GROUND-WATER PUMPING IMPACTS ON SURFACE WATER IRRIGATION DIVERSIONS FROM BIG LOST RIVER

by

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ABSTRACT

The water table in the Big Lost River valley is declining due to increased irrigation pumpage and decreased recharge from surface-water irrigation, resulting from the use of more efficient application methods and an accompanying expansion to about twice the irrigated acreage of two decades ago. The lower water table reduces the already deficient river flows, and impacts the senior water rights of many surface water irrigators.

Recorded irrigation diversions have decreased in relation to river flow in the last two decades. Diversions are estimated to be depleted by about 30,000 acre-feet per year in dry periods, such as 1987 through 1990. Depletion of diversions is estimated by a linear relationship to river flow, based on data from below normal water years. Extrapolating that relationship to all years, the depletion in a normal water year is estimated to be 13,000 acre-feet. A negative relationship between ground-water pumpage and river flow was extrapolated to estimate pumpage as 47,000 acre-feet during a normal water year.

Senior surface-water irrigators are due mitigation from those depleting river flows. The mitigation may take any of several forms, but should be supported by a self-funding group of ground-water, or combined surface and ground-water irrigators in the valley.

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STATEMENT OF THE PROBLEM

Many irrigation wells have been constructed in Big Lost River valley since 1960. The ground-water resource over much of the valley is hydraulically interconnected with the Big Lost River; consequently, ground-water pumpers often are accused of depleting the already deficient supplies of surface water irrigators. The water right priorities of surface water irrigators generally are far senior to ground-water users, suggesting that the liability for stream depletion rests with the ground-water pumpers.

The stream depletion issue is clouded by several factors. The complicating conditions include:

1) River depletion by ground-water pumping is neither instantaneous nor equal in magnitude to the amount of water pumped. The attenuation of pumping effects are influenced by the location of the well with respect to hydraulically connected reaches of the river, the physical properties of the aquifer formation, and the depth from which the well extracts water.

2) The river reaches that are hydraulically connected to the ground water and the degree of hydraulic interconnection vary from year to year, and even from season to season, depending upon the depth of the water table. During droughts, the water table in the lower parts of the valley drops well below the river bottom, and the effects of further decline in water table are probably minimal.

3) Surface water often is conveyed through the canals rather than the river channel to reduce seepage losses. Therefore, pumping impacts on surface water also are related to canal seepage in the lower valley.

4) Ground-water pumping is only one component of a combination of factors that are impacting ground-water levels and the depletion of surface water supplies. The greatest impact results from variation in precipitation. In addition to climatic variability, the widespread conversion from flood irrigation to sprinklers, and the associated expansion of irrigated acreage, have diminished ground-water recharge and increased discharge.

Ground-water pumping undoubtedly is one of several developments which affects flows in the surface channels in Big Lost River valley. Water supply conditions of earlier years, however, can only be restored fully by returning to the practices and irrigated acreage of those years. The economic consequences of such drastic measures would certainly be severe and undesirable. Resolution of the conflict for the water resources should therefore focus on an efficient and equitable use of the resource, based on the appropriate legal considerations and the best available hydrologic knowledge.

OBJECTIVES

The general objective of this report is to assess the impact of ground-water pumping on surface-water flows and evaluate the alternatives for resolution of the conflict. Specific objectives include:

1) to develop an understanding of the operation of the irrigation system in Big Lost River valley, and the historic changes that have occurred in that system,

2) to collect, assemble, and summarize the available and pertinent information on the water supply and irrigation diversions in the valley,

3) to relate changes in available water to changes in irrigation practices in the valley, especially the expansion of ground-water pumping,

4) as far as possible, to quantify the impact of ground-water pumping on surface water supply, and describe the limitations and assumptions associated with that determination, and

5) to recommend a procedure or procedures for compensating surface water users for flows lost as a result of ground-water pumping.

METHODS OF ANALYSIS AND DATA DESCRIPTION

In this study, the effects of pumping on surface-water supplies are evaluated by examination of historic changes in water supply and delivery that have occurred since the expansion of ground-water pumping, beginning about 1960. This method requires long-term records of precipitation, river discharge, and irrigation diversions.

Climatic variations have had a significant impact on water availability in the basin. However, the effects of climate variation on the results of this study were minimized by comparison of similar water years and the use of long periods of record.

Big Lost River discharge is available from U.S. Geological Survey Records for extended periods at three stations: 1) at Howell Ranch (13120500) in the upper part of the valley, 2) below Mackay Dam (13127000), and 3) below Arco (13132500). The locations of these stations are shown in figure 1. Data on summer flows at Howell Ranch are available for all years as early as 1920. Year-round data is available since 1949. There are about 3,000 acres of irrigated land above the Howell gage (U.S. Geological Survey, 1991). The station below Mackay Dam includes all water released from Mackay Reservoir except that diverted in the Sharp ditch. The discharge of the Sharp ditch has been recorded in watermaster records for Water District 34. A

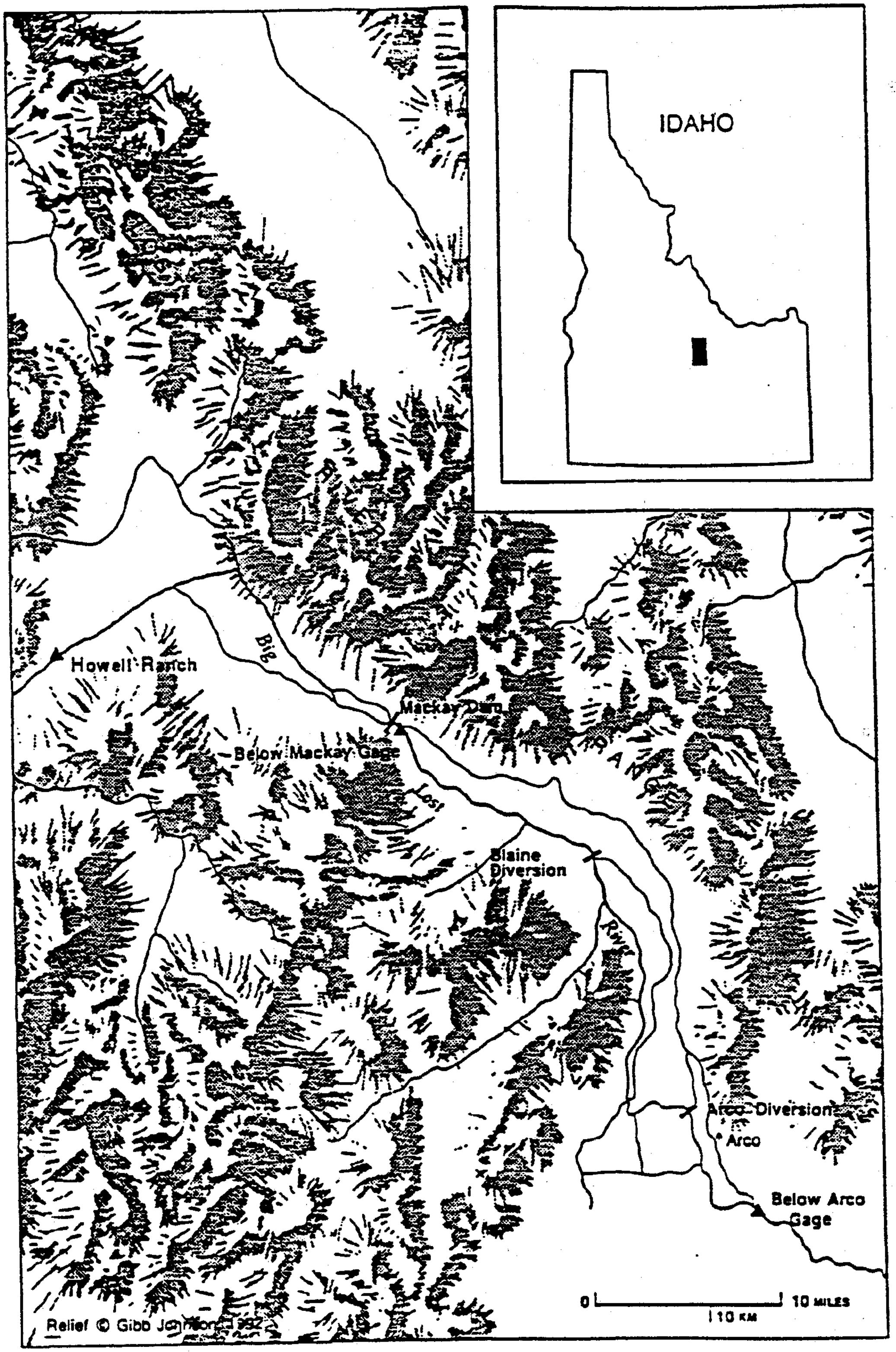


Figure 1. Map of Big Lost River Valley.

continuous record is available from the station since 1919. The station below Arco is below all major irrigation diversions in the Big Lost River valley. Discharge at the Arco station is available from 1946 through 1961, 1966 through 1980, and from 1982 through 1990. Storage in Mackay Reservoir also is available continuously since 1919. Monthly values of river flows and reservoir storage are listed in Appendix A.

Irrigation diversion records for the Big Lost River Water District dating back to 1923 were collected from the Idaho Department of Water Resources for this study. Annual summaries, prepared by the watermaster of Water District 34, were the source of information on the monthly volume of irrigation diversions for four reaches of Big Lost River (shown in figure 1): 1) Above Mackay Dam, 2) Mackay Dam to Blaine Diversion, 3) Blaine Diversion to Arco, and 4) below Arco. In the early records, the diversions were only distributed into two reaches: Above and below Mackay Dam. Annual summaries could not be obtained for 1938, 1939, 1941, 1955, and 1971 water years. Monthly diversion data from 1922 through 1990 are presented in Appendix B.

The validity of diversion records is uncertain. Changes in watermasters and measuring devices may have caused differences in diversion records over the years. Although the results of this study are sensitive to the accuracy of the records, methods of analysis are employed that minimize that sensitivity.

Monthly values of river discharge, reservoir storage, precipitation at Mackay and Arco, and irrigation diversions were compiled and stored in a DBASE III+ format. These records were analyzed graphically and statistically using several commercially available software packages.

The water year used by the Big Lost River Water District 34, extending from November 1 to October 31 of the following year, was used as the base for all annual values presented in this report. Flow and storage volumes are consistently presented in acre-feet.

WATER SUPPLY AND IRRIGATION IN BIG LOST RIVER VALLEY

The Big Lost River basin is a mostly mountainous area of 1,400 square miles in south-central Idaho (figure 1). The area is drained by the Big Lost River and tributaries. All surface-water and ground-water discharge from the basin is tributary to the Snake Plain aquifer. The estimated average annual water yield of the basin is 470,000 acre-feet (Crosthwaite and others, 1970). In 1970, Crosthwaite and others estimated that an average of 54,000 acre-feet were lost as surface water discharge to the Snake River plain, 308,000 acre-feet were discharged as subsurface flow, and 109,000 acre-feet were lost by evapotranspiration, annually. Mackay Reservoir, on the Big Lost River near Mackay, has a current storage capacity of about 44,000 acre-feet, and is principally used to store snowmelt runoff for irrigation.

