# Colorado WATER RESOURCES

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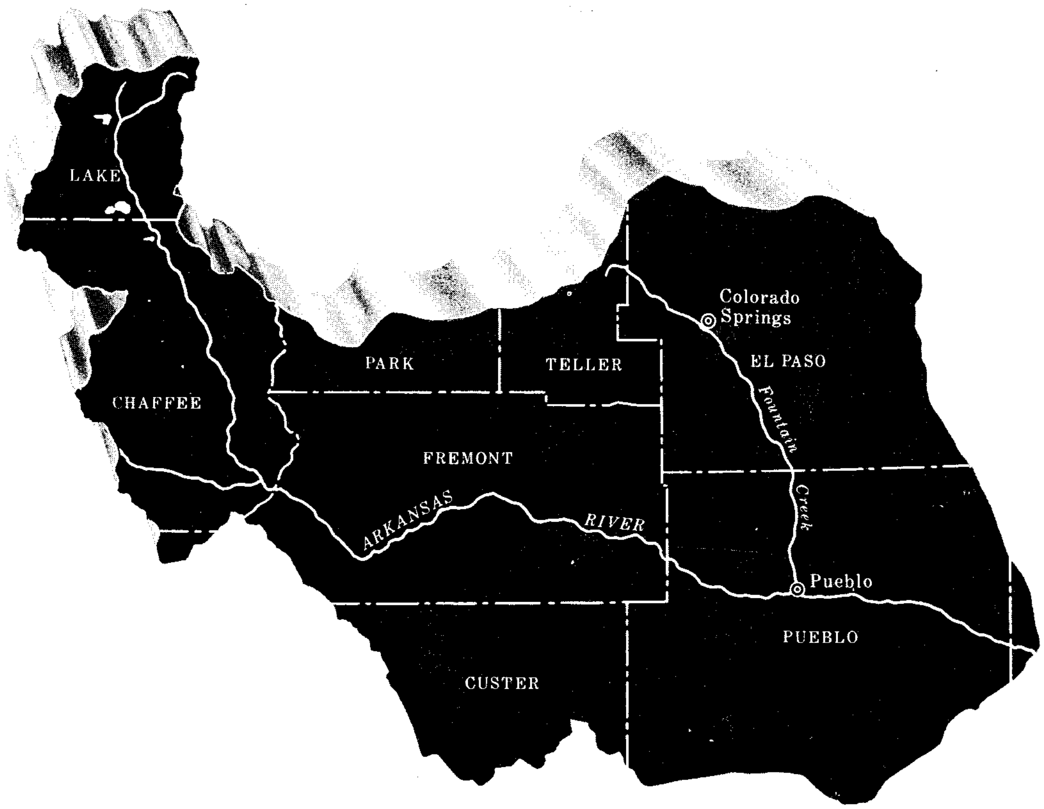


TRANSIT LOSSES AND TRAVEL TIMES FOR RESERVOIR RELEASES, UPPER ARKANSAS RIVER BASIN, COLORADO

1973

STATE OF COLORADO
John D. Vanderhoof, Governor

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COLORADO WATER RESOURCES
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# TRANSIT LOSSES AND TRAVEL TIMES FOR RESERVOIR RELEASES, UPPER ARKANSAS RIVER BASIN, COLORADO

*By* Russell K. Livingston

*Prepared by the*
*U.S. GEOLOGICAL SURVEY*
*in cooperation with the*
*COLORADO DIVISION OF WATER RESOURCES, OFFICE OF THE STATE ENGINEER*
*and the*
*SOUTHEASTERN COLORADO WATER CONSERVANCY DISTRICT*

COLORADO WATER CONSERVATION BOARD
1845 Sherman Street
Denver, Colorado 80203

*1973*

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# TRANSIT LOSSES AND TRAVEL TIMES FOR RESERVOIR RELEASES, UPPER ARKANSAS RIVER BASIN, COLORADO

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## ABSTRACT

Factors influencing reservoir releases were analyzed for the upper reach of the Arkansas River in Colorado.

The time of travel of releases from Twin Lakes Reservoir to Colorado Canal, a distance of 175 miles, ranges from 29 to 69 hours depending on the antecedent flow of the Arkansas River. Travel time of releases from Turquoise Lake is 4½ hours more and travel time of releases from Clear Creek Reservoir is 1½ hours less than for the Twin Lakes Reservoir to Colorado Canal reach.

At the Colorado Canal, the streamflow hydrographs resulting from upstream reservoir releases are modified by channel and bank storage, inadvertent diversions, and evapotranspiration. During an average reservoir release of about 450 cubic feet per second for about 12 days, the released water arriving at the Colorado Canal is reduced by about 7 percent due to bank storage, by about 8 percent due to inadvertent diversions, and by about 1 percent due to evaporation. All release water in channel storage arrives at the Colorado Canal headgate during the release recession soon enough to be diverted and does not cause a loss. Transpiration losses due to bank storage are assumed to be negligible. This total average *transportation loss* of 16 percent can vary from about 6 to 28 percent due to the antecedent river conditions, the amount and duration of the reservoir release, and the time of year the release occurs.


## INTRODUCTION

As a result of the nation's rapidly growing population, increasing use of water for industrial and agricultural purposes, and the legal demands of interstate water compacts, efficient water utilization is becoming increasingly important. This situation has led to a need for more precise information with regard to the administration and management of water.

Colorado has felt a particular need to strengthen its water policies. Interstate compacts have placed demanding requirements on the water crossing Colorado's boundaries. The development of irrigation and growth of metropolitan areas east of the Continental Divide have further complicated Colorado's water problems.

