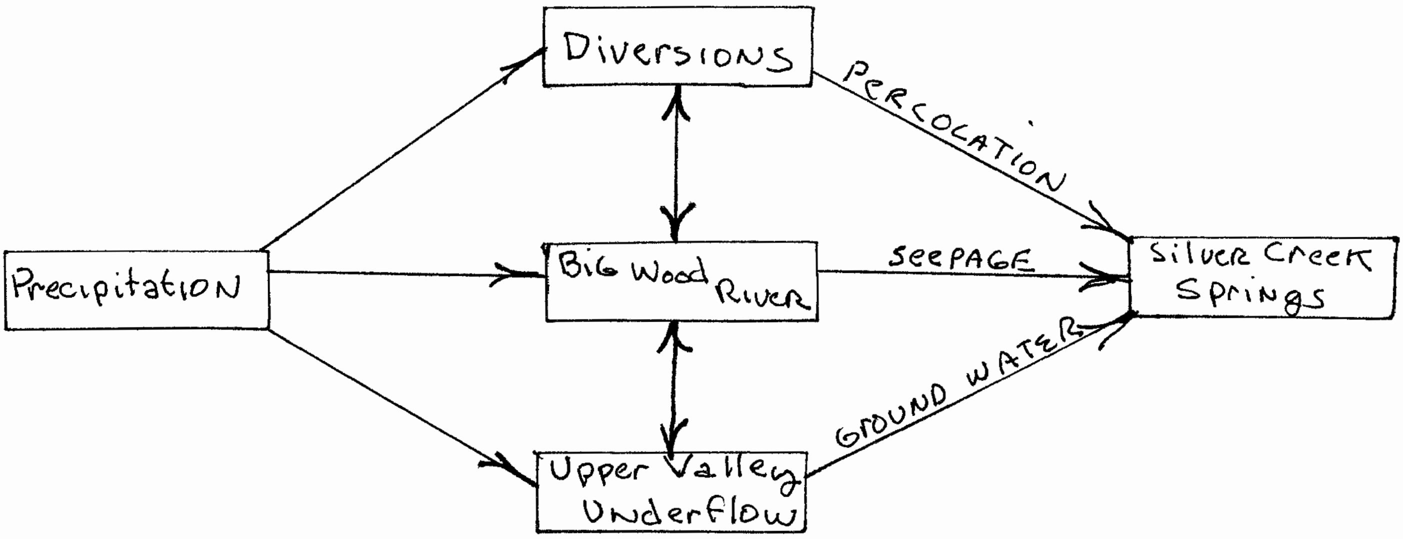
Before launching into the results of the statistical testing a word is necessary about the notion of proportionality and how it applies to augmented water as well as discussing the topic of data limitations.

### The Concept of Proportionality

Making sense of the hydrologic "plumbing" of Silver Creek is not complicated. The overall conceptual model can be explained easily in terms of four basic terms: precipitation, irrigation diversions, river seepage, and ground water underflow. Undoubtedly, the engine driving the system is precipitation. If nature elected to withhold her charms of rain and snow there would be no rivers or streams, no groundwater, and no Silver Creek. Over the 880 square mile watershed falls an average of about 1 million acre feet a year as precipitation. A considerable amount of this precipitation---some 80 percent----is returned to the atmosphere through the processes of evaporation and the transpiration of plants and animals, the remainder finds its way into the surface and ground waters of the Wood River Valley. Hydrologists know that Silver Creek is an entirely spring fed water body and the source of these springs comes from precipitation falling on its recharge zone, ground water coming down the valley from percolating waters, seepage from the Big Wood River, and irrigation canals diverting water out of the Big Wood River below Bellevue (see Figure 1).

Being able to identify the sources of Silver Creek's headwaters, though, does not clarify the complexity involved in quantifying augmented water. To address carefully the notion of augmented water calls for the introduction of the concept of "Proportionality."

**Figure 1. Conceptual Model of Four Sources (Variables) and Their Relationship to Silver Creek**




The notion of proportionality emphasizes not <u>all</u> the water falling as precipitation, flowing through the ground, seeping from the river or being diverted to irrigation will eventually wind up in Silver Creek. Instead, only a <u>portion</u> of these contributing factors will become part of Silver Creek.

What makes the study of augmented water so difficult from an aggregate statistical perspective is the complexity introduced in trying to define precisely the "portion" of each source. For example, consider seepage from the Big Wood River. The concept of proportionality informs us not all of the water seeping out of the river channel will wind up in Silver Creek. Some of the seepage water will encounter a shifting geohydrologic phenomenon known as the ground water divide and be returned to the Big

Wood River channel itself. From the seepage water that manages to cross the divide ground water pumps will extract some of its volume for irrigation part of which will be lost to evapotranspiration and part of which will deep percolate to the springs of Silver Creek.

The daunting task of specifying accurately the connection between Silver Creek and its sources is made infinitely more complex when one considers the concept of proportionality. If simply acquiring knowledge of how much precipitation, under flow, seepage or irrigation diversion was deposited was all that was required, the task of computing augmented water would be much simpler (see Appendix 1).

Limitations of the Data

Ideally it would be best to examine the connectivity of river seepage, underflow, precipitation, and irrigation diversions in constructing our model. Two of these variables, however, are ill-understood and estimates of their volume vary tremendously. Estimates of river seepage vary 250 percent. In 1984, Luttrell *.et .al* said seepage was 22,360 af/y while the 1999 Brockway *et. al.* estimated it to be 79,300 af/y. Turning to underflow the same problem exists. Smith (1959) thought it to be 34,000 af/y, Luttrell and Brockway (1984) 40,000 af/y, Frenzel (1989) 13,000 af/y, and Brockway *et. al.* (1999) 34,800 af/y. Similar incongruities exist for estimates of yield, groundwater pumpage, and evapotranspiration.

Faced with these wide variances it was decided to restrict the conceptual model to the primary factors of precipitation, diversions, and flows in the Big Wood River and Silver Creek. This meant I had to construct my own databanks. It was ultimately possible to assemble databanks for each variable and they will be described below. At the onset it should be stressed these assemblages are not without problems. Data are collected by a wide array of agencies and organizations using different methods, time periods and units of analysis. Some agencies collect data for "water years" (October 1 to September 30), some for "calendar years" (January 1 through December 31st), and others for "fiscal years." The units of analysis often lack comparability or continuity. Stream measures, for instance, are collected as acre feet, cubic feet per second, or in miner's inches.

Another daunting problem is that Periods of Record rarely coincide. In the case of precipitation, the U.S. Weather Service (USWS) began collecting statistics at Sun Valley (108906) in 1937, Ketchum Ranger Station (104845) and Hailey (103942) in 1948, and Picabo (107040) in 1958. A connected problem revolves around the tendency of agencies to move their recording stations. The USWS moved its recording stations at Hailey 3 times since 1948, Sun Valley 3 times since 1937, the USGS also moved its gauging stations for Hailey, Stanton Crossing and Silver Creek several times.