Irrigated agriculture is concentrated on the coarse alluvial deposits of the Big Lost River valley. In 1970, Crosthwaite and others estimated the acreage irrigated by flow from Big Lost River above Mackay Reservoir to be 12,680 acres, and 36,540 acres irrigated below the reservoir. They determined that an additional 8,500 acres were irrigated from ground-water, at that time. Prior to 1960, stream flow supplied nearly all the irrigation water. However, since 1960, many wells have been constructed to supplement the surface water supplies and irrigate new lands.

Concurrently, there has been a partial conversion from flood irrigation to sprinkler application methods and an expansion of the irrigated acreage.

The Big Lost River basin is divided into two principal parts for this analysis, above and below Mackay Dam. These areas represent distinct and somewhat independent units from water supply and irrigation management perspectives. This report focuses on lands below the dam, where most of the recent irrigation development has occurred. Irrigation below Mackay Dam is regulated separately from that above the dam except in periods of high flow, when the river is considered to be a single water body throughout its entire length. Irrigation supplies below the dam are supplemented by reservoir storage. Big Lost River flow below Mackay Dam is measured by a gaging station near Mackay and a station on the Sharp irrigation ditch. A relatively small amount of underflow, 15 cfs (Crosthwaite and others, 1970), is estimated to occur in the alluvium at the gaging station near Mackay. Several small tributaries to Big Lost River also contribute to water supply below the dam.

HISTORIC WATER SUPPLY PATTERNS

Annual and seasonal variations in precipitation on the Lost River watershed result in variations in streamflow and in the amount of water available for irrigation and for ground-water recharge. The total annual, and winter precipitation at Mackay for the period of 1925 through 1989 are shown in figure 2. Annual values are expressed on a water year basis, extending from November 1 through October 31 of the following year, matching the water year normally used by the water district. Low elevation annual precipitation records, such as at Mackay, do not show a high degree of correlation to annual stream flow. Only the general wet and dry periods of precipitation at Mackay are reflected in flow of the Big Lost River at the three primary gaging stations. Bar graphs illustrating discharge in each water year (November through October) at Howell Ranch (station 13120500) and at the gaging station below Mackay Dam (station 13127000) are shown in figures 3 and 4. Flow in the Big Lost River below Arco (station 13132500) is more variable (figure 5) and includes several years with zero discharge. The monthly discharge at each of the gaging stations and the volume of water stored in Mackay Reservoir are listed in Appendix A. The median flow at Howell Ranch (1925 - 1990) is 238,000 acre-feet, below Mackay Dam (1925 - 1990) is 214,000 acre-feet, and median flow below Arco (1947

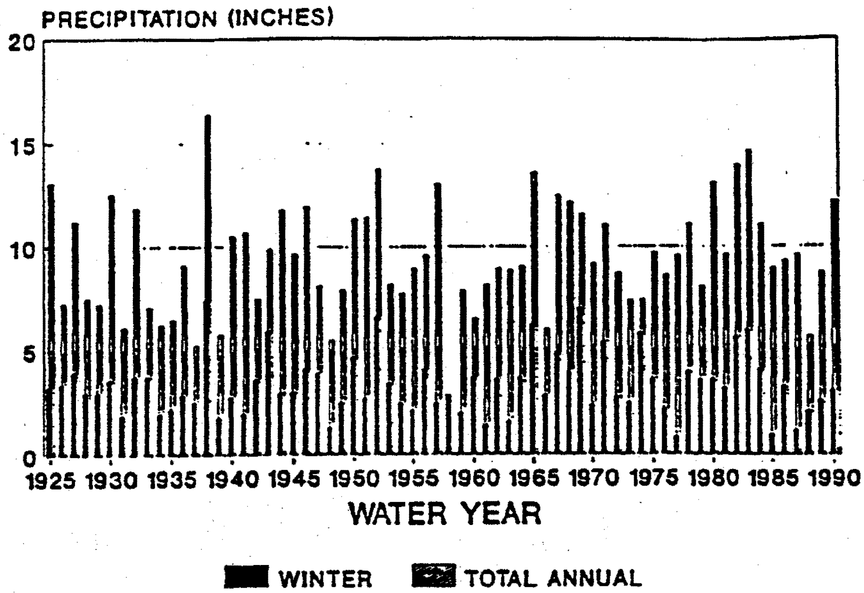


Figure 2. Precipitation at Mackay

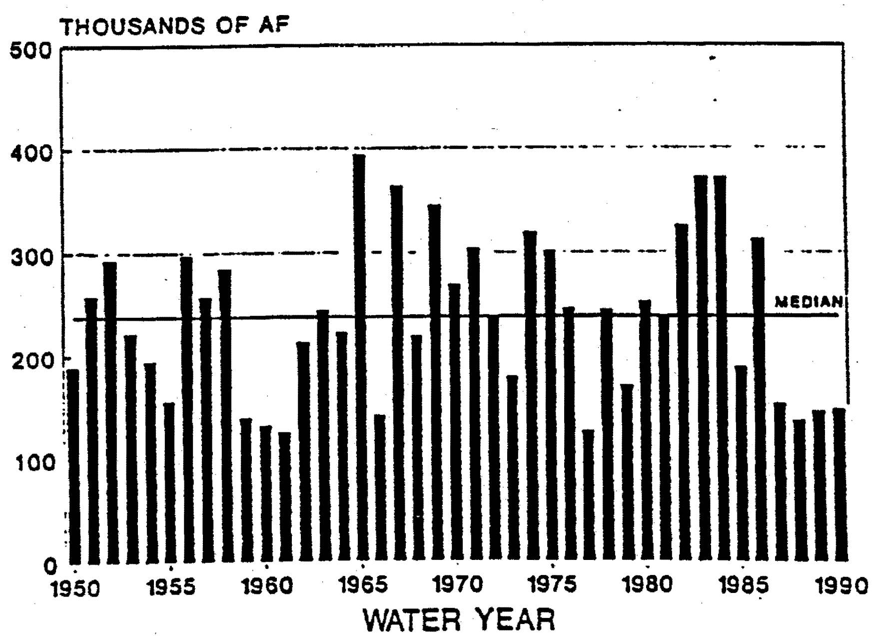


Figure 3. Big Lost River Discharge at Howell Ranch.

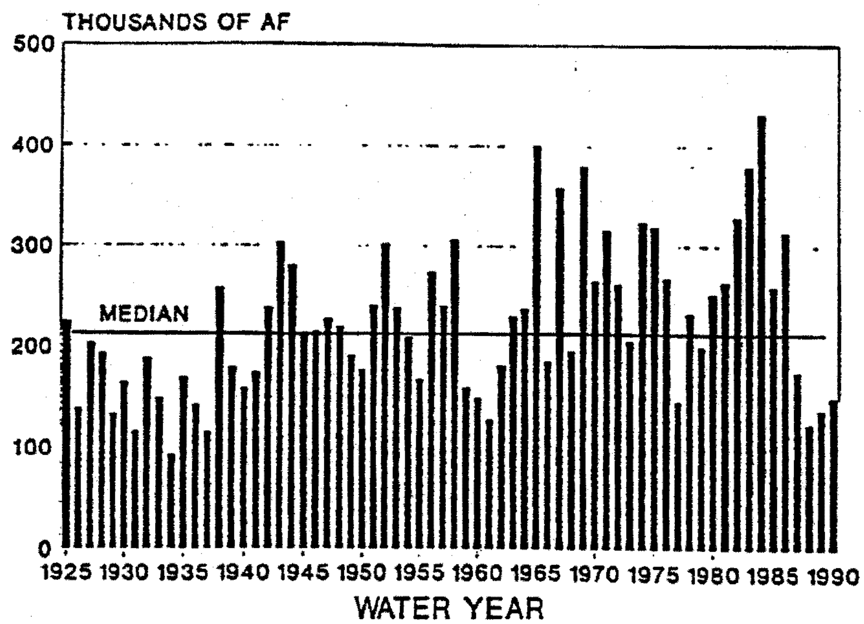


Figure 4. Big Lost River Discharge Below Mackay Dam.

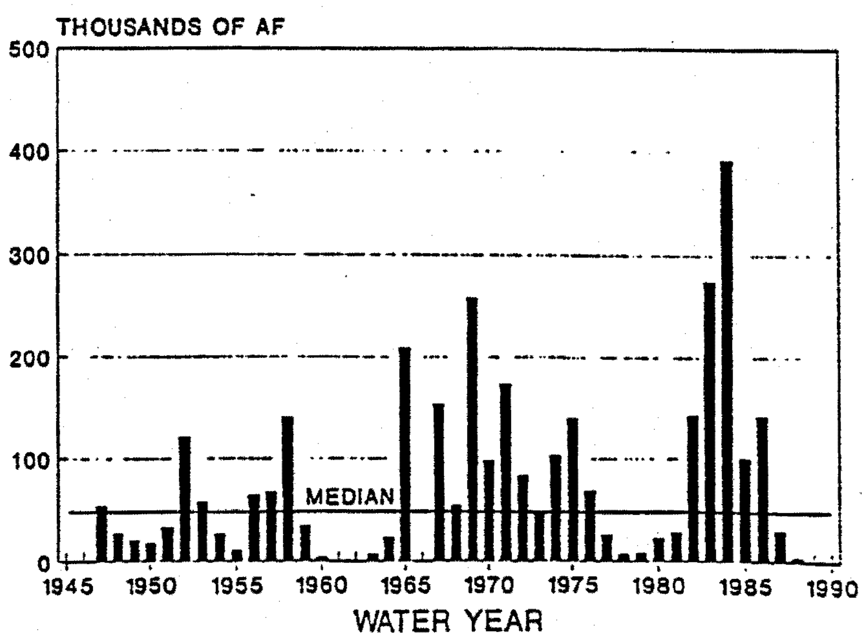


Figure 5. Big Lost River Discharge Below Arco.

- 1990) is 47,000 acre-feet. Annual and monthly flows below Mackay and below Arco are not adjusted for changes in storage in Mackay Reservoir.

Droughts, sometimes extending for several years, have been experienced several times during the history of irrigation in Big Lost River valley. Recent competition for water supply has been accentuated by the drought conditions experienced since 1986. River flow below Mackay Dam during the drought of 1987 through 1990 is similar to flow during the 1959 to 1962 period. The drought of the early 1930's is similar, but of longer duration than the current drought (through 1990). Mean river flows and irrigation diversions below Mackay Dam for the 1959 to 1962, and 1987 to 1990, periods are presented in table 1. River flows at the three gaging stations during the 1987 to 1990 period are slightly less than the flows during the 1959 to 1962 period. Diversions show a greater relative difference between the two periods than river flows. Average flow below Mackay dam varied only 4 percent between the two periods; but irrigation diversions below Mackay dam averaged 30 percent less in the later period.