In an attempt to solve some of these problems, many water projects have been constructed in Colorado to provide storage for better distribution of the annual water supply. Some projects also enhance the supply within a watershed with the transbasin or transmountain diversion of water. The Fryingpan-Arkansas Project will bring water from headwater tributaries of the Fryingpan River in the Upper Colorado River Basin into tributaries of the Arkansas River. This water will be stored in nearby reservoirs, used for hydroelectric power generation, and then transported more than 170 miles in the Arkansas River to fulfill irrigation and municipal needs downstream. The design and operation of such water development plans greatly influence the economic and hydrologic success of the project.

## Purpose and Scope

In July of 1970, the U.S. Geological Survey, in cooperation with the Colorado Division of Water Resources, Office of the State Engineer, and the Southeastern Colorado Water Conservancy District, began a study to determine transportation losses along the Arkansas River resulting from deliveries of stored water to downstream water users, and to determine time of travel of reservoir releases from the reservoir to the point of delivery. This report summarizes the results of that study.

The study concentrated on a 175-mile reach of the upper Arkansas River valley from Twin Lakes Reservoir near Granite, Colo., to the Colorado Canal headgate near Avondale, Colo. (fig. 1). The study consisted of analyzing historical records of reservoir releases, Arkansas River streamflow, and ditch diversions; of making detailed measurements of streamflow and water-table changes before and during reservoir releases; and of gathering weather and river-water temperature data.

## Previous Investigations

Shortly after completion of the Twin Lakes Tunnel project in the early 1930's, several studies were made by State Engineer M. C. Hinderlider (Colorado State Plan. Comm. and others, 1939) to determine transportation losses of reservoir releases down the Arkansas River. As the result of these studies, a policy was adopted charging releases a loss of 0.07 percent per mile of river. For example, if the release is 100 $ft^3/s$ (cubic feet per second), the loss along the 175 miles of river between Twin Lakes and the Colorado Canal headgate would be 12.2 $ft^3/s$.

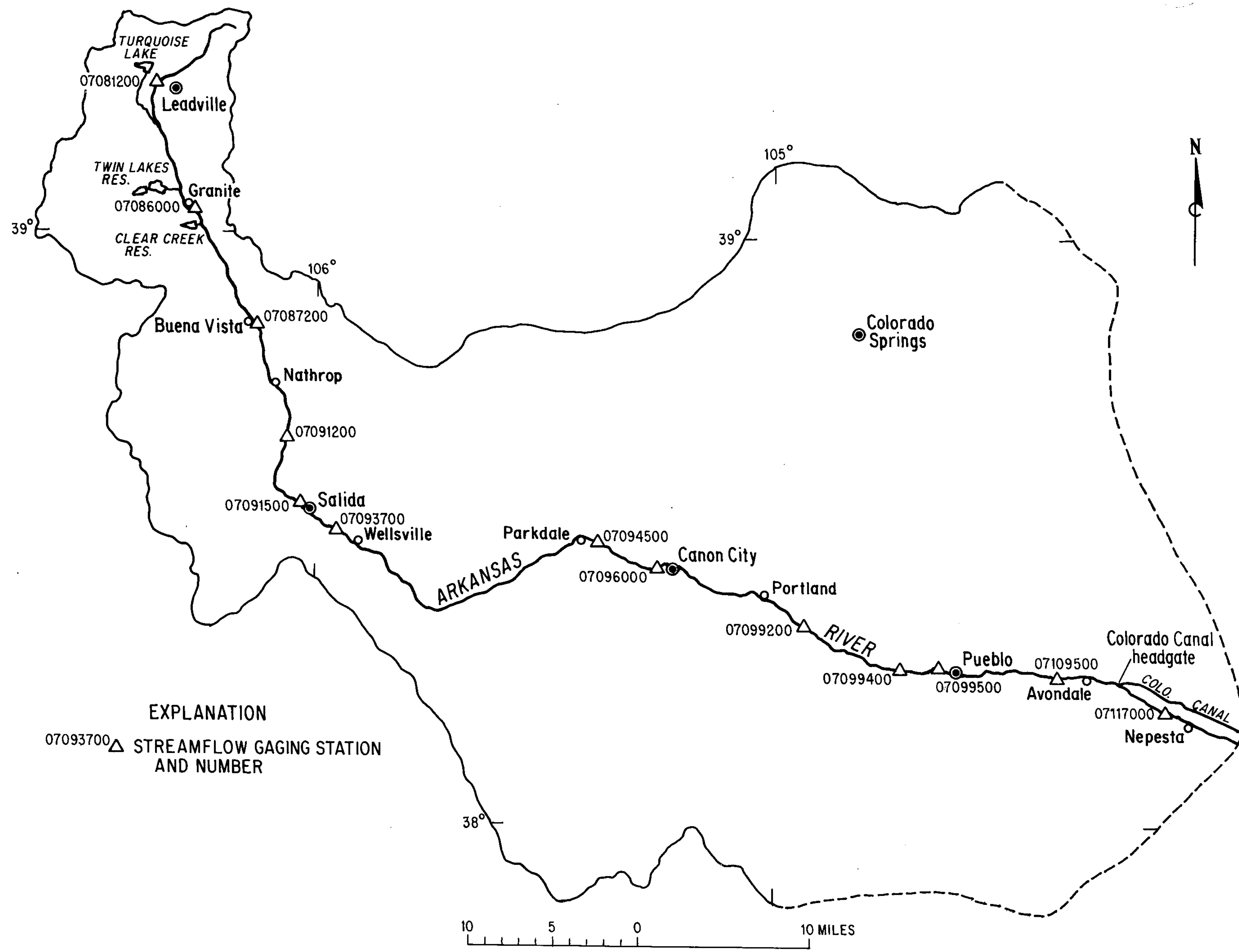


Figure 1.--Index map of upper Arkansas River basin.

Thus, the canal could divert only 87.8 $ft^3/s$. This 12-percent loss has been charged against reservoir releases to the Colorado Canal since that time.