How the data are collected varies considerably. At one end information is collected by electronic recorders, subsequently reviewed by experts and calibrated for error. In the middle are deputized individuals who take periodic observations of non-electronic devices such as weirs or stream gauges. At the other end information can be recorded anecdotally by asking users to estimate how much water they "think" was used.

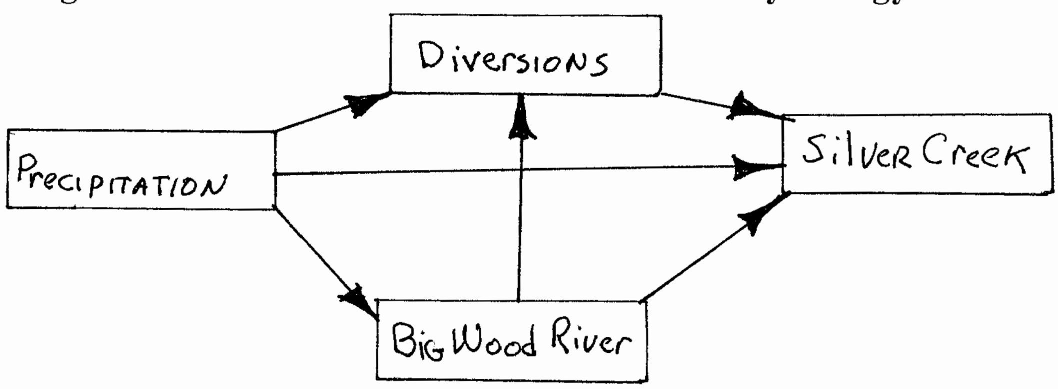
In a word, data are assembled by a wide array of federal, state, municipal, water districts and private organizations, each of which can utilize different methods of collection, equipment, and individuals. Information is frequently missing, gathered at different locations, collected in non-comparable time periods, and in alternate units of analysis.

Standing behind this backdrop of limitations looms the biggest problem of all. Moreover, we do not have a long-term, consistent way to measure the crucial dependent variable: flows in Silver Creek. The USGS began taking flow values on Silver in 1920 with a recorder near Picabo. For sixteen years USGS recorded only seasonal measurements associated with the growing season and even these measurements varied from 122 days, to 153 days then to 183 days. In 1936, the government began collecting stream flows in Silver Creek on an annual basis and did so until 1963 when it suddenly quit. Eleven years later, service was reinstituted (1975) at a new location several about five stream-miles to the west. The upshot is the dark cloud cast upon statistical results attempting to assay the effect of augmented water on Silver Creek.

## *STATISTICAL TESTS & COMPUTATIONS*

Being faced with these limitations does not foreclose other statistical approaches to probe augmented water. Basically I rewrote the conceptual model to try and shed light on the two propositions put forward by Phase I and Phase II. This reformulation of the basic model presented in Figure 1 posits a stochastic relationship between precipitation, flows in the Big Wood River, irrigation diversions, and Silver Creek ( Figure 2).

**Figure 2. Stochastic Model for Silver Creek Hydrology**



Multivariate Regression

Originally, it appeared the question of augmented water could be best un-packed by using the linear approximation known as step-wise multiple regression. The rationale for selecting regression is it: (1) predicts both the aggregate and singular effects of independent variables; (2) offers a test of significance at varying levels of confidence; (3) provides a measure of the strength of the relationship between variables; and (4) is capable of rendering an answer specifying what percent of Silver Creek's flow is associated with which source.

This equation is in the general form:

$$\hat{Y} = \alpha + b_1X_1 + b_2X_2 + b_3X_3 + Z$$

In this equation, the dependent variable ($\hat{Y}$) represents the varying annual flows in Silver Creek while the independent variables (b) are sources of Silver Creek water. Stated differently, variation in Silver Creek flows are postulated to be a function of the three independent variables of precipitation, ($b_1$), Big Wood River flow ($b_2$), and irrigation diversion ($b_3$) (or augmented water). Where $\alpha$ (y intercept) is the value of Silver Creek stream flow when the independent variable is zero and ***b*** (unstandardized coefficient) is the slope or expected change in Silver Creek flow with a unit change in the independent variable.

Approximately a dozen regression formulas were run, each addressing an analytically different perspective of augmented water. Practically all of results were rejected as not statistically significant. When a regression equation is found "not significant" by the standardized F ratio test, few conclusions can be drawn. In the argot of the statistician, results were more likely than not due to, chance, errors in data, or violations of the assumptions of the model itself. Said in other words, the variations in the data were of such a nature (given the laws of probability) they could be happening by chance as opposed to being "caused" by something. This is especially true with respect to the notion of multicollinearity stipulating variables must be independent of each other. The interconnections between rain and river flow, for example, are probably tied to each so closely the statistical model is incapable of sniffing out subtleties with an acceptable level of confidence.

In isolated cases the formula was able to tease some relationships out of the data. In the case of a bivariate regression between irrigation diversions for District 45 and flows in Silver Creek (between 1928-1963) the Square of the Correlation Coefficient (MR) was 0.49 while the Coefficient of Determination ($R^2$) was 24. With an F critical value where P = <0.05 we interpret this as meaning 24 percent of the variation in Silver Creek's flows between 1928-63 is explained by irrigation diversions from District 45 ( or 76 percent of the variation is explained by "other" things or "Z"). The MR of 0.49 indicates a moderate association between irrigation (District 45 only) during these years. In one instance, a multivariate regression indicated a significant relationship between Silver Creek flows and flows from the Big Wood River plus irrigation diversions (1928-63). The net effect of these two independent variables explained 29 percent of variance with another "moderate" correlation of 0.54.

To say the least, these results are less than conclusive and of limited value since they did not establish any strong, clear, and trustworthy statistical relationships.

**Correlation: An Alternative Approach**

Absent success with multivariate regression, an alternative approach was pursued. In this second effort it appeared best to take into account the limitations of the data and structure the scope of analysis to fit realities of the databank. More specifically, this meant building a stochastic model of Silver Creek's plumbing through a combination of *t* tests, Pearson product moment correlations, and one-way analysis of variance (ANOVA). These statistical formulas tried to explicate the relationships between precipitation, flows in the Big Wood River and Silver Creek, and irrigation diversions as illustrated in Figure 2. In all, some 75 tests were conducted.

Databanks

As mentioned previoiusly it was necessary to compile new databanks updating the information to the year 2000. This information does not exist in any published document/s so it required telephone calls, internet contacts, personal visits, and even field meeting s with technicians.