Table 1. Mean River Flow and Diversion Comparison, 1959 to 1962 and 1987 to 1990.

Period	Howell	Mackay	Arco	Diversions Below Mackay
	Acre-Feet/Year			
1959-1962	152,200	154,000	6,600	110,900
1987-1990	136,491	147,900	5,800	77,600
Ratio[1]	0.90	0.96	0.88	0.70

[1] Ratio = (mean for 1987 to 1990) / (mean for 1959 to 1962)

HISTORIC PATTERNS IN IRRIGATION DIVERSIONS

Surface Water Diversions

Monthly diversion data are available from the District 34 Watermaster Annual Summaries for each canal, and sometimes by river reach. The temporal comparability of these records, however, is compromised by the changes that have taken place in the irrigation system over the decades. Some canals have changed names or service areas. Water transfers and exchanges have also occurred, changing the point of diversion from the river. The most valid year-to-year comparisons probably can be made on the total diversions for the two river segments, above and below Mackay Dam. Comparisons of diversions may also be possible within the smaller river reaches frequently reported in the Annual Summaries:

1) Above Mackay Dam,
2) Mackay Dam to Blaine Diversion,
3) Blaine Diversion to Arco Diversion, and
4) below Arco Diversion.

However, the reach diversions may have changed because of changes within the irrigation system. This report concentrates on the diversions below Mackay Dam, since this part of the valley has experienced the most extensive ground-water development.

Diversion data reported in the Watermaster Annual Summaries represent the measured or estimated flows at the point of diversion of each canal from Big Lost River. The magnitude of the diversions are affected by:

1) the water supply in the river,
2) the demand for water, and
3) river gains and losses.

The third factor, river gains and losses, is the component which is impacted by ground-water pumping. The means of measuring or estimating diversions has changed with time and the reliability of the reported values has also changed. Apparently, less emphasis was placed on water measurement and record keeping from 1973 through 1985, and consequently the records may be less reliable during this period.

At times during most years, the demand for water exceeds the available supply, and diversions are strongly related to the flow in the river below Mackay Dam. This relationship is shown by the nearly parallel distributions of annual diversions and river flows presented in figure 6. Several years are absent from the graph of figure 6, where data are missing or incomplete. A notable feature of figure 6 is the increased difference between river flow below Mackay Dam and irrigation diversions after 1965. In years of below normal river flow below Mackay, the mean ratios of annual diversions to river flow below Mackay (including

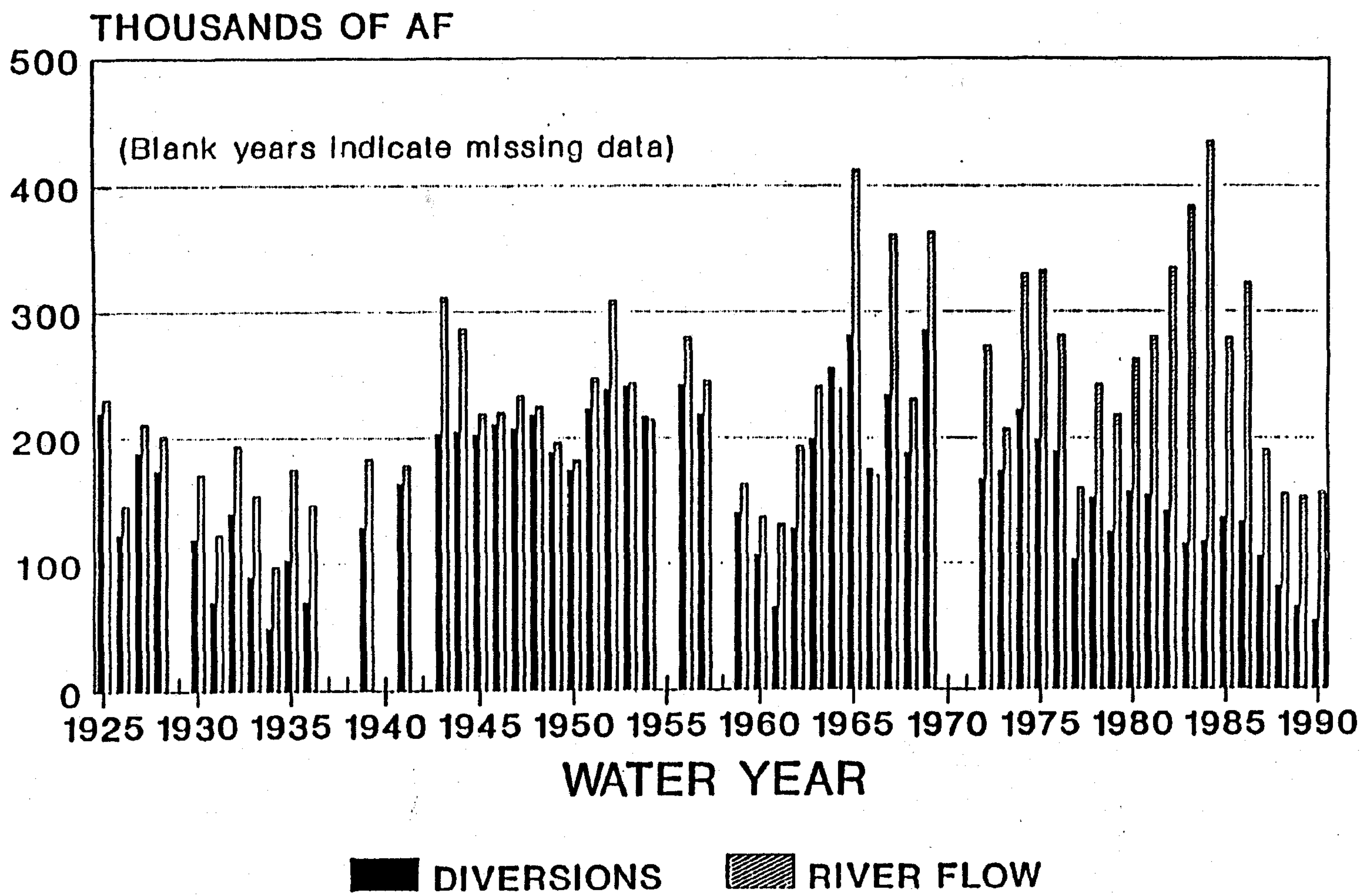


Figure 6. Annual Diversions and River Flow Below Mackay Dam.

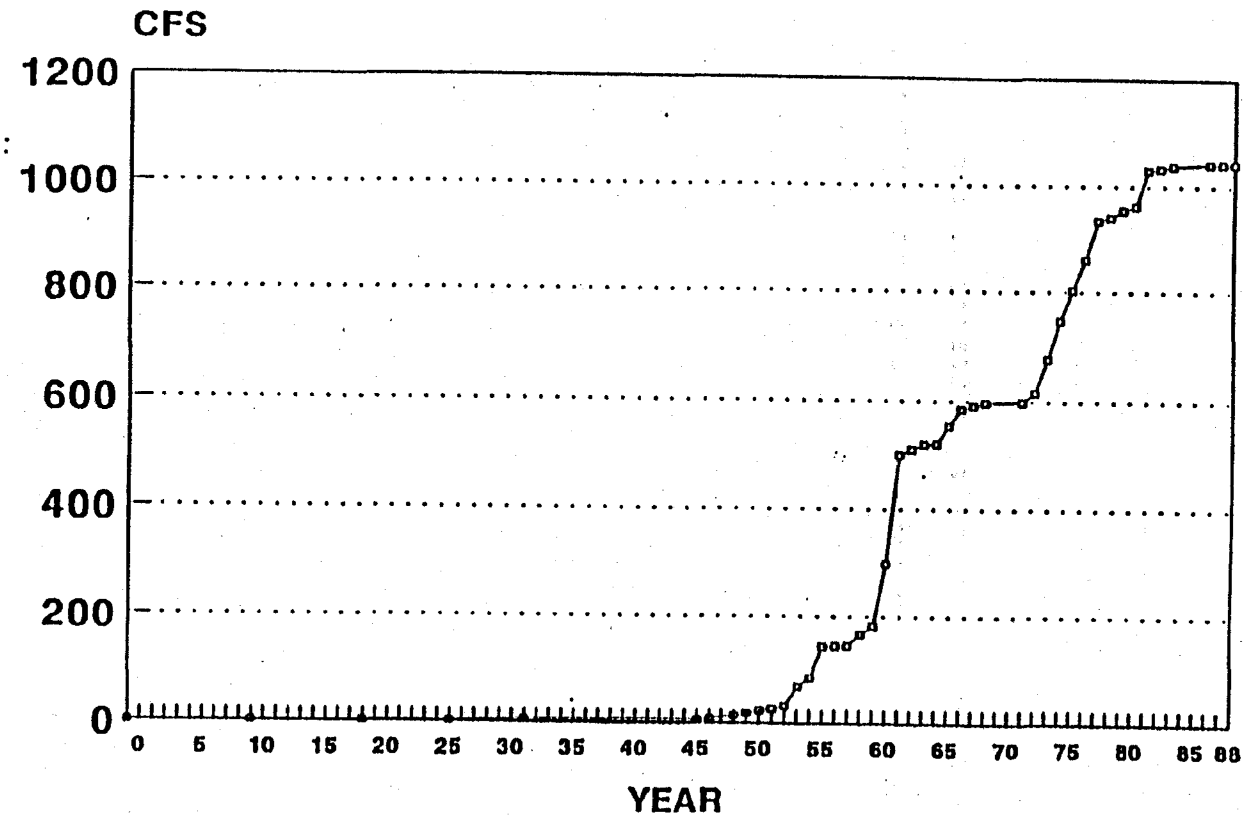
Sharp ditch and pumpage additions) is 0.80 for the period before 1965, and 0.59 for 1965 and after.

Diversions in high water years are generally limited by demand rather than water supply. In some high water years in the early 1980's, the recorded diversions were substantially less than in many previous years of lower water supply. In 1984, the watermaster report indicated that all rights were filled all season, with only 50 percent of the water diverted during the growing season as in previous high water years, like 1965. This difference suggests that either the watermaster records are in error, or the demand for surface water has declined during the 1980's. The former seems to be the more likely possibility.

Ground-Water Diversions

The amount of ground-water pumpage for irrigation changes from year to year in response to variations in irrigation demand and the changing degree of irrigation development in the valley. Prior to 1960, only a few irrigation wells were present in the valley. The drought of the early 1960's combined with other development incentives, however, resulted in a boom in ground-water development in the early 1960's, and again in the early to middle 1970's. The quantity of ground water pumped during these years is unknown, except for the 1984 through 1990 period which is addressed in a following chapter, "Estimation of Irrigation

Pumpage." Historic changes in ground-water development are reflected by the amount of ground-water claimed in water rights filings with the Idaho Department of Water Resources. Figure 7 illustrates changes in the cumulative total of ground-water rights claims in Big Lost River valley. The extensive claims with priorities dating to the early 1960's and 1970's indicate the rapid rate of growth of ground-water development during these periods. The amount of ground-water claims provide an approximate indicator of the potential for ground-water pumping. It does not imply the amount of actual pumping due to the effects of weather and other factors.