The problem of transportation loss to the Colorado Canal was again studied by Lacey (1941). During the course of his investigations, every reasonable control over the river and the diversions was exercised. After studying in elaborate detail each of the seven reservoir releases made in 1939-40, Lacey concludes:

> "In my opinion, exact determinations as to loss in transit to the reservoir head in progression are impossible because of the many influencing factors encountered which are beyond control. There are too many variables present in the situation, which tend to obscure the graphic record and make objective conclusions difficult."

In the final analysis, Lacey could not justify changing the 12-percent loss rate.

Lacey (1941) also noted travel time during his studies, but because the seven reservoir releases were all made during periods with similar antecedent river conditions, the results indicated similar travel times. As a result, these determinations were not valid for different antecedent flow conditions.

Recently, Wright Water Engineers (1970) did a preliminary study of travel time and transit losses along the Arkansas River. Three categories of losses were studied: evaporation, bank storage, and "unauthorized diversions." The magnitude of these losses varied with the amount of the release and the natural river flow at Canon City. For typical reservoir releases, the losses as defined from their report are somewhat less than the 12-percent rate. Time of travel is also given in the report for releases from Twin Lakes, Turquoise Lake, and Clear Creek Reservoirs to several locations downstream, including the Colorado Canal headgate. The flow at Canon City and the amount of the reservoir release were used in determining travel time.

## Hydrologic Setting of the Upper Arkansas River

The upper Arkansas River is that portion of the Arkansas River that extends from the Continental Divide north of Leadville (elevation, 10,200 feet) downstream to the vicinity of Pueblo (elevation, 4,670 feet), a distance of about 170 river miles (fig. 1). Above Canon City, the river typically consists of pools and rapids. Although the river primarily flows through hardrock canyons in this reach, it also traverses a total of about 37 miles of alluvial deposits north of Salida, near Buena Vista, and south of Leadville. Land in these areas is widely used to grow hay, with flood-type irrigation commonly practiced. Below

Canon City, the river crosses alluvial deposits and is more tranquil in nature. Truck farming predominates on irrigated land just east of Canon City. Wheat, corn, hay, alfalfa, and sugar beets are also grown in this reach.

The natural streamflow of the upper Arkansas River results from snowmelt from the high mountain peaks bordering the basin, rainfall, and return flow from irrigated land. This flow, however, is supplemented by eight transmountain diversions including the new Charles H. Boustead Tunnel. Average flow in 1962-71 for the other seven diversions was 71,370 acre-feet per year. The Boustead Tunnel, which began diverting in 1972, is expected to bring an average of 69,200 acre-feet per year to the Arkansas River basin as part of the Fryingpan-Arkansas Project. Average flow at 13 current streamflow gaging stations on the mainstem Arkansas River is given in table 1.

Three reservoirs on tributaries of the upper Arkansas River--Turquoise Lake, Twin Lakes Reservoir, and Clear Creek Reservoir--store water for release during times of critical irrigation and industrial demand. The current combined usable storage of these reservoirs is 186,400 acre-feet. The Fryingpan-Arkansas Project will increase this storage by 363,700 acre-feet (including 234,000 acre-feet of storage in Pueblo Reservoir on the Arkansas River mainstem west of Pueblo). River hydrographs during a reservoir release are shown in figure 2.

As table 1 indicates, the upper Arkansas River basin has an area of over 5,000 square miles. It includes all of Lake, Chaffee, Fremont, and Custer Counties, and parts of Saguache, Park, Teller, El Paso, and Pueblo Counties. Precipitation in the basin ranges from less than 10 to more than 40 inches per year, generally increasing with elevation. On an annual basis, and assuming no change in storage, about 86 percent (4 million acre-feet) of the water entering the basin is consumed by evapotranspiration and about 14 percent leaves the basin as surface- and ground-water outflow (P. A. Emery, written commun., 1972).

## TRAVEL TIME OF RESERVOIR RELEASES

Records of 51 reservoir releases made during the period 1939-71 were analyzed to show the relation of release travel time to river flow. Figure 3 shows this relationship. It indicates that time of travel of reservoir releases varies from 30 to 70 hours depending on the antecedent river flow, the travel time being longer for lower river flows.

The time scale shows the number of hours elapsed between the release from Twin Lakes Reservoir and the arrival at the Colorado Canal headgates. The time of release was determined either directly from chart records for the outlet of Twin Lakes, or by subtracting about 1½ hours from the time the release arrived at the Granite gaging station (07086000). The time of arrival at the Colorado Canal headgates was

Table 1.--*Average discharge of the upper Arkansas River*

| Station number | Streamflow gaging station name | Drainage area (square miles) | Period of record | Average discharge (acre-feet per year) |
|---|---|---|---|---|
| 07081200 | Arkansas River near Leadville--- | 97.2 | 1968-71 | 54,700 |
| 07086000 | Arkansas River at Granite------- | 427 | 1910-71 | 261,500 |
| 07087200 | Arkansas River at Buena Vista--- | 611 | 1965-71 | 378,200 |
| 07091200 | Arkansas River near Nathrop----- | 1,060 | 1965-71 | 490,500 |
| 07091500 | Arkansas River at Salida-------- | 1,218 | 1898-99, 1901-03, 1909-71 | 457,200 |
| 07093700 | Arkansas River near Wellsville-- | 1,485 | 1962-71 | 517,300 |
| 07094500 | Arkansas River at Parkdale------ | 2,548 | 1946-55, 1965-71 | 572,400 |
| 07096000 | Arkansas River at Canon City---- | 3,117 | 1889-1971 | 523,100 |
| 07099200 | Arkansas River near Portland---- | 4,280 | 1965-71 | 591,200 |
| 07099400 | Arkansas River above Pueblo----- | 4,670 | 1966-71 | 465,900 |
| 07099500 | Arkansas River near Pueblo------ | 4,686 | 1886-87, 1894-1971 | 514,400 |
| 07109500 | Arkansas River near Avondale---- | 6,327 | 1940-51, 1966-71 | 631,000 |
| 07117000 | Arkansas River near Nepesta----- | 9,345 | 1913-71 | 497,000 |