1. **Precipitation** is measured at Ketchum Ranger Station by the USWS (1938 to 2000) in calendar years by hundredths of an inch. In order to make these records comparable required two data transformations: (1) converting the measures for 22,630 days of precipitation into annual inches; and (2) reconfiguring calendar years into water years. The decision was made to use KRS (as opposed to Picabo or Hailey) for several reasons. First, it is the closest approximation to precipitation falling high in the watershed and can represent the "lagged" effect of thawing which drives the Big Wood River. Second, its data have been kept for the longest period of record. Lastly, while it was relocated, as were the others, the relocation seems to be nearly climatologically identical (from Sun Valley garages to KRS).

2. **Irrigation diversion** (1928-2000) data were obtained from the State Water Master's office for Districts 45 and 55. The decision to focus only these two district systems was based on the field observation they are responsible for most all of the recharge to Silver Creek from irrigation. The districts provide recharge to Silver Creek through the three main branches of District 45. District 55 (Baseline Canal) supplies most of the water irrigating farms to the west of the ground water divide but two laterals do take a portion of its flow under Highway 75 and east of the divide. An entire day was spent with the manager of District 45 walking the branches and laterals to try and "ground truth" my suspicion the two districts provided most of the irrigation to Silver Creek's recharge zone.

Recording of flows by deputies ceases after September 30$^{th}$ even though diversion continues for "pasture" purposes. From my own observations, however, the districts continued to take water from the Big Wood River for almost 6 weeks after the State Water Master ceased recording! While this amount was reduced from the highpoint of the summer it still means reported diversions are underestimated.

In the case of District 55, much of this water remains west of the recharge zone for Silver Creek and returns to the Big Wood River. In the larger of the two laterals crossing under the highway and distributing water onto the recharge zone for Silver Creek I measured (May 4, 2000) it flowing at 79.93 cfs. When this figure was compared with the Water Masters measurements for the entire canal on that same day I was surprised to learn they were identical. Obviously something was haywire, either my measurement was high or the deputy's recording that day was low? After several attempts to get gain access were un-successful (required by my contract) no more surreptitious measurements were made last summer.

3. **Silver Creek** measures are taken by USGS and have been explained previously. Early records of stream flow began in 1920 and were only taken during growing seasons until 1936. From 1920 these measurements were recorded near Picabo until cancelled in 1963. When data logging resumed in 1975 for the new gauging station was placed approximately 5 stream miles up at Sportsmans Landing.

4. **Big Wood River** flows are taken by USGS at Hailey and available from 1916 to 2000.

Pearson Correlations and One Way Analysis of Variance (ANOVA)

Preliminary runs were made for calibration and verification. For example, the relationship between calendar years and water years was very strong but not at unity (Ketchum Ranger Station vs. Hailey (1949-1981) was $r = 0.79$; Ketchum Ranger Station vs. Picabo (1961-1999) was $r = 0.86$. The fact these correlations were less than unity informs us that even under the strongest of conditions variance will occur due to other factors.

**Silver Creek Flow: 1936-2000**

Flows in Silver Creek were examined from 1936-2000. The data from 1920 to 1936 is not presented here because the results of its analysis were similar even though these were partial years. Looking at Figure 3 not much leaps out other than there is wide variability in the flow. It is, of course, difficult to compare the early (1936-63) period with the later period (1975-2000) because of the differences in the locations of the two recorders.

The mean of the earlier period was 110 af/y while the mean of the later period is 114 af/y. Perhaps it is precisely what is missing here that is important: ***viz.*** no clear, sustained, long term downward trend of lessening flow.

Looking more closely at the past quarter century tends to reinforce the conclusion there appears to be no long term downward trend. The average annual flow in Silver Creek between 1975 and 2000 was approximately 114 acre feet or slightly higher than the pre 1963 period.

Another way of examining this information is by noticing what happens 10 percent above (124 af/y) and 10 percent below (104 af/y) the mean. For the past quarter century, flows exceeded the $110^{th}$ percentile 44 percent of the time while falling below the $90^{th}$ percentile only 32 percent (Figure 4). If anything, Silver Creek flows appear more robust in later years but again, caution must be exercised in comparing these data points due to differences in locations.

**Precipitation and Silver Creek: 1938-2000**

When precipitation is introduced, the picture is somewhat clarified. Correlations indicate a moderate, positive association between annual precipitation at the Ketchum Ranger Station and Silver Creek between 1938 and 2000. During the years the USGS stream gauge was located near Picabo the association was measured as $r = 0.31$ while for the period after 1975 the association grew stronger with $r = 0.49$. Here, variability in Silver Creek appears positively tied with the variability in snow and rain falling in the high watershed mountains above Ketchum.

Curiously, the relationship between the two variables is rather constant for the early period but grows more complex for the 1975 to 2000 years. In the early period, the curves approach each other but rarely intersect. In the later period, however, intersection is pronounced (crossing ten times) and probably reflective of intervening variables such as drought, introduction of more efficient irrigation and groundwater pumping. Nonetheless, there is a clear and positive association between precipitation and Silver Creek. In all likelihood, this is about as strong a statistical correlation possible given that the connection between high mountain precipitation and Silver Creek is indirect and must be carried through underflow, seepage, and diversions. A slightly different equation found nearly the same relationship when using the Picabo rain gauge Silver Creek ($r = 0.41$). These findings are illustrated in Figure 5

**Precipitation and Irrigation Diversions:**

Statistical analyses were conducted to probe the relationship between precipitation and irrigation diversions. This relationship was studied from several perspectives such as looking at Hailey precipitation and District 45 from 1949 to 1990 for the months of April through September ($r = 0.16$) as well as May through September ($r = 0.29$). Ultimately, it seemed the best way to compare these two variables was to operationalize "diversions" as the creation of an index collapsing measurements for both District 45 and 55 from May through September. Precipitation was measured as the USWS gauge at Ketchum Ranger Station.

For the 62 year time period from 1939 until 2000, the overall correlation was $r = 0.44$. The strength of this relationship is strong and indicates a clear connection between fluctuations the wet/dry year cycle and water withdrawn for crop irrigation. In some ways the relationship between these factors is counter intuitive in that in wet years one would think farmers needed less water for irrigation and vice versa for dry years. Perhaps this phenomenon is reflected more in the magnitude of withdrawal than in its periodicity.

If one were simply plotting irrigation diversions since 1975 it would d be relatively easy to conclude that irrigation diversions are declining since they no longer appear to move beyond the 100,000 af/y level as they did in the early 1950s, mid 1960s, and early 1970s. It is also appears as if the level of precipitation that used to trigger such large diversions no longer does so in recent years. Thus 20 inches of rain in 1970 seems to correspond with a much higher level of diversion than 20 inches of rain in the 1990s. Undoubtedly, there is some attenuating effect apparent after, say, the later 1970s. Whether this occurrence is due to increased irrigation efficiencies, changes in district pricing policies for surplus water, increased groundwater pumpage, or diminution of irrigated acreage is difficult to say. In all likelihood it is explained by changes in all these elements. When all is said and done, however, there still remains a sustained clear relationship between annual precipitation falling high in the watershed and water diverted out of the Big Wood River for crops. Figure 6 presents this information graphically.