BASED ON ADJUDICATION CLAIMS

Figure 7. Historic Changes In Ground-Water Claims In Big Lost River Valley (from the Idaho Department of Water Resources).

COMPARISON OF DIVERSIONS TO RIVER FLOW

In most years, surface water diversions for irrigation are limited by the available supply. During these years a strong relationship exists between flow in the Big Lost River below Mackay Dam and irrigation diversions below the dam. A scatter plot of annual river flow against diversion data for all years with complete record, from 1923 through 1990, is presented in figure 8. The water year associated with each point is given by the two digit number at the appropriate grid point. An approximately linear relationship is apparent during years where river discharge is less than about 250,000 acre-feet. In years with high flow, however, little or no relationship is apparent. The low ratio of diversions to river flow in the 1980's does not appear to be due to intense, short duration runoff. Diversions in high water years in the 1980's are substantially less than in earlier high water years, as was also apparent from figure 6. Scatter plots based on flow during the growing season appear similar, and consequently, are not presented.

The impacts of development on hydrologic observations, or systematic changes in the method of measurement, are often apparent in a double-mass balance graph. A double-mass balance plots the cumulative volume of one station

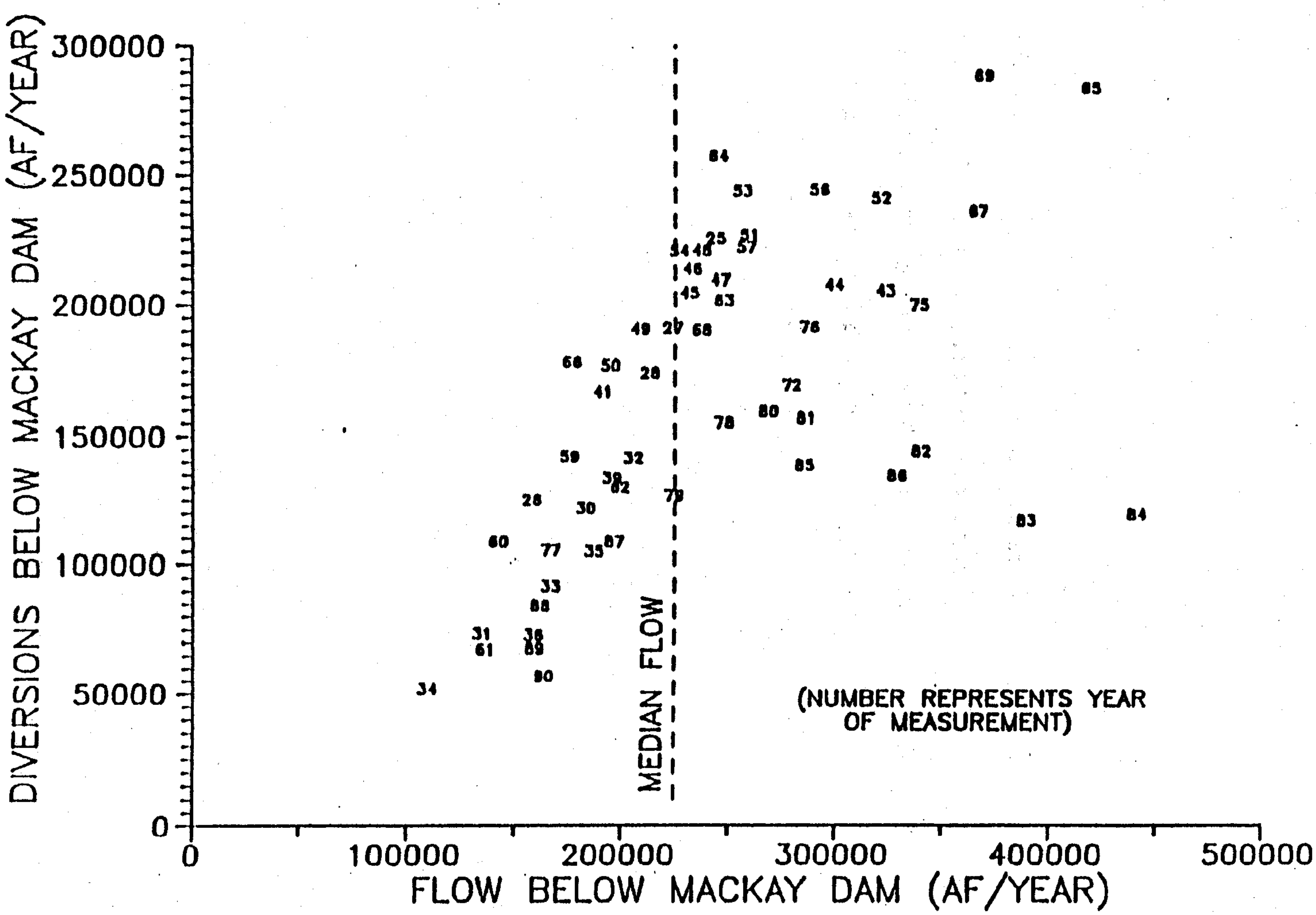


Figure 8. Scatter Plot of Diversions Against River Flow Below Mackay Dam.

against the cumulative volume at a second station, or set of stations. Figure 9 shows application of the double-mass balance to display changes in the relationship between river flow below Mackay Dam and irrigation diversions above and below the dam.

Long-term changes in slope of a double-mass balance would indicate that the relationship between diversions and river flow has changed. Changes in slope are most apparent in the line representing diversions below Mackay Dam. Some of the curvature is due to differences in the relationship between diversions and river flow at high and low flows. In addition to this, however, there appears to be a general flattening of the slope (below Mackay Dam) beginning about 1960, and more noticeably, after about 1970. This indicates that either the proportion of river flow diverted for irrigation has been reduced, or that a new watermaster made significant changes in measurement methods and record keeping.

A straight line plot on the double-mass balance indicates that no change has occurred in the relationship between river flow and diversions, nor in the validity of the measurements. The diversions above Mackay Dam, in contrast to those below the dam, plot as a relatively straight line in figure 9. However, a slight change in slope is apparent before 1940, and after 1983. The relative linearity of the plot representing diversions above the dam,

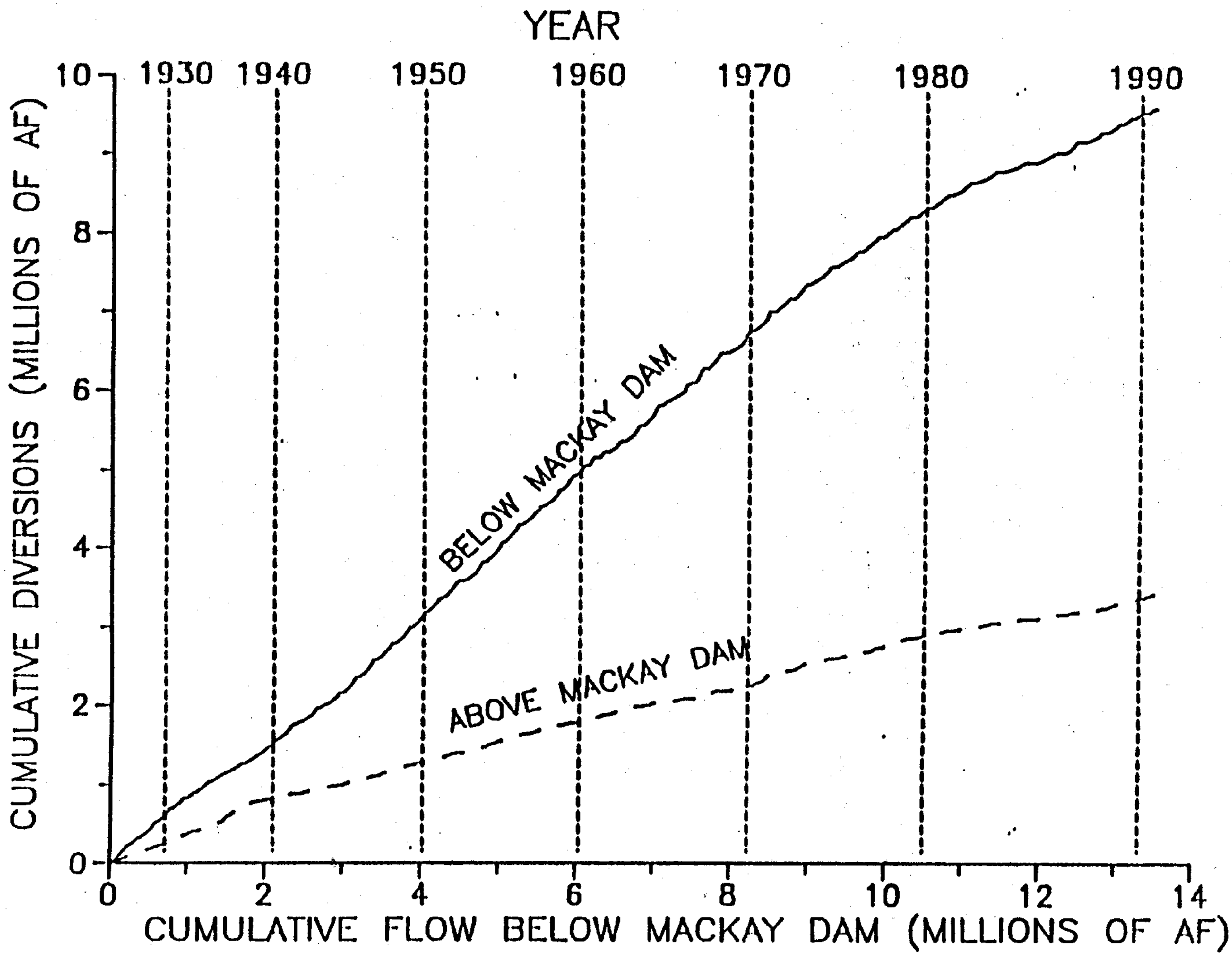


Figure 9. Double Mass Balance of Diversions Above and Below Mackay Dam Against River Flow Below Mackay Dam.

coupled with the relatively unchanging irrigation practices in that area, lends credibility to the double-mass balance as a method of observing the impacts of development.

ESTIMATION OF DIVERSION DEPLETION

Irrigation of new lands in, and near Big Lost River valley, has been made possible by the conversion to more efficient sprinkler irrigation, and by the construction of irrigation wells. The expanded irrigated areas transpire more water than the smaller, and partially irrigated, areas of earlier years. Ground-water withdrawals for irrigation, and diminished recharge from sprinkler irrigated lands has caused a general decline in the water table in the valley. The lower water table results in increased seepage losses from the river and reduced ground-water inflow. The increase in river losses results in less water being available for diversion into the canal systems of the valley. The objective of this section of the report is to estimate the amount of depletion of diversions that has occurred from the combined effects of expanded irrigation, conversion to sprinklers, and ground-water pumpage.