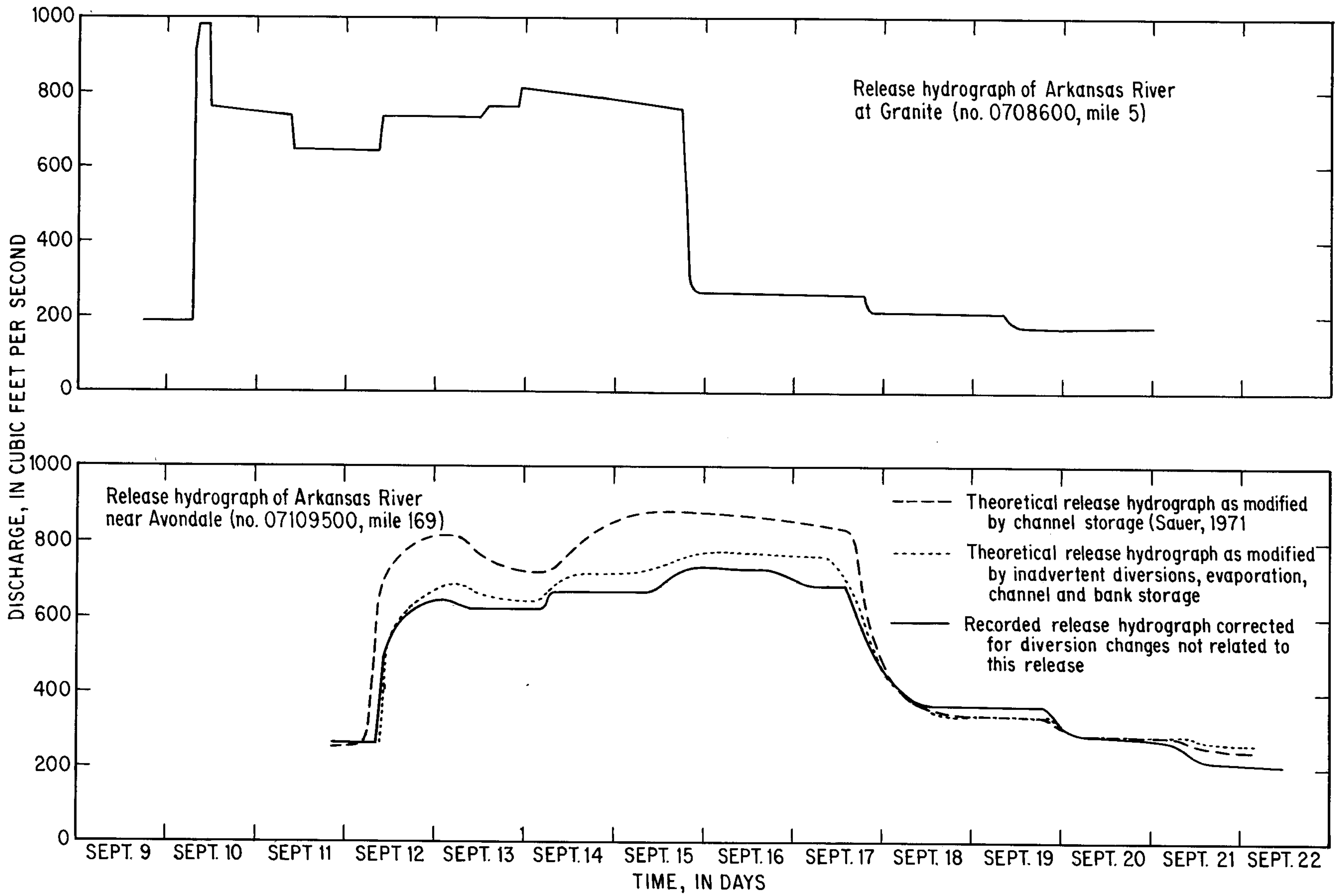


Figure 2.--Hydrographs of reservoir releases, September 10-19, 1951.