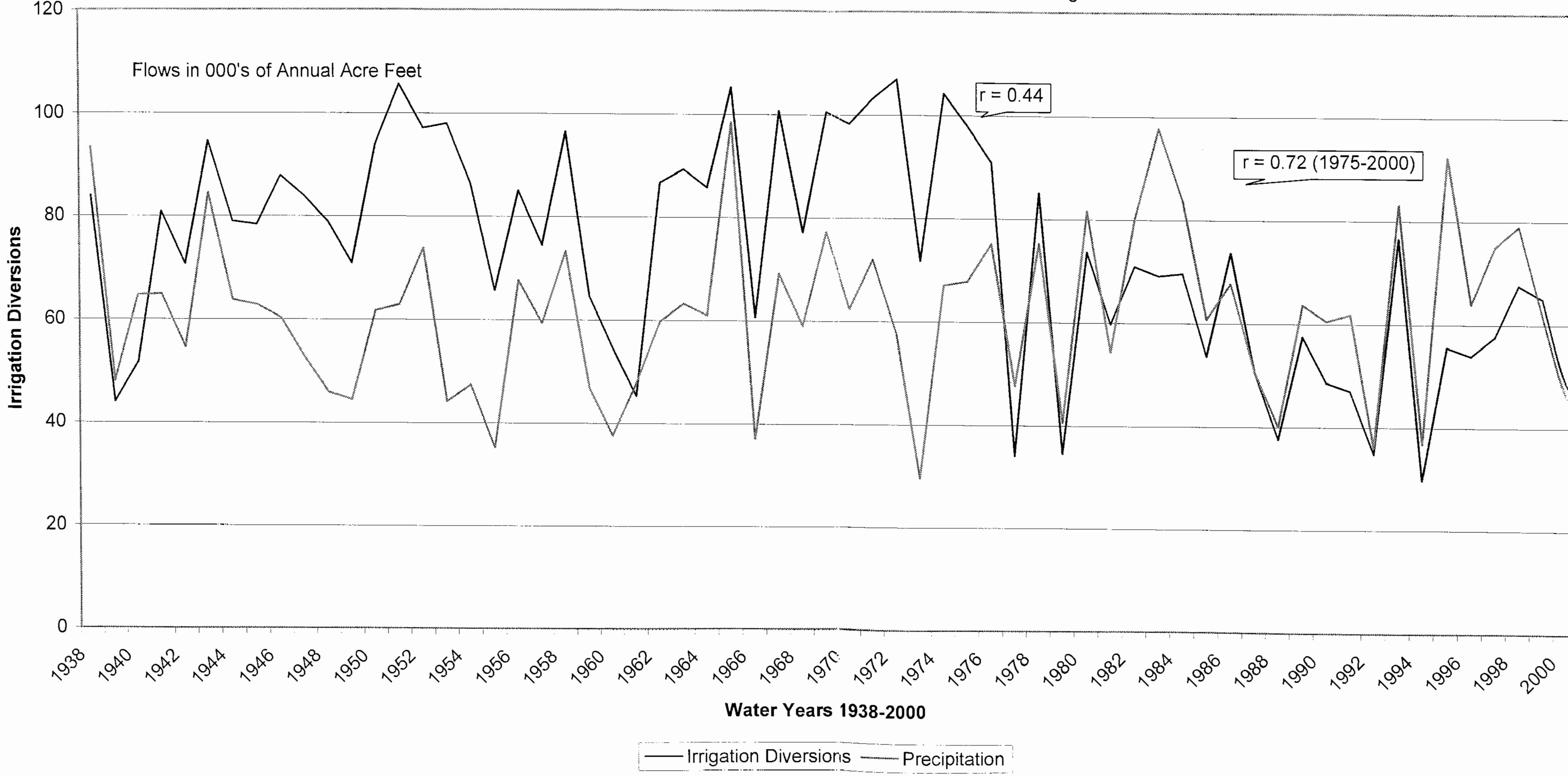
**Precipitation and Big Wood River: 1938-2000**

One of the two most straightforward statistical relationships is found between precipitation and the Big Wood River. Precipitation data analyzed from the USWS (Ketchum Ranger Station) and flow reports from USGS (Hailey)1938 until 2000 revealed a strong connection. Both the statistical measurement ($r = 0.77$) and the visual picture underscore the bonded nature of this connectivity (Figure 7). Why is this measurement not stronger given the conceptual model? Correlations from "real" world data rarely exceed 0.80 for a variety of reasons including sampling error, overlap of measurements periods, evaporation and withdrawals above Hailey all play a part. In fact, knowing the sole source of water for the Big Wood River is precipitation and the correlation is still 0.77 tells something about the actual strength of other associations whose correlations are less.