Two methods are applied to estimate diversion depletion from the diversion and river flow data. The methods rely on different periods of record to minimize the effects that different record keeping and measurement procedures may have on conclusions.

Method 1: Comparison of Periods of Similar Water Supply

Depletion of diversions is estimated by comparison of periods of relatively similar water years, before and after the extensive development of the 1960's and 1970's. The periods from 1959 through 1962, and 1987 through 1990, are suitable for this type of comparison (table 1). The ratio of irrigation diversions to river flow below Mackay Dam is 0.72 for the pre-development period of 1959 through 1962. During the 1987 through 1990 period, the respective ratio is 0.52. The difference between these ratios (0.20), multiplied by the average annual river flow during the periods of estimation of 147,000 acre-feet, yields an estimate of average diversion depletion for that period equal to 29,600 acre-feet per year.

Flow during the periods of analysis was below normal, and the estimated depletion is, therefore, representative of below normal flow conditions in the river. This method provides no information on how depletion changes in times of different water supply.

Method 2: Differences in Regression Lines

The competition for water supply in Big Lost River valley is most intense in low water years. Low water years are also those which display a relatively strong linear relationship between annual irrigation diversions and river flow below Mackay Dam. Figure 10 shows the relationships between diversions and river flow for two periods during years in which flow below Mackay Dam was less than normal (220,000 AF). The period before 1960 represents the era prior to extensive irrigation expansion and ground-water development. The second period presented in figure 10, from 1960 through 1990, represents the era of transition to sprinklers, expanding acreage, and increasing ground-water development. The solid line in figure 10 is a regression line based on below normal flows prior to 1960. The dashed line is based on below normal flows from 1960 through 1990. The mathematical expressions of the two lines are as follows:

Before 1960,

$$\text{DIVERSIONS} = -86799 + 1.300 \times \text{FLOW}$$
$$r^2 = 0.77 \text{ , and}$$

1960 and after,

$$\text{DIVERSIONS} = -123{,}104 + 1.405 \times \text{FLOW}$$
$$r^2 = 0.73 \text{ ,}$$

where:

DIVERSIONS = Annual irrigation diversions below Mackay Dam in acre-feet, and

FLOW = Annual discharge of Big Lost River below Mackay Dam, including Sharp ditch, in acre-feet.

The difference between the two regression lines of figure 10 indicates that changes in irrigation practices and ground-water pumpage probably have impacted the available

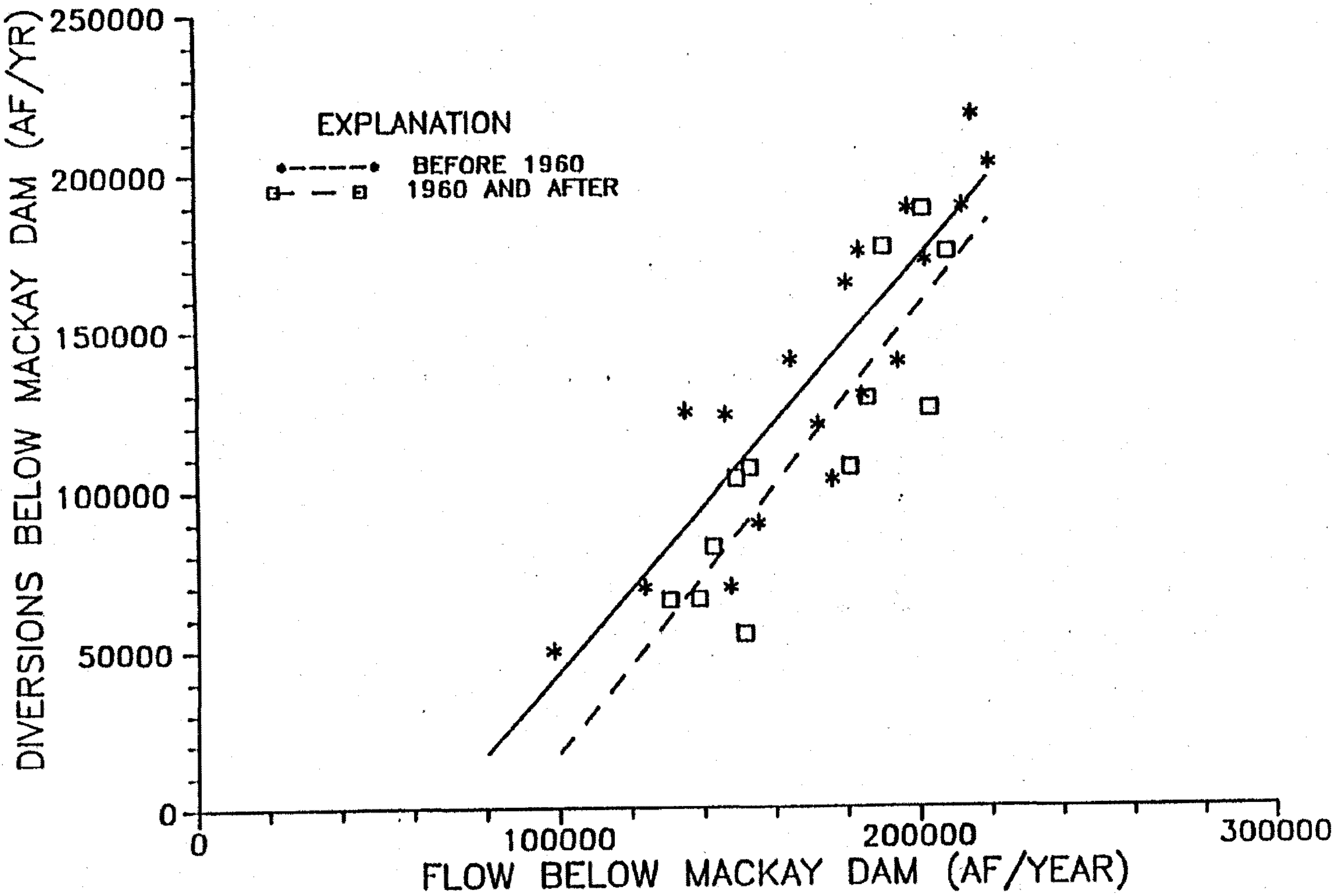


Figure 10. Irrigation Diversions and River Flow Regression For Below Normal Flow Years, Before and after 1960.

surface-water supply. That impact has been the result of a lower water table that induces more river losses and decreases gains. In below normal flow years, the average impact can be estimated as the difference between the two regression lines. Subtracting the second equation (1960 - 1990) from the first (before 1960), yields the following equation for difference, as a function of river flow:

DEPLETION = 36,300 - 0.1055 x FLOW

where

DEPLETION = estimated annual diversion depletion in acre-feet, and

FLOW = annual river flow below Mackay Dam, including Sharp ditch, in acre-feet.

Diversion depletion estimated by the above equation decreases as annual river flow increases. This may be related to the increased ground-water pumpage needed to supplement surface water supplies during dry years. For the 1987 to 1990 period used in derivation of Method 1, the river flow below Mackay averaged 147,000 acre-feet. The estimated depletion of diversions is 20,800 acre-feet for that period. In the normal year the river flow below Mackay Dam is about 220,000 acre-feet, and the estimated depletion of diversions is 13,100 acre-feet.

This method "averages out" differences in diversions for two periods of 18 years (before 1960), and 12 years (1960 and after) of record. The effects of development, however, are certainly not fully apparent by the 1960's and therefore, this method may tend to underestimate the impacts on diversions. The post-development period was not represented with more recent data in order to contrast the first method of estimation, and because of lack of confidence in regression based on only a few data points. The regression equations also only describe the general relationship between diversions and river flow. A little more than 70 percent of the variation in diversions can be accounted for by variation in river flow. The remainder is attributed to other factors such as residual effects from the previous year. The post-development period was not limited to more recent years in order to contrast the first method of estimation, and because of the lack of confidence in regression based on only a few data points. It is acknowledged that different regressions can be developed by the selection of different periods of record.

Comparison of Methods for Estimating Depletion

The most valid period for comparison of Methods 1 and 2 is for those years used in derivation of Method 1, from 1987 through 1990. In this period, depletion estimated by the first method is about 30,000 acre-feet per year. The second method, based on the difference between regression equations, estimates the diversion depletion to be about 21,000 acre-feet per year, for the same river flow conditions. The smaller value of the second estimate may be due to the use of a longer period of post-development record, which included the transitional years in which irrigation development was taking place, and impacts were not fully evolved.

The first estimation method, based on comparison of two periods of similar river flow, provides a depletion estimate for specific low river flow periods. The second method is somewhat more versatile, estimating depletion as a function of flow based on below normal water years. Neither method specifically addresses estimation of depletion during periods of above normal river flow.

In above normal water years, a surplus of water often exists during spring and early summer. By late summer, however, surface water supplies may be inadequate to meet crop demands. The deficiencies during this time are probably amplified by increased seepage and decreased river inflow, induced by irrigation expansion and ground-water pumpage.

Extrapolation of the second, regression-based method, to years of above normal river flow provides reasonable estimates of diversion depletion; even though the method is based on below normal water years. It is recognized that extrapolation of this method to above normal flow years can not be supported conceptually; but this procedure may be the best available means of estimation. Depletion, calculated by this method, decreases in years of increasing river flow. The estimated depletion ultimately becomes zero when the annual discharge of Big Lost River below Mackay Dam (including Sharp Ditch) exceeds 344,000 acre-feet.

The frequency of occurrence of depletion volumes can be predicted by applying the depletion equation of Method 2 to historic river flow records. A depletion duration curve, produced in this manner, is presented in figure 11. According to figure 11, no depletion occurs in about 4 percent of the years, and, in contrast, 18 percent of the time depletion estimated by this method would be in excess of 20,000 acre-feet per year.