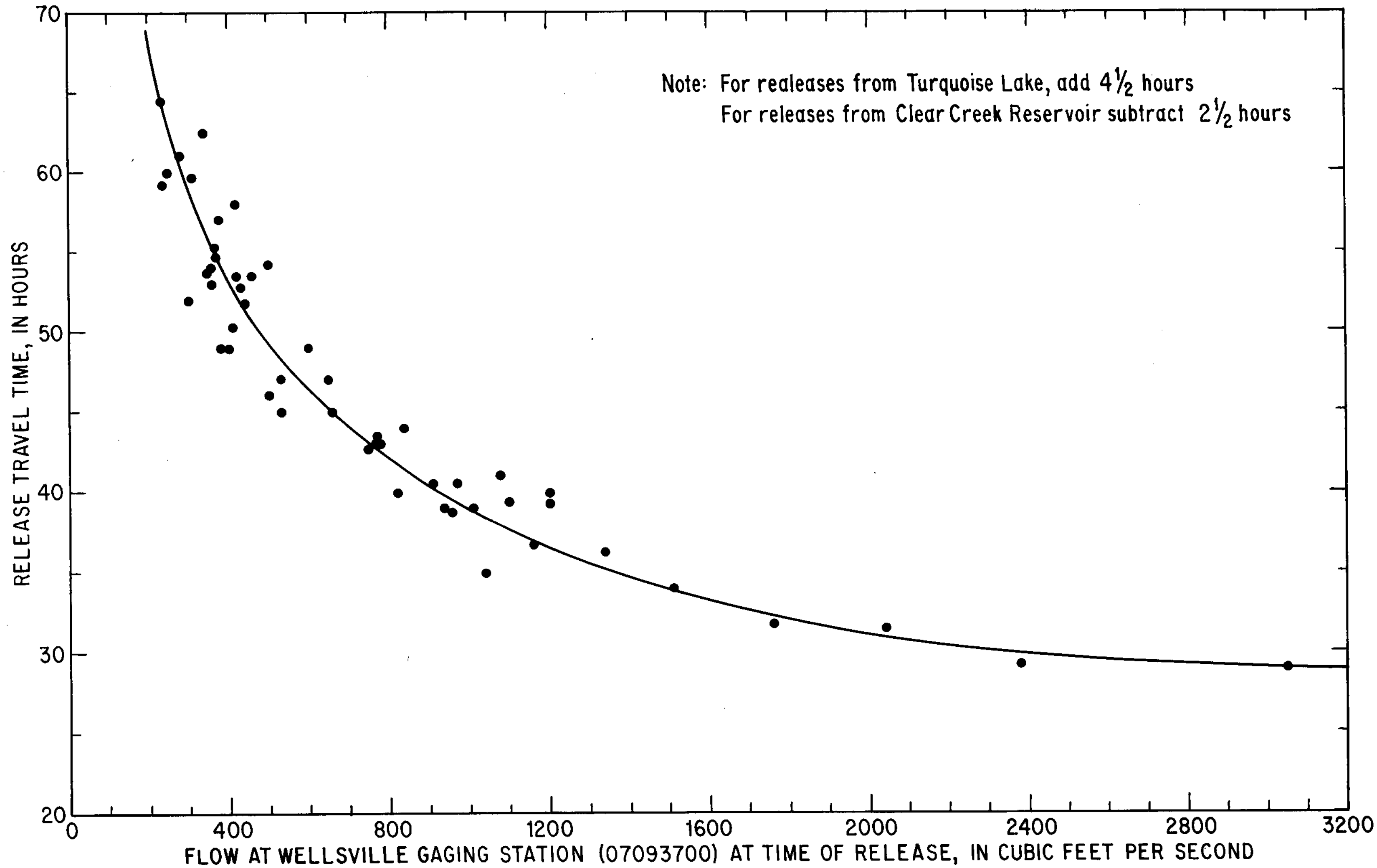


Figure 3.--Travel time of releases from Twin Lakes Reservoir to Colorado Canal headgate.

determined by noting the time when the first perceptible rise in stage occurred on the gage height charts for either the "near Pueblo" (07099500) or "Avondale" (07109500) gaging stations, and adding to this a computed time of travel from these stations to the canal headgates. This computed time of travel from these two stations to the canal headgates was based on field measurements of mean river velocity at various river discharges.

Figure 3 also notes that for releases from Turquoise Lake 4½ hours must be added, and for releases from Clear Creek Reservoir 2½ hours must be subtracted, to determine travel time to the Colorado Canal headgate. These figures are based on field observations, streamflow measurements, and gaging-station records.

The discharge scale on figure 3 shows the streamflow at the "near Wellsville" gaging station (07093700) immediately prior to the time of release. The discharge at this particular station was chosen as an index for the entire reach for the following reasons: (1) analysis of past records indicated the discharge at the "near Wellsville" station best approximates the average flow in the reach, (2) this gaging station is equipped with an instrument by which the stage can be determined by telephone, (3) the stage-discharge relationship is relatively stable, and (4) there are no diversions which bypass the station. The stage discharge relationship for this gaging station is given in table 2.

## SOURCES OF TRANSPORTATION LOSS

Colorado water law allows owners of reservoirs to use natural streams to transport their water provided allowances are made for transit losses (Radosevich and Hamburg, 1971). Transportation loss, or transit loss, refers to released water that cannot be utilized at the downstream delivery point. The transit loss currently being charged for the Arkansas River is 0.07 percent of the reservoir release per mile of river.

Reservoir releases down the upper Arkansas River typically range from 300 to 500 $ft^3/s$ for a duration of from 6 to 14 days. During these periods, the release water can temporarily be retained in channel and bank storage, inadvertently diverted, or evapotranspired. Only evapotranspiration removes water from the stream system and, therefore, can be considered a true loss. Channel storage, bank storage, and inadvertent diversions may or may not be other sources of transportation loss.

During the past 2 years, a careful study has been made of channel and bank storage, inadvertent diversions, and evapotranspiration, and their effects on reservoir releases from Twin Lakes Reservoir to the Colorado Canal headgate. The following discussions report the findings of this study.

Table 2.--*Stage-discharge relationship for the Arkansas River near Wellsville gaging station (07093700)*

| 07093700 Arkansas River near Wellsville, Colo. Rating No. 3 dated May 4, 1966 | | | | | |
|---|---|---|---|---|---|
| Stage (feet) | Discharge ($ft^3/s$) | Stage (feet) | Discharge ($ft^3/s$) | Stage (feet) | Discharge ($ft^3/s$) |
| 2.40 | 118 | 4.10 | 700 | 5.80 | 2,170 |
| 2.50 | 132 | 4.20 | 760 | 5.90 | 2,270 |
| 2.60 | 150 | 4.30 | 830 | 6.00 | 2,380 |
| 2.70 | 170 | 4.40 | 905 | 6.10 | 2,500 |
| 2.80 | 195 | 4.50 | 980 | 6.20 | 2,630 |
| 2.90 | 770 | 4.60 | 1,060 | 6.30 | 2,760 |
| 3.00 | 250 | 4.70 | 1,145 | 6.40 | 2,900 |
| 3.10 | 285 | 4.80 | 1,230 | 6.50 | 3,040 |
| 3.20 | 320 | 4.90 | 1,320 | 6.60 | 3,190 |
| 3.30 | 360 | 5.00 | 1,410 | 6.70 | 3,340 |
| 3.40 | 400 | 5.10 | 1,500 | 6.80 | 3,490 |
| 3.50 | 440 | 5.20 | 1,590 | 6.90 | 3,640 |
| 3.60 | 480 | 5.30 | 1,680 | 7.00 | 3,800 |
| 3.70 | 520 | 5.40 | 1,770 | 7.10 | 3,960 |
| 3.80 | 560 | 5.50 | 1,870 | 7.20 | 4,120 |
| 3.90 | 605 | 5.60 | 1,970 | 7.30 | 4,290 |
| 4.00 | 650 | 5.70 | 2,070 | 7.40 | 4,460 |

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## Channel Storage

Even if no losses or gains occur in a reach of channel, the shape of an upstream hydrograph will be modified downstream by the storage characteristics of the channel. The effect of channel storage can be determined by various routing methods. In a recent study, Sauer (1971) successfully used the unit-hydrograph technique to route releases from Toledo Bend Reservoir to three locations as far as 50 miles down the Sabine River on the Texas-Louisiana State line.