**Figure 6 Precipitation by Irrigation Diversions**

Diversions for District 45 + District 55 Measured by State Water Master

Precipitation in Annual Inches by US Weather Service at Ketchum Ranger Station



**Big Wood River and Irrigation Diversion:1928-2000**

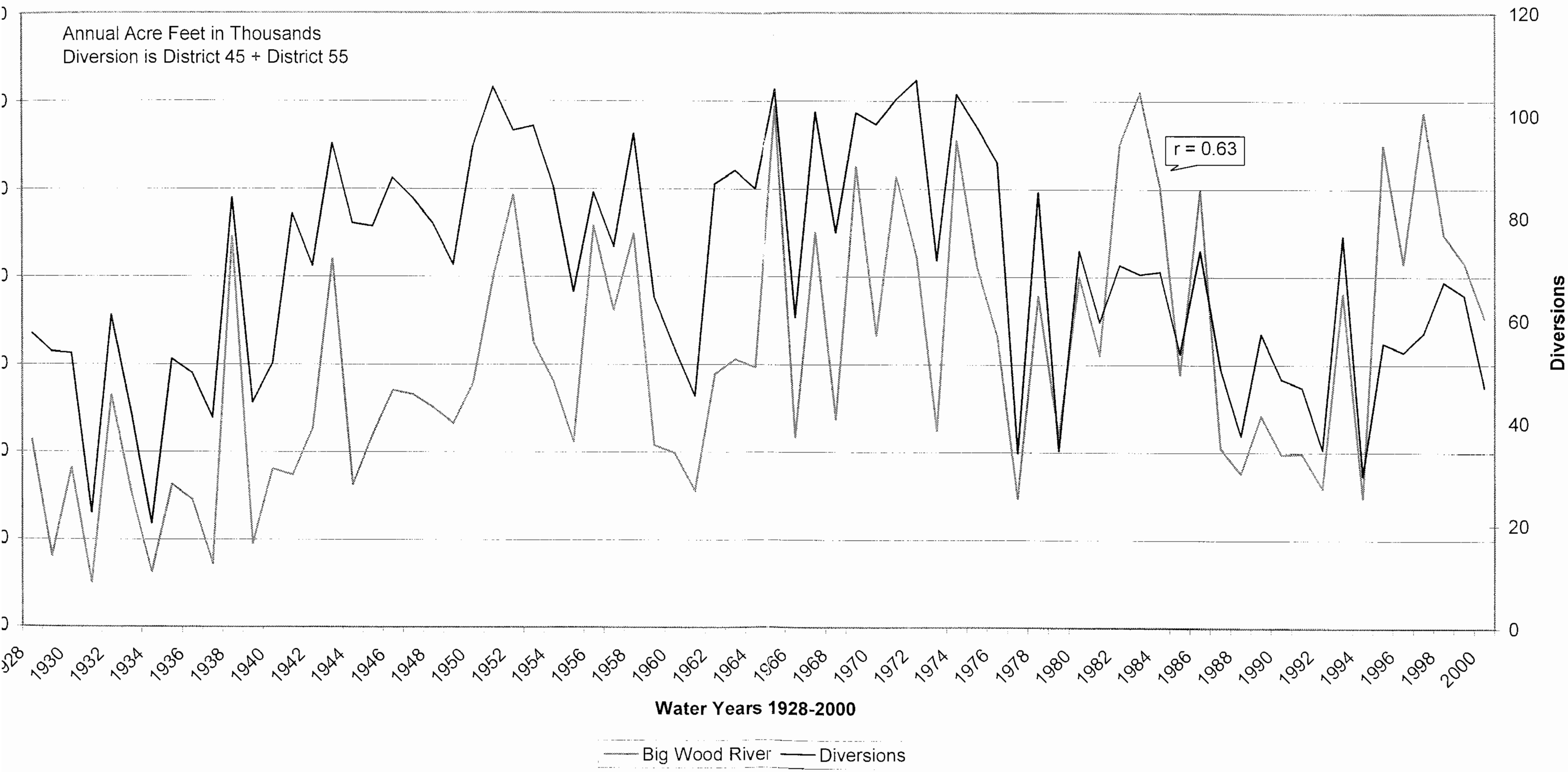
A key question about the Silver Creek hydrologic systen around the relationship between the Big Wood River and the dis irrigation diversions simply mirror water available in the river o factors enter the picture? Perhaps canal capacity establishes a ( diversions, or maybe the districts take as much water as they can of varying river levels? Computational analysis between 1928 produced a moderately strong relationship between variation in the variation in diversion (r = 0.63). The tendency for river flows and ( to rise and fall in harmony is presented visually in Figure 8. interesting about Figure 8 isn't so much its obvious covariance some subtleties within this range. In the early years it seems "pushes" the diversion and, graphically speaking, always remains river's curve. In more recent years, though, it appears the rive diversion and its curve is sometimes below and sometimes above curve. This unique feature is most pronounced in the 1982-84 p again in 1995 to about 1998. One possible interpretation for this a that these were two of the wettest years of record (1982-84; 1996-9 a result irrigation water was in far less demand.

Another curious aspect of these recent anomalies is tha appears to occur when precipitation is up rather than down. In oth during the wet years of the early 1980s diversion lagged far bel rainfall but in the dry periods the magnitude of the two curves almc each other.

What to make of this I am not sure and it may, in fact, porter term tendency to divert less irrigation water than has proportionally

## Figure 8 Big Wood River and Diversion

Big Wood River data (Hailey) by USGS, Diversion data by State Water Master



done in the past. What remains clear is the strong tendency of the river and diversions to covary in a synchronized pattern.

Of incidental note is the relationship between the two irrigation districts. Two correlations were run on these two organizations for time period 1928 through 1999. For District 45 by 55 (April-September) the product moment correlation was r = 0.61 and for the same time period but using five month growing season (May-September) it was r = 0.66.

**Big Wood River and Silver Creek: 1920-2000, 1936-2000**

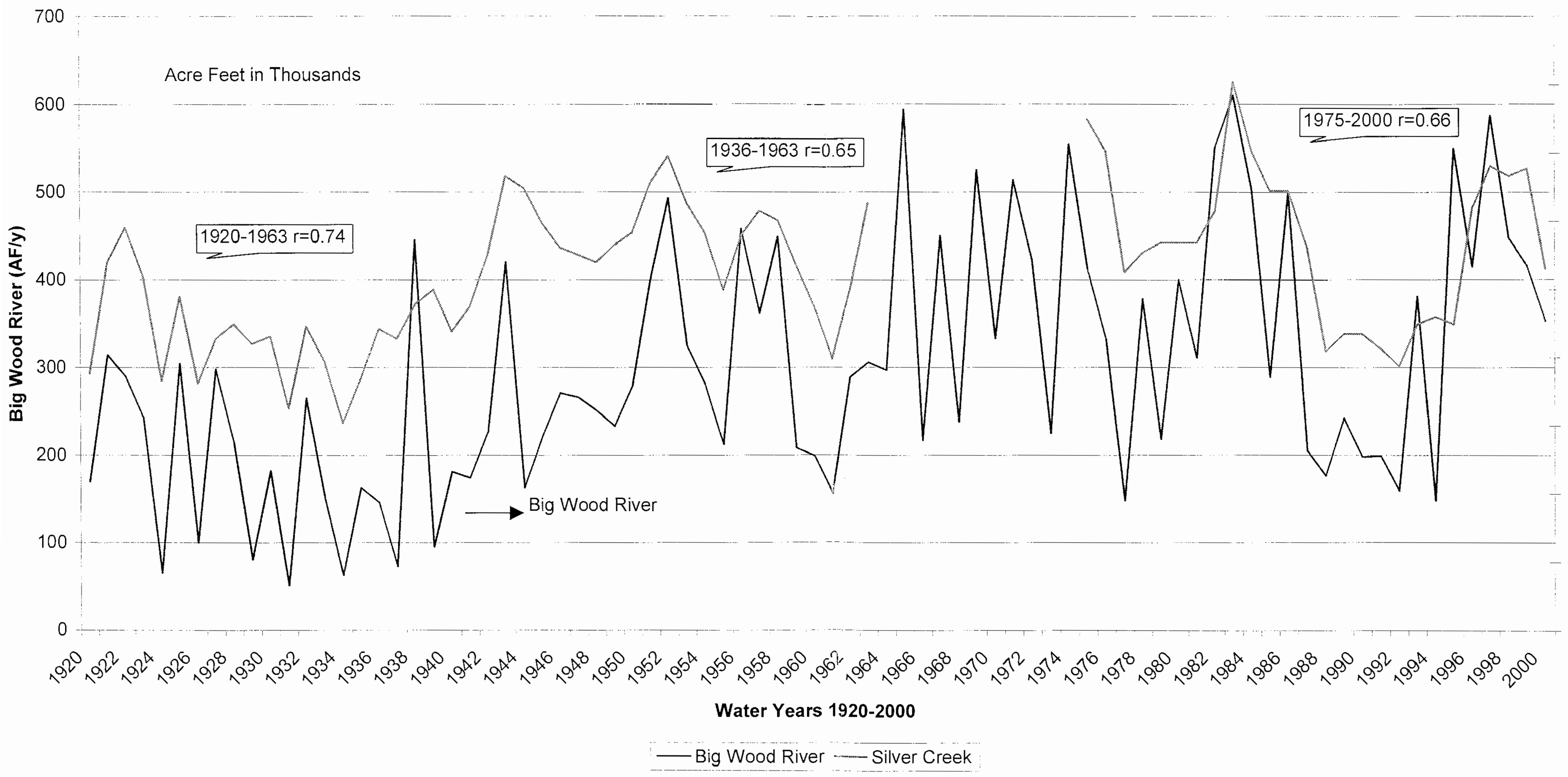
The Big Wood River interacts with Silver Creek in two, primarily indirect, ways. Firstly, a portion of the river's water seeps below the river channel south of Bellevue and crosses the ground water divide to become part of the Silver Creek hydrologic system. Secondly, water is diverted out the river and into the mains and laterals of Districts 45 and 55. From these diversions some of the molecular water will deep percolate to join ground water and eventually find its way into the Silver Creek headwater springs.