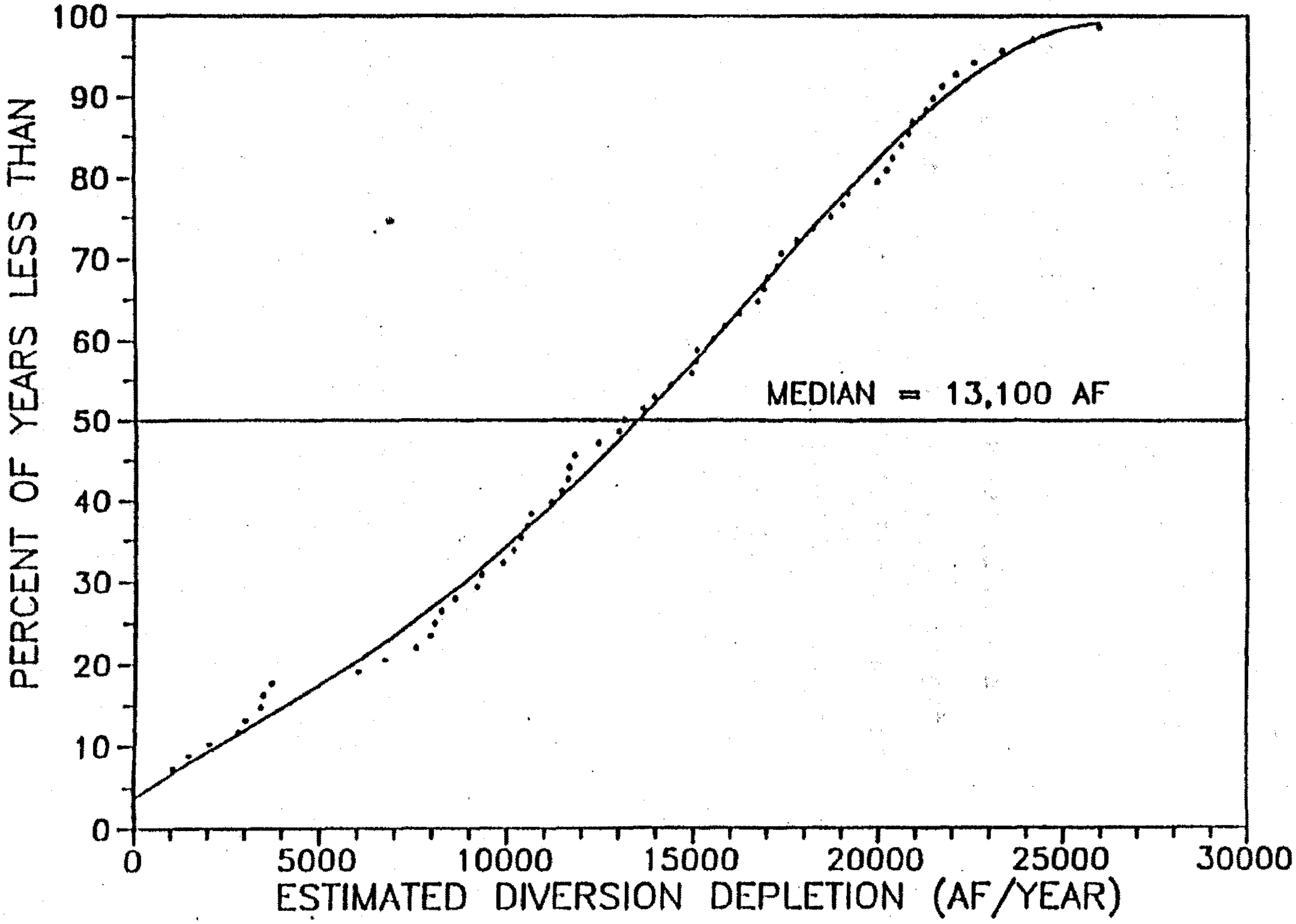


Figure 11. Duration Curve of Estimated Annual Diversion Depletion.

ESTIMATION OF IRRIGATION PUMPAGE

Annual ground-water pumpage from the Big Lost River Valley below Antelope Creek has been estimated for the period of 1984 through 1990 (table 2). The annual pumpage fluctuates in response to variations in annual surface-water supplies and crop demands. A scatter plot and linear regression line of annual ground-water pumpage below Antelope Creek against river flow below Mackay (including Sharp Ditch) is presented in figure 12. The corresponding regression equation is:

$$\text{PUMPAGE} = 61{,}200 - 0.1284 \times \text{FLOW} \qquad (r^2 = 0.88)$$

where

PUMPAGE = annual pumpage in acre-feet, and

FLOW = annual discharge below Mackay Dam, including Sharp Ditch in acre-feet.

Table 2. Annual Pumpage Below Antelope Creek.

Calendar Year	Pumpage (af)
1984	8,300
1985	27,500
1986	17,300
1987	28,700
1988	44,500
1989	48,600
1990	43,800

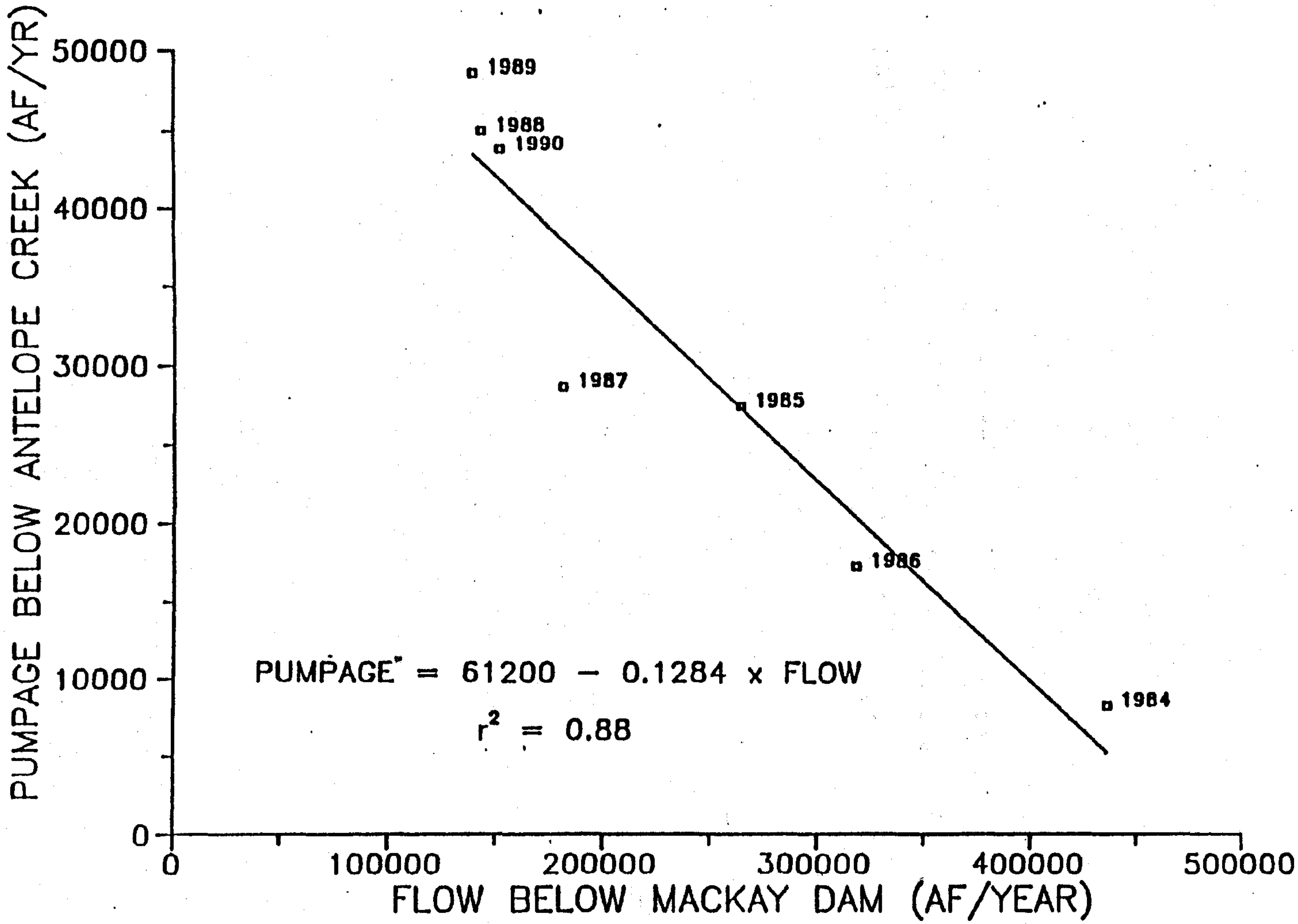


Figure 12. Linear Regression of Annual Pumpage Below Antelope Creek to Flow Below Mackay Dam.

Many irrigation wells in Big Lost River valley are located above the point where Antelope Creek is tributary to Big Lost River and therefore, are not included in the values of table 2. Approximately 700 out of a total of 1000 cfs of claimed ground-water rights in the valley are located below the junction of the two streams (Idaho Department of Water Resources, unpublished map). Total annual pumpage in the valley was estimated by assuming that the relative pumpage in an area is proportional to the claimed ground-water rights. Pumpage below Antelope Creek was, therefore multiplied by 1.428 (1000 cfs divided by 700 cfs) to estimate total pumpage. The multiplier was applied to the developed regression equation expressing the relationship between annual pumpage and flow below Mackay Dam to generate the following expression:

TOTAL PUMPAGE = 87400 - 0.1834 x FLOW

where

TOTAL PUMPAGE = Annual pumpage from the entire Big Lost River valley, in acre-feet, and

FLOW = annual discharge below Mackay Dam, including Sharp Ditch in acre-feet.

Pumpage estimates presented in table 2 span a period of only 7 years, and probably do not represent the long-term normal pumpage that would occur in the absence of further ground-water development. Long-term pumping estimates, at the current stage of well development, were determined by application of the regression equation relating total valley pumpage to river flows below Mackay Dam. Annual discharges below Mackay Dam, for the 1923 through 1990 period, were substituted into the equation to estimate the long-term variability of pumpage. The resulting estimates were used to develop the pumpage-duration curve shown in figure 13. Normal annual pumpage in the Big Lost River valley, as estimated by this procedure, is 47,000 acre-feet. The estimated valley pumpage experienced in 1989 of 69,400 acre-feet would occur only a few times every 100 years.