As part of the Sabine River study, a computer program was developed which routes reservoir releases by the unit-hydrograph technique. This program was used to determine the effects of channel storage along the Arkansas River from Granite to Avondale (fig. 2). The hydrographs at the Granite gaging station for eight actual reservoir releases were routed approximately 170 miles downstream by means of the program. The releases selected for study included a variety of release discharges and antecedent river conditions. The results of this analysis were used to define channel storage as a function of time. This relationship is shown in figure 4. Figure 4 shows that although the rate at which release water enters channel storage is initially high, it decreases rapidly with time and ceases in from 7 to 31 hours depending on the amount of the release. Figure 4 also gives a table which summarizes the average channel storage for selected time intervals.

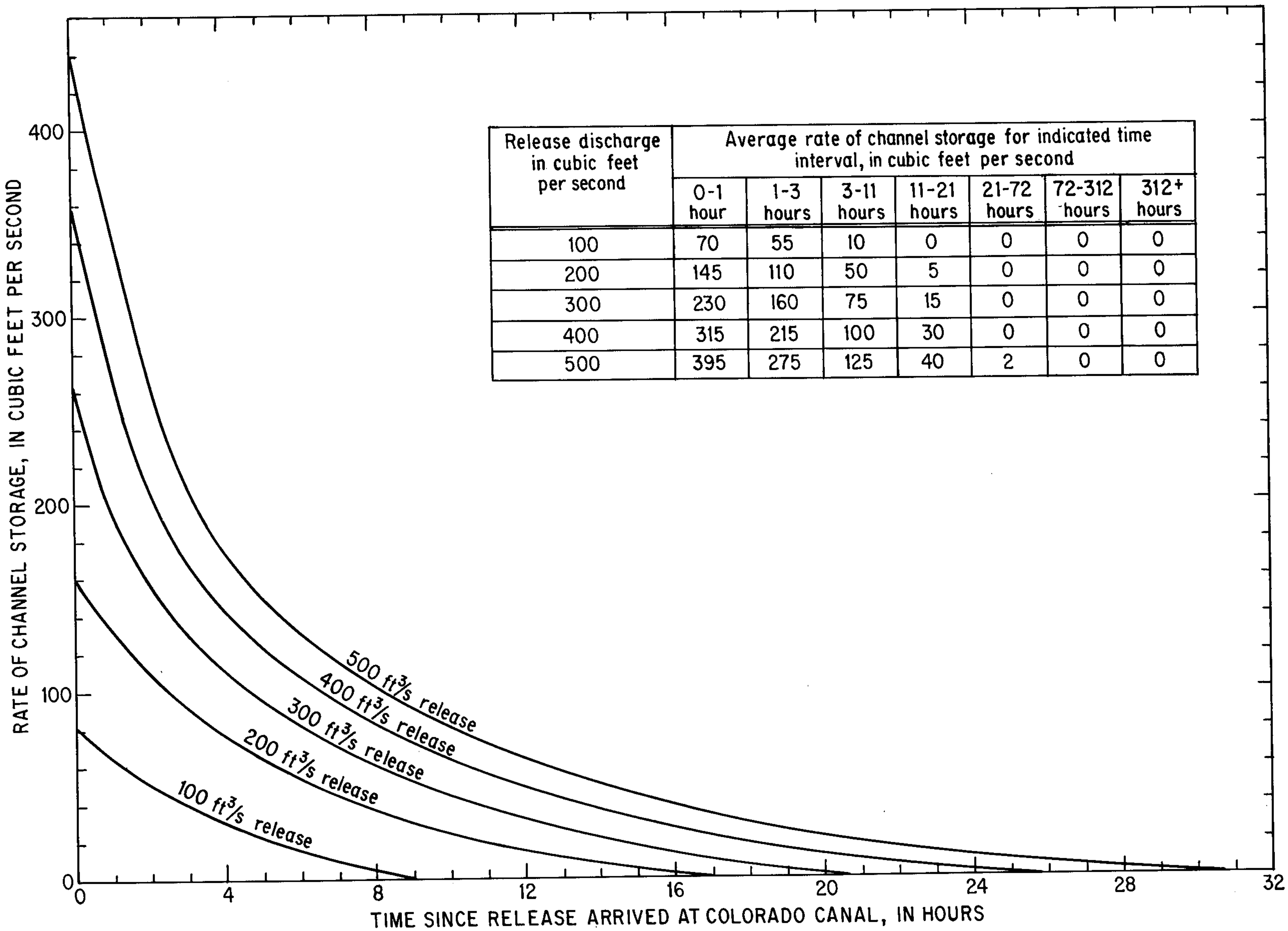
## Bank Storage

If the alluvium and river are hydraulically connected, an interchange of water is possible. For example, if the stage of a river increases, flow which normally occurs from the alluvium to the river may be reversed, and bank storage occurs.

Two approaches to define bank storage during reservoir releases were investigated. The first approach was to study streamflow gains and losses before and during a reservoir release. The second approach was to monitor head changes in observation wells near the river as a release passed.