Mapping this connection called for the comparison of USGS flow records for Silver Creek with records for the Big Wood River. While a continuous POR exists for the river it does not for Silver Creek, thus the study was divided into two correlation periods: 1920-63 and 1975-2000. The first time period was further sub-divided because from 1920 to 1935 the USGS only recording stream flow for the actual five month growing season, beginning in 1936 records were kept annually. Correlation coefficients were r = 0.74 for 1920-63 and r = 0.65 for 1936-63. Analysis of the 1975 to 2000 data taken from the new location at Sportsman's resulted in r = 0.66.

Figure 9 represents the graphs of these data and again reveals a strong tendency for Silver Creek to respond to indirect fluctuation in the Big Wood River. If anything, these results reveal some of the strongest connections in

## Figure 9 Big Wood River & Silver Creek

Partial Years for Silver Creek 1920 to 1935



the study. In certain years, for example 1985-86, the spring fed creek will fall as the river does but not with the same rate of response or magnitude. More likely than not this "dampening" effect is due to the modulation by the aquifer's storativity, limited as it may be. Still the covariance is strong.

**Irrigation Diversions and Silver Creek:1928-2000**

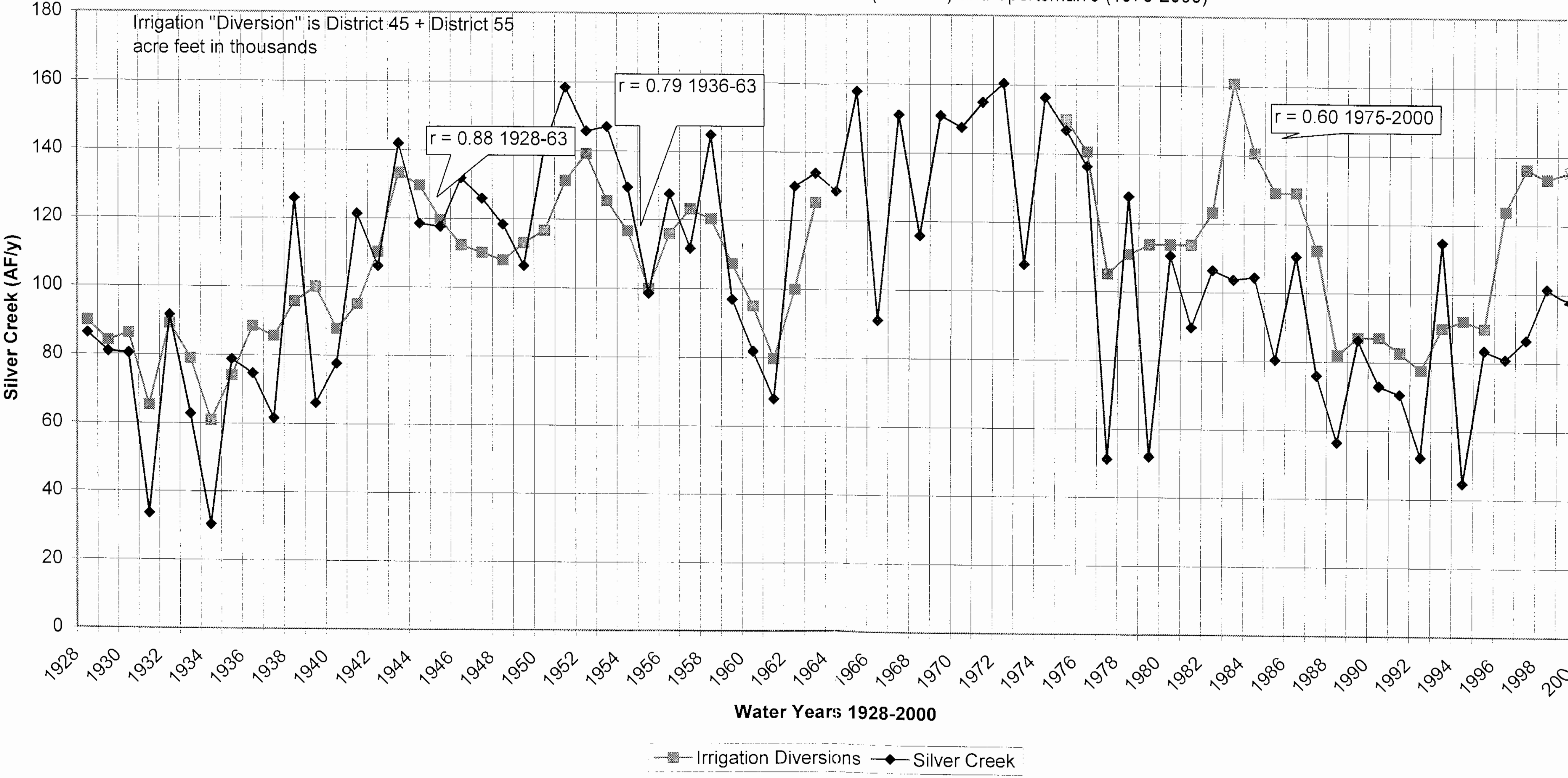
A final element of the model centers upon the connection between irrigation diversions and Silver Creek. Analyzing this bond posed several choices. For example, should we use only District 45 or only District 55 statistics? Should we use the April-September or the May through September growing season? Should an effort be made to estimate water running through the system after September 30th until the freeze sets in? The variables were operationalized as (1) diversions – an index combining May through September data for the additive sum of both District 45 and 55; (2) Silver Creek flow - quantified as annual acre feet for 1928 to 1963; 1936 to 1963 and 1975 to 2000; and (3) period - the May through September growing season. The results of these computations are displayed in Figure 10 where r = 0.88 (1928-63) and r = 0.60 for 1975 to 2000. When the early time period was truncated to full annual reporting (1936 to 1963) the correlation dropped from 0.88 to 0.79.