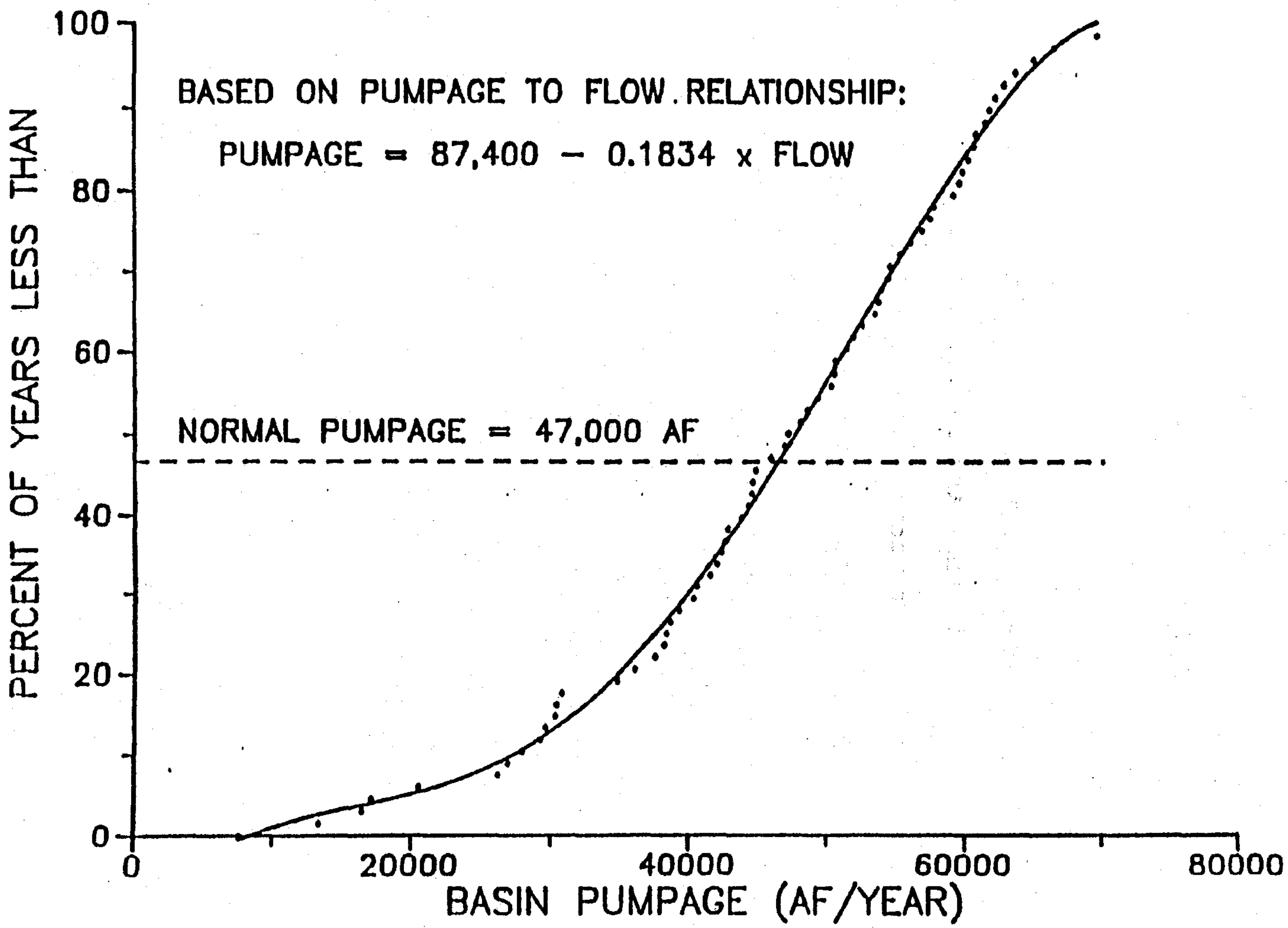


Figure 13. Duration Curve of Estimated Annual Pumpage.

DISTRIBUTION AND EXPANSION OF IRRIGATED LAND

Water is lost from Big Lost River valley by four mechanisms: 1) river discharge to the plain, 2) ground-water underflow to the plain, 3) irrigation conveyance outside of the basin, and 4) by evaporation and transpiration. Ground-water pumping, and the accompanying conversion to sprinkler irrigation, has contributed to an expansion of irrigated lands and resulted in a sizable increase in the fourth component listed above, relating to crop consumptive use. About 80 percent of the water applied by sprinklers is lost through crop consumptive use, the remaining 20 percent returns to the ground-water as deep percolation (C.E. Brockway, personal communication). Transporting water out of the basin for irrigation on the Snake River plain results in loss of the entire application, as the deep percolation from the irrigated areas will not return to the ground-water system of the Big Lost River valley.

The land area irrigated by the water resources of Big Lost River basin has significantly expanded since about 1970. The change in irrigated acreage in Butte County is shown in figure 14. The majority of irrigated land in Butte County is in, or receives water from, the Big Lost River basin. The graph shows that irrigated acreage in Butte County, and probably Big Lost River valley, nearly doubled

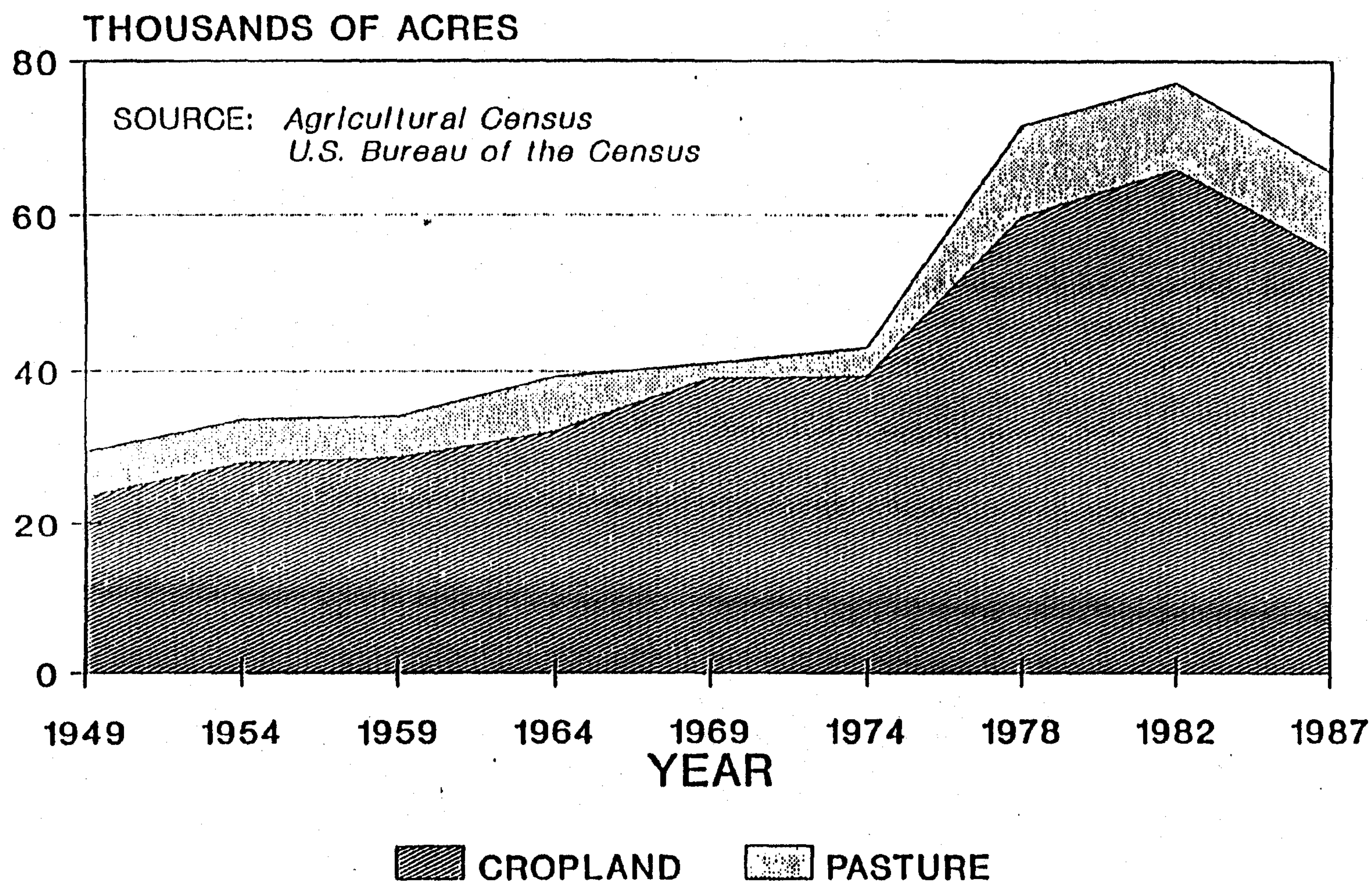


Figure 14. Historic Changes in Butte County Irrigated Acreage.

between 1974 and 1982. The acreage expanded from about 43,000 acres to about 77,000 acres in 1982. Much of this expansion is thought to have occurred with surface and ground water from the Big Lost River valley. An expansion of 34,000 acres in Butte County results in additional water consumption of about 41,000 acre-feet, assuming an irrigation requirement of 1.2 feet per year (Crosthwaite and others, 1970). Irrigation requirements calculated from the methods of Allen and Brockway (1983) are about 2.0 feet per year, implying that the additional water consumption may be as large as 68,000 acre-feet per year. Figure 14 is based on past records of the U.S. Census Bureau, Agricultural Census which determines irrigated acreage every four or five years.

PUMPAGE IN PERSPECTIVE

Ground-water pumping depletes the ground-water resource of the valley by an amount equal to the crop consumptive use on the irrigated lands, unless the pumped water is applied outside of the valley. Water applied in excess of the crop consumptive use returns to the ground-water reservoir as deep percolation. Approximately 20 percent of the water applied by sprinkler irrigation returns to the aquifer as deep percolation (C.E. Brockway, personal communication). The total consumptive use resulting from the normal year pumpage of 47,000 acre-feet is, therefore, estimated to be about 40,000 acre-feet, depending upon the amount of pumpage exported out of the basin.

Consumptive use losses associated with ground-water pumping are relatively small compared with basin underflow in a normal year. Estimated losses resulting from irrigation pumping of 40,000 acre-feet per year represent about 13 percent of the basin underflow estimated by Crosthwaite and others (1970) for the period before 1970. On a long-term basis, more water is lost by surface discharge onto the Snake River Plain than is consumptively used by irrigation pumpers.

The estimated pumpage in a normal year compares reasonably well with increased crop demands resulting from expanded acreage shown in figure 14. The estimated normal pumpage of 47,000 acre-feet is sufficient to irrigate between 19,000 and 31,000 acres, assuming 80 percent application efficiency and 1.2 to 2.0 feet of irrigation demand. Conveyance losses decrease that acreage somewhat more. The recent increase in irrigated acreage in Butte county is about 34,000 acres according to Agricultural Census statistics.

Depletions of surface water diversions estimated in the section on "Relationships Between Diversions and River Flow" are less than estimates of basin pumpage, as expected. Diversion depletion for the 1987 through 1990 water years averaged 29,600 acre-feet per year, according to the first method of depletion estimation. The pumpage during that period averaged 41,400 acre-feet per year, or about 1.4 times the estimated depletion.

A relationship between estimated diversion depletion and pumpage can also be developed by combining the depletion equation of Method 2:

$$\text{DEPLETION} = 36{,}300 - 0.1055 \times \text{FLOW},$$

with the adjusted pumpage regression equation representing pumpage in the entire valley:

$$\text{PUMPAGE} = 87{,}400 - 0.1834 \times \text{FLOW}.$$

Depletion, expressed as a function of pumpage, is therefore:

$$\text{DEPLETION} = 0.575 \times \text{PUMPAGE} - 14{,}000,$$

where

DEPLETION = annual depletion of diversions below Mackay Dam in acre-feet,

FLOW = annual flow of Big Lost River below Mackay Dam, including Sharp Ditch, in acre-feet, and

PUMPAGE = annual pumpage within the entire basin, in acre-feet.

According to the above equation, the ratio of diversion depletion to pumpage decreases in years of low pumpage. When surface water supplies are such that less than 14,000 acre-feet of ground-water are pumped, then depletion is estimated to be zero. As pumpage volumes increase the ratio of estimated depletion to pumpage increases. In the normal year, pumpage is 47,000 acre-feet, and estimated depletion (by Method 2) is 13,100 acre-feet, resulting in a ratio of depletion to pumpage of 0.28.