### Gain-loss studies

During August 28-31, 1970, in the reach from Turquoise Lake to the Arkansas River at Nepesta gaging station, gain-loss investigations were conducted within 36 hours before and 24 hours after the passage of a 392-$ft^3$/s release to Colorado Canal. The study involved measurement of 235 inflows, 58 outflows, 15 miscellaneous mainstem sites, and 12 mainstem gaging stations. The flow at each mainstem gaging station was independently measured by two hydrographers to insure accurate determination of river flow. The same procedure was used during a second series of




| Release discharge in cubic feet per second | Average rate of channel storage for indicated time interval, in cubic feet per second | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0-1 hour | 1-3 hours | 3-11 hours | 11-21 hours | 21-72 hours | 72-312 hours | 312+ hours |
| 100 | 70 | 55 | 10 | 0 | 0 | 0 | 0 |
| 200 | 145 | 110 | 50 | 5 | 0 | 0 | 0 |
| 300 | 230 | 160 | 75 | 15 | 0 | 0 | 0 |
| 400 | 315 | 215 | 100 | 30 | 0 | 0 | 0 |
| 500 | 395 | 275 | 125 | 40 | 2 | 0 | 0 |

Figure 4.--Rate of channel storage for releases from Twin Lakes Reservoir to Colorado Canal.

intensive gain-loss investigations for a 473-ft$^3$/s release made August 21-24, 1972, for the reach between the Granite and Nepesta gaging stations. The results of these two gain-loss investigations are summarized in figure 5.

Because the flow of the Arkansas River has been progressively adjusted for all inflows and outflows, figure 5 represents the cumulative total effects with distance of the ground-water contribution to river flow. For example, figure 5 shows that river flow in the reach between the "near Wellsville" (07093700) and "at Parkdale" (07094500) gaging stations is consistently supplemented by ground water, but at a rate less than the reach between the "at Buena Vista" (07087200) and "near Nathrop" (07091200) gaging stations. Similarly, the Arkansas River between the "at Salida" (07091500) and "near Wellsville" (07093700) gaging stations loses water to the ground-water system. Bank storage was obtained by subtracting the channel storage from the total effects as shown in table 3.

The difficulty with this method is that large errors are possible due to the sensitivity of the stage-discharge relationships at the gaging stations, and any errors are accumulated through the reach. For these reasons, the bank storage can be determined only for particular points in time when actual flow measurements were made. Data derived by extrapolation are subject to considerable error.

## Observation well studies

During January 1972, 16 observation wells were installed at six sites along the Arkansas River in the vicinity of Salida, Colo. At each site two or three observation wells were placed at varying distances perpendicular to the river. The wells closest to the river were about 10 feet from the bank and consisted of 4-inch pipes with a 5-foot slotted section and instrumented with a float-driven digital recorder. The wells farthest from the river were about 120 feet from the river bank and, along with other intermediate wells, were of 1¼-inch galvanized pipe with sand point and not instrumented. Each site also had a staff gage in the river directly adjacent to the 4-inch well which established the datum to which the wells were leveled.

Response in all wells and in the river was repeatedly measured for several days before and after the 445-ft$^3$/s release of Arpil 6, 1972, passed the sites. For each site, the observation well hydrographs were used to determine the response of each well at selected times since the first release impulse reached the site. Using the responses, the rate of bank storage for the selected times and, hence, the average bank storage rate for the interval between the selected times, could be determined. The average response of all sites and an estimated storage coefficient, S, of 0.15 were used in the calculations. The average bank storage rates were express in cubic feet per second per mile for both sides of the river.