Additional computer runs indicated District 45 (May to September, 1928-63) also resulted in r = 0.88 as did District 55 for the same time periods. When the two districts were separated in the 1975-2000 period, correlations dropped to 0.42 for District 55 but remained the same for District 45.

# Figure 10 Diversions and Silver Creek

Irrigation Diversion Data Provided by State Water Master

USGS Silver Creek Flow collected near Picabo (1928-63) and Sportsman's (1975-2000)



## *SUMMARY*

The key results of correlation analyses are presented in Figure 11. This stochastic model describes the probabilistic interrelationships between:

- Precipitation and Silver Creek in two time periods
- Precipitation and flows in the Big Wood River
- Precipitation and Diversions
- Flows in the Big Wood River and Diversions
- Flows in the Big Wood River and Silver Creek
- Irrigation Diversions and Silver Creek

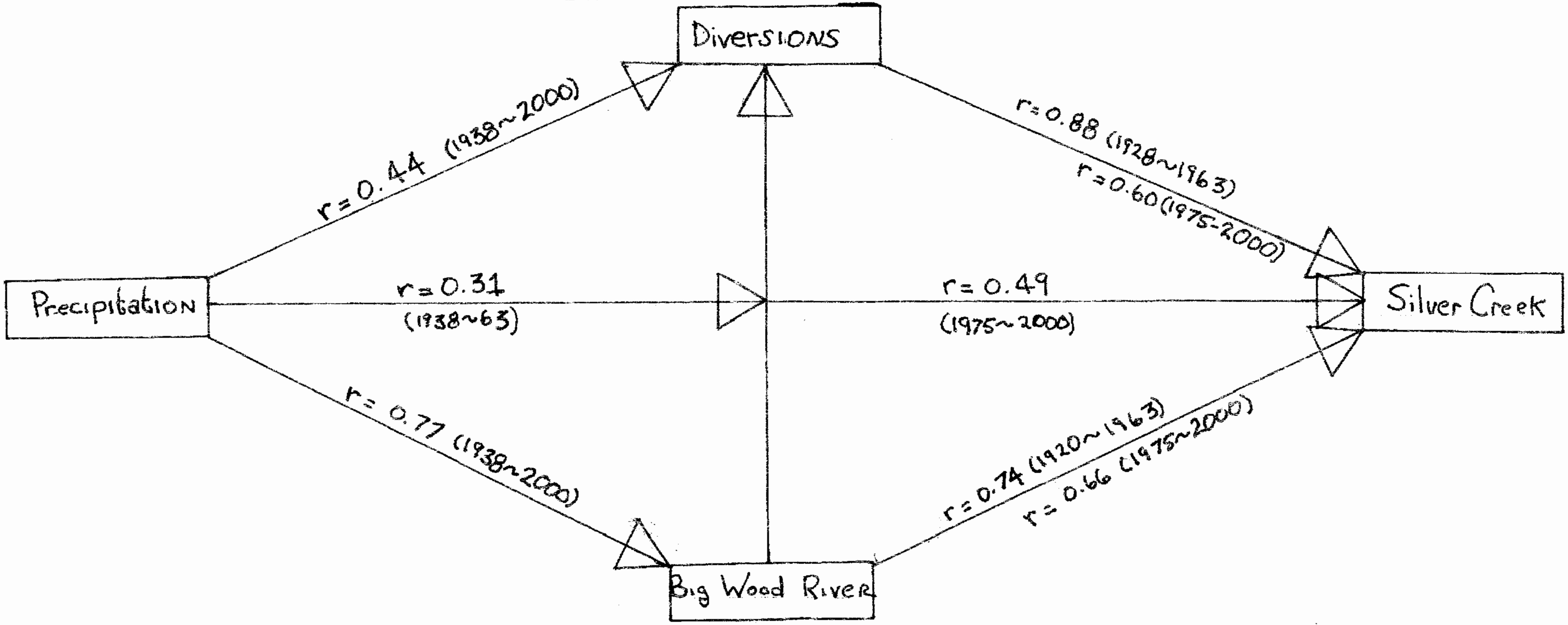
Statistical inter-relationships are stated in varying time periods as a function of available data. Overall, Figure 11 and its supportive analyses suggest what most any school child could tell us; ***viz.*** --- the key independent variable explaining the variance in all elements of flow and diversion is precipitation falling high in the mountains over an 880 square mile watershed. Stored as snow and ice this temporal aqueous release appears to set the tempo for the hydrologic system as a whole.

Having said this, however, our attention is directed to the important subtleties of the system. Can we use this temporal data to shed light on trends? Can this model and other computations be used to evaluate two propositions put forth in both Phase I and Phase II of the ***Hydrologic Assessment of the Big Wood River and Silver Creek Watersheds***? More specifically, the two assertions were: (1) diversions are decreasing over time; and (2) if all diversions were absent then Silver Creek flows would drop by about two thirds relative to its current level.

# FOUR VARIABLE STOCHASTIC MODEL FOR SILVER CREEK HYDROLOGIC SYSTEM

## Correlations for Precipitation, Big Wood River, Irrigation Diversions, and Silver Creek

### Pearson Product Moment Coefficients




Note: Precipitation measured in calendar years converted to water years (Ketchum Ranger Station-USWS) 1938-2000
Big Wood River measured in water years in acre feet (thousands) (Hailey gage-USGS) 1928-2000
Diversions measured (May-September) in Calendar Years as District 45 + District 55 by State Water Master in average daily cfs converted to acre feet (thousands)
Silver Creek measured in water years in acre feet (thousands) by USGS from 1928-63 near Picabo and 1975-2000 near Sportsman's Landing

## DECREASING DIVERSIONS

Phase I contended diversions between 1932 through 1995 show a "decreasing" trend and from 1975 to 1993 diversions declined by 37,000 acre feet (p. 45). Proffered in 1994, this proposition rests curiously on a point to point comparison; the year 1975 compared to the year 1993.

While I cannot say with complete confidence diversions have not decreased somewhat during the past quarter century, I am puzzled by evidence to the contrary. The danger of a point to point comparison is it can anomalous. In 1975, for example, 98,000 acre feet were diverted by Districts 45 and 55. Yet if the years 1973 or 1977 had been the point of reference the statement would have been altered dramatically since diversions were 71,000 acre feet and 34,000 acre feet respectively.