Ground-water pumping is only partially responsible for the depletion of river flow and irrigation diversions. Expansion of surface water irrigation rights to larger land areas also contributes to the problem by increasing crop consumptive use and generating less ground-water recharge. The actual expansion of acres irrigated from surface and ground-water of Big Lost River basin is presently unknown, making it impossible to proportion additional water use between surface and ground-water sources.

ALTERNATIVE MANAGEMENT OPTIONS

Increased consumptive water use in Big Lost River valley has impacted the availability of water for senior surface water right holders. We believe that the increased consumptive water use has resulted from expanded acreage irrigated with both surface and ground-water. Possible alternatives for regulation and mitigation or compensation are described in this section; however, responsibility for recommendation of a specific alternative rests with the Idaho Department of Water Resources.

Steps associated with the development and implementation of possible alternative management strategies are illustrated in the flow chart presented in figure 15. A number of steps, and/or decisions are shown on the flow chart. The first two steps of this process are: 1) The Department must determine the extent of areas in which ground-water pumping and increased consumptive water use by surface water expansions have impacted flows of the Big Lost River, and 2) a means of proportioning impacts between ground-water pumping and expansion of surface water acreage needs to be developed.

We recommend that the impacting area include the entire alluvial deposits of the valley (single basin concept). The southern boundary of the impact area should coincide with the location of the steep water table decline into the Snake Plain aquifer, based on long-term average water levels. The

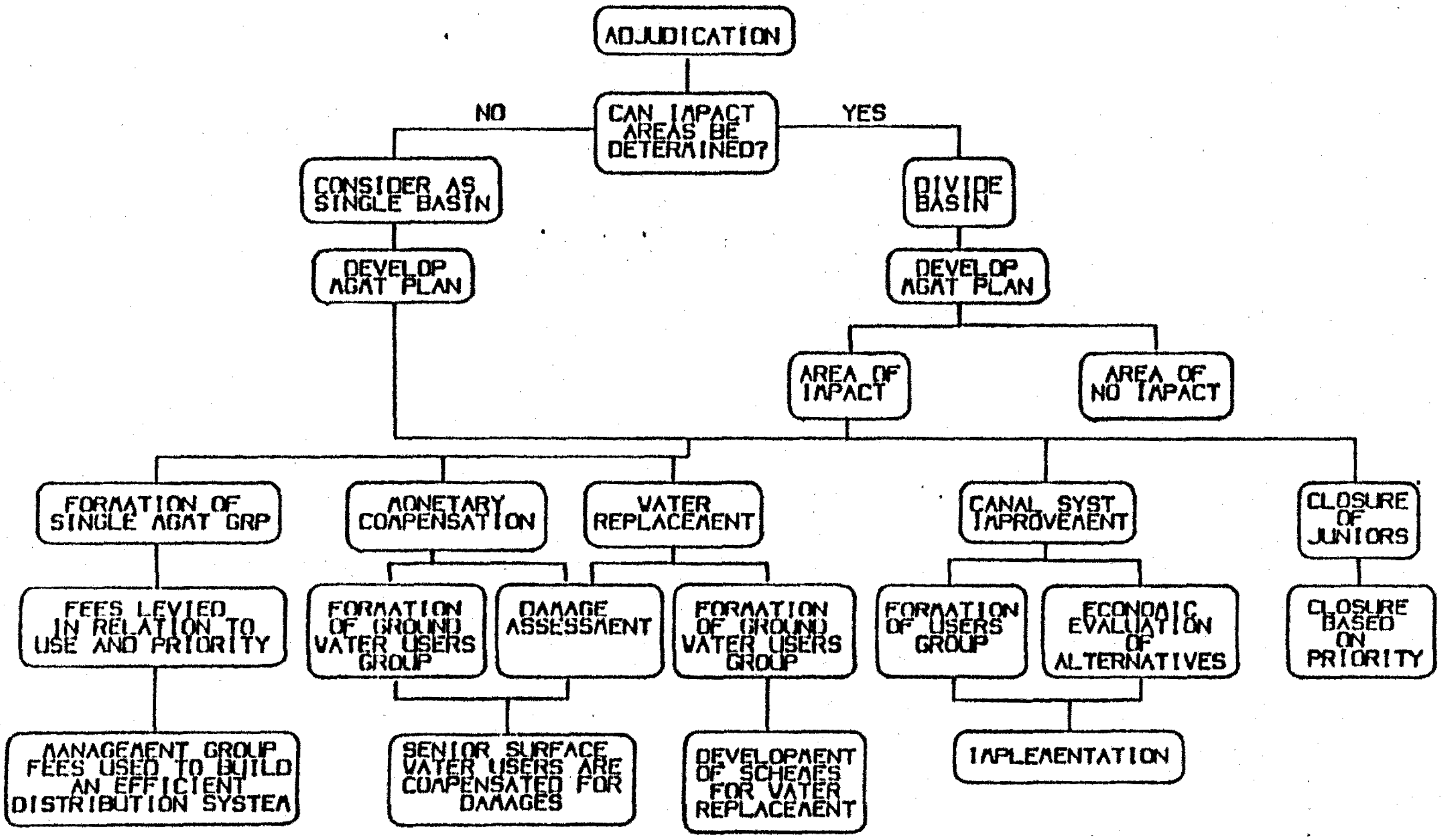


Figure 15. Diagram Illustrating Alternative Management Options.

basin may be further subdivided if the single basin concept is unacceptable to those involved. Subdivision into multiple units should be based on a detailed hydrologic analysis of the hydraulic connection of the river and the propagation of pumping and recharge effects.

A detailed management plan must be developed, regardless of whether the basin is considered as a single unit or multiple units. The plan should address whether compensation or mitigation are due to senior surface water irrigators, the type and degree of mitigation or compensation, and the structure of the organizational group responsible. The plan should be cooperatively prepared or reviewed by all parties involved.

If compensation or mitigation are to be awarded, then criteria must be established to determine liability. We believe that depletion is most directly associated with additional consumptive water use in recent decades, from both surface and ground water sources. Thus, the logical, although not necessarily legal, basis for assessing responsibility is in proportion to the amount of expanded irrigated acreage.

Five alternative courses of action are outlined on the flow chart (figure 15). They include: 1) Conjunctive management of surface and ground-water resources by a single management entity, 2) monetary compensation of impacted senior surface-water users by the liable parties, 3) water replacement for impacted senior surface water users by pumping into surface channels with financial support based on liability, 4) improvement of the surface irrigation system to improve conveyance efficiency, and 5) closure of junior users in proportion to the estimated impacts. We believe that the effectiveness and efficiency of the first four alternatives is dependent on the degree of cooperation that is achieved among the water users of the basin.

We conclude that cooperative water management by surface and ground-water users is the best solution and would result in the most efficient use of the water resources of the basin. Development of a cooperative management unit requires that surface and ground-water users generally agree on the impacts of pumping and acreage expansions, and the remedial measures needed. In such a situation, those deemed responsible would be assessed fees in proportion to their perceived impact, and generated revenues would be spent according to the consensus of the managing unit. This alternative implies that the water users of the Big Lost River would be responsible for managing their own resource in a fair and equitable manner.

Monetary compensation by an organization of surface and ground water users deemed liable for depleted surface flows may be the most achievable of the alternatives. Those implicated as impacting surface flows would need to form a self-funding unit with the purpose of compensating senior surface water users for damages. We recommend that the degree of compensation or mitigation be consistent with the diversion depletion estimated in this report.

Water replacement, funded by a similar organization, would rely on new wells to supplement the river flows, to a degree determined by depletion estimation procedures outlined in this report. These wells would be constructed and operated with funding provided by the liable parties, in proportion to their ground-water pumpage and surface water acreage expansion.

Several methods are available to improve the water supply of surface water users without additional pumping. These primarily deal with canal modification and lining, and the construction of additional surface water reservoirs. The economic feasibility of these measures should be evaluated relative to monetary compensation and water replacement schemes. Effective canal lining could improve the separation of the surface and ground-water resources, and reduce the question of interference. Both surface and ground-water users should share in the costs of system improvements.

We believe that the most economically unacceptable of the alternatives is the regulation of all rights in the valley on the basis of the priority. This alternative would result in closure of many or all of the irrigation wells, and drastically reduce agricultural production of the valley. Although this may be a legal alternative, it would be highly undesirable to nearly all parties, and is not recommended.

In summary, we recommend that the highest possible degree of cooperation be developed among the involved parties. In this way, the resource largely will be managed by its users. All ground-water pumpers (irrigation wells) and those with expanded surface water irrigated acreage should assume responsibility for depleted flows of senior surface water irrigators, in an amount consistent with the depletion estimates of this report. The management plan should involve all interested parties.

CONCLUSIONS AND RECOMMENDATIONS

Several conclusions are apparent from this investigation. They include:

1. Flow of the Big Lost river is affected by weather and by long-term changes in the amount of consumptive water use in the valley.

2. The consumptive water use has increased substantially in the last few decades due to an extension to full season irrigation and an expansion of the irrigated acreage.

3. Ground-water pumping has made the expansion of irrigated acreage possible, and provides a sizable proportion of the water applied on the expanded acreage.

4. Ground-water pumping is largely used to supplement surface-water diversions, and ground-water pumping increases in years of low surface water supply.

5. Ground-water recharge from surface water irrigation has diminished due to application over larger acreage and conversion to more efficient sprinkler application methods.

6. Diminished recharge from surface water irrigation and increased ground-water withdrawals, together have caused a reduction in flow of Big Lost River and consequently have depleted the supplies of surface water irrigators.

7. Diversion records indicate that surface water diversions for irrigation have decreased in recent years. The magnitude of the depletion varies with the water year.

8. The reliability of the diversion records, and consequently of the depletion estimates, is uncertain. Diversion depletion estimation procedures of this report, however, are probably the best available. With the available information it was not possible to proportion the amount of diversion depletion into components resulting from ground-water pumping and that caused by expansion of surface-water irrigated acreage.

9. The impact attributable to ground-water pumping or expansion of surface water irrigated area varies with the year and the proportion of the total irrigation water derived from pumping. Pumping is reduced in years of plentiful surface water supply, however the recharge from surface water is probably diminished in those years (relative to pre-1960), due to application over larger cropped areas.

Recommendations for managing the water resources of the basin, and for future investigation include:

1. A cohesive organization of all water users in the basin could greatly contribute to development of water management strategies, and improve the effectiveness and efficiency of implementation of the selected strategies.

2. Relationships developed in this report provide a method that may be used for determining the magnitude of mitigation to damaged surface water users.

3. Further investigation into changes in the irrigation practices and areas of the basin should be initiated. This research would help refine estimates of depletion and would further the understanding of the individual impacts of ground-water pumping and expansion of areas irrigated with surface water.

4. Irrigation pumpage and diversions should be closely monitored in future years to refine the understanding of pumping impacts on diversions.

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