The key question revolves around whether or not diversions are actually declining due to the introduction of more efficient methods of irrigation/land use practices or are they fluctuating within a normal range given the variability in climate? To answer this question we need to ask some basic questions? Do irrigation diversions appear correlated with precipitation? Yes. In Figure 6 we can see a moderate correlation for the overall model ($r = 0.44$) increasing substantially for the last quarter century ($r = 0.72$). What makes this analysis even more interesting is during the latter time period some remarkably large diversions occurred. In four of the five years between 1995 and 2000 diversions were so high they exceeded 93 percent of diversions made by Districts 45 and 55 for the entire period of record!

In an effort to look at the issue of decreasing diversions in a different light records comparing the first and last quartiles were undertaken. Records for first precipitation and diversion in the years 1938-1954 were matched for the years 1984-2000. Table 1 presents the results of a one-way analysis of variance (ANOVA). In comparing both 1st and 4th Quarters for precipitation and diversion the F ratio failed to reject the null hypothesis. In other words, statistically speaking (alpha p>.05), we cannot accept or trust the differences in the means between the two time periods for these factors because the variability between and within them indicates otherwise.

**Table 3. Analysis of Variance for Precipitation and Diversion comparing First and Fourth Quartiles**

| | Mean Precipitation (KRS) | Mean Diversions (Dist's 45+55) |
|---|---|---|
| 1938 - 1954 | M = 18 inches/yr | M = 81,000 af/yr |
| 1984 - 2000 | M = 18 inches/yr | M = 54,000 af/yr |
| | P > 0.05 Fail to reject | P> 0.05 Fail to reject |

The general conclusion I draw from analyzing available data is the "decline" in diversion is not abundantly clear and appears much more attenuated with oscillations in weather patterns.

**DIVERSIONS and SILVER CREEK**

The second proposition of interest is made in Phase II. Using MODFLOW to simulate a pre-irrigation development scenario the researchers constructed a pre-irrigation resulting in the conclusion that under these conditions Silver Creek would have 67 percent less water relative to its flow (Phase II, p. 88). This is a tricky postulate to model because it requires adjusting estimates for seepage, replacing crop coefficients for ET, as well as making estimates on the amount of marshland, aquifer transmissitivities, porosity, and conductances. A tough job by any standard.

No doubt irrigation provides a portion of Silver Creek's headwaters; a contention corroborated by the correlation analyses. Using the 1928 to 1963 data we find r = 0.88 which falls to r = 0.79 for 1936 to 1963. Even the correlation for the past twenty-five years, while further declining to r = 0.60, still indicates a moderately strong connection. In any event, both correlations for the pre-1963 period are so strong I believe they reflect differences more between the locations of the two recorders (Picabo vs. Sportsmans) than changes in stream flows. This "hunch" is supported by the results of one-way analysis of variance using ANOVA. In Table 2 we see the mean annual flow in Silver Creek increased from 94,000 acre feet in

**Table 4. Analysis of Variance for Silver Creek Flow and Irrigation Diversion comparing First and Fourth Quartiles**

| | Mean Annual Flow, Silver Creek | Mean Annual Diversion, (45+55) |
|---|---|---|
| 1928-1946 | M = 94,000 af/y | M = 59,000 af/y |
| 1982-2000 | M = 111,000 af/y | M = 56,000 af/y |
| | $P < 0.05$ reject null $H_0$ | $P > 0.05$ fail to reject null $H_0$ |

the first quartile to 111,000 acre feet in the fourth quartile. This F ratio did reject the null hypothesis and thus we trust the differences are actual and not related to chance. At the same time, ANOVA failed to reject the first and fourth quartile comparisons for diversions thus meaning we cannot accept the differences in mean annual diversions with confidence.

Looking at the past twenty-five years presents curious associated with factors other than the relocation of the recorder. At times diversions and creek flow go hand-in-hand as one would expect, yet in other years we find converse. In some cases large swings in diversions (1977-81) appears to have little effect on Silver Creek. In other instances, though, diversions fall yet Silver Creek flow goes up (1978-79, 1983-84, 1993-94, and 1995-96)! Continuing in this vein, it can be observed there are periods when diversions increase but the creek stays constant (mid 1979-80; mid 1985-86, and 1994-95).

When all is said and done it is difficult to find a clear pattern. Only a fool would contend Silver Creek is not bonded in some way with irrigation diversions and for that matter not bonded in a relatively strong way. Surely, if irrigation diversions were to cease tomorrow there would be a profound and subsequent lessening of Silver Creek flow. My own sense of things is that while Silver Creek is connected to diversions I do not think it is as strong as the 67 percent figure produced by the model. My feeling is that more water flows from the Upper Valley as underflow than has been taken into account not to mention the absence of water coming northward from the Picabo/Timmerman Hills area.

Whether I guess at it being 35, 45, or even 55 percent of Silver Creek's annual flow is really moot. What is for sure is that whatever happens in terms of future diversions will happen incrementally. Factors as land use planning, state and county policies, and marketplace prices will play a large role in determining the future of irrigation in Silver Creek's recharge zone. For that matter I am less worried about farmers adopting more water efficient measures and letting their water rights be lost than I am by growth in the upper valley. If the Wood River Valley follows the well-established pattern found elsewhere in the West, we can anticipate three trends: (1) developers in the upper valley will seek to buy water rights from Bellevue Triangle farmers and transfer these rights northward; (2) developers in the Bellevue Triangle will seek permits for changes in "points of diversion" so they can convert their existing surface rights to ground water; and (3) the upshot of the Snake River Basin Adjudication will either be minimal or likely to try and leave more water in the river for use downstream.

If these prognostications are at all true then the policy implications are clear. Assuming change will be incremental we must design a monitoring system that includes not only biological and physical parameters for Silver Creek but also scans the horizon for the anticipated changes as outlined outlined above.

## APPENDIX

Eq 1 $$W_a = Q_{SC_o} - \sum^{i=1} \left[ (P_p + V_{UF} + V_s) S \right]$$

where: $$P_p = P_{p'} - (ET_c + ET_N + GW_o)$$

Eq. 2

Eq. 3 $$V_s = V_{s'} - Q_{BWR} + \left[ V_{GWP} - (ET_c + ET_N) \right]$$

Eq. 4 $$V_{GWUV} = V_{GWUV'} - \left[ (V_{UV} - (ET_c + ET_N) \right]$$

$W_a$ = AUGMENTED WATER

$Q_{SC_o}$ = FLOW of Silver Creek "OUT"

$P_p$ = PRECIPITATION AT LOCATION (Picabo)

$P_{p'}$ = PRECIPITATION AT Picabo (NET)

$ET_c$ = EVAPOTRANSPIRATION crops

$ET_N$ = EVAPOTRANSPIRATION NATURAL

$GW_o$ = ground WATER OUT

$V_s$ = Volume of seepage

$V_{s_1}$ = Volume of seepage (NET)

$V_{GWUV}$ = Volume of upper valley underflow

$V_{GWUV'}$ = Volume of ground water NET

$Q_{BWR}$ = Flow of BIG WOOD River