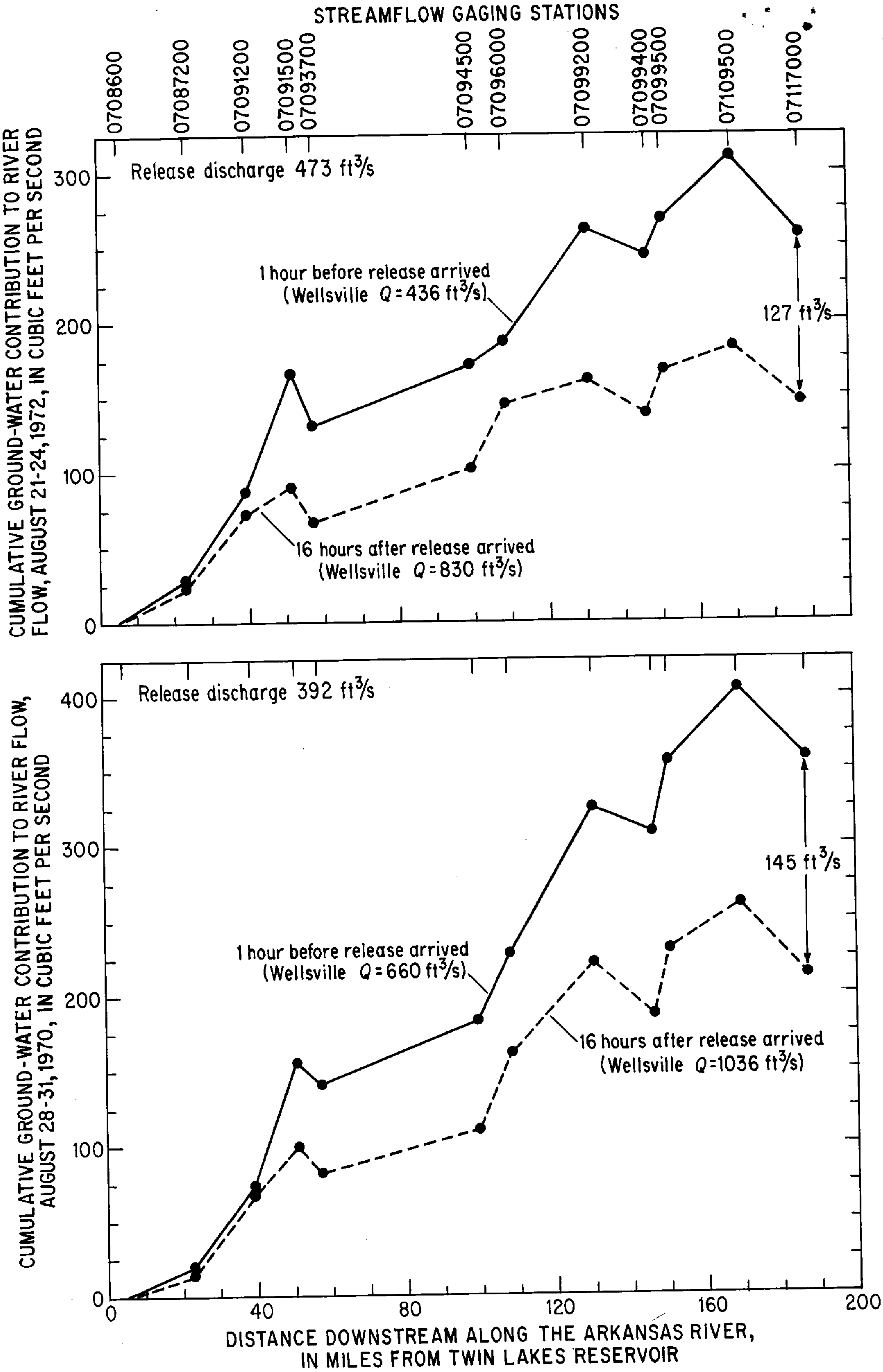



Figure 5.--Effect of reservoir releases on the ground-water component of the flow in the upper Arkansas River.

Table 3.--*Bank storage from gain-loss relationships 16 hours after arrival of release, Granite to Colorado Canal*

| Date of reservoir release | Release discharge (in cubic feet per second) | Initial flow at Wellsville gaging station (in cubic feet per second) | Cumulative effect of bank and channel storage at Avondale gaging station after 16 hours from figure 5 (in cubic feet per second) | Effect of channel storage at 16 hours from figure 4 (in cubic feet per second) | Bank storage effect at 16 hours (in cubic feet per second) |
|---|---|---|---|---|---|
| August 29, 1970 | 392 | 660 | 145 | 29 | 116 |
| August 22, 1972 | 473 | 436 | 127 | 37 | 90 |

A theoretical bank storage curve was developed from an equation given by Ferris, Knowles, Brown, and Stallman (1962):

$$Q_s = 0.0692\ s_o\sqrt{\frac{ST}{t}} \qquad (1)$$

in which $Q_s$ is bank storage for both sides of the stream in cubic feet per second per mile, $s_o$ is the abrupt change of stage in the stream in feet, S is the storage coefficient, T is transmissivity in square feet per day, and t is time in days since the abrupt change of stage occurred in the stream. Increases in stream stage result in positive values of $s_o$ and $Q_s$ which indicate water entering bank storage; water will leave bank storage when the stream stage declines. Water leaving bank storage will be discussed in the section on the recession following reservoir releases.

To estimate the transmissivity (T) near Salida, the observed bank storage rate ($Q_s$) at time t, $s_o$, and an assumed S, were used in equation 1 for elapsed times (t) ranging from 5 minutes to 21 hours. The average T by this method, and the assumed value of S used in its derivation, were then tested using two other equations given by Ferris, Knowles, Brown, and Stallman (1962):

$$s = s_o\left[1 - \frac{2}{\sqrt{\pi}}\int_0^{\frac{x}{2\sqrt{Tt/s}}} e^{-u^2}du\right] = s_oD(u)_h \qquad (2)$$

and

$$u^2 = \frac{x^2S}{4Tt} \qquad (3)$$

in which x is the distance of the well from the stream in feet, s is the observed change of head in the well in feet, and $D(u)_h$ is the complimentary error function which is given for calculated values of $u^2$. Equations 1 and 3 test T and S because equation 1 evaluates the product ST and equation 3 evaluates the ratio S:T. Using this trial and error method of evaluating T and S in conjunction with the observed bank storage rate, the average transmissivity in the vicinity of Salida was estimated to be 4,760 $ft^2$ (feet squared) per day (35,600 gallons per day per foot) and the storage coefficient to be 0.15.

Equation 1 shows that bank storage is proportional to $s_o$, the stage change in the river. In the preceding analysis of observation well data, $s_o$ was determined from staff gage readings at each site. To extend the bank storage relationship for different antecedent river conditions and release discharges, the expected change in river stage was evaluated on the basis of miscellaneous mainstem discharge measurements and the stage-discharge relationships at mainstem gaging stations.

Effective river miles represent the length of theoretical channel having specific values of T and S which produce the same bank storage effects as the natural channel. Table 3 gave calculated bank storage after 16 hours as 116 and 90 $ft^3/s$ for the reservoir releases of August 29, 1970, and August 22, 1972, respectively. For the antecedent river conditions and release discharge of these two releases, equation 1 with T=4,760 $ft^2$ per day, S=0.15, and t=16 hours, gives bank storage rates of about 1.4 and 1.7 $ft^3/s$ per mile, respectively. Consequently, the number of effective river miles would be 83 (116 $ft^3s^{-1}/1.4\ ft^3s^{-1}\ mi^{-1}$) and 53 (90 $ft^3s^{-1}/1.7\ ft^3s^{-1}\ mi^{-1}$), or an average of about 65 miles (the release of August 22, 1972, was weighted slightly more due to the favorable conditions at this time).

By combining selected $s_o$ values with equation 1 for 65 effective river miles, bank storage along the Arkansas River from Twin Lakes Reservoir to Colorado Canal was determined for various antecedent river conditions (flows at Wellsville, 07093700) and release discharges. The results from the calculations are summarized in table 4. Figure 6 is a nomograph developed from table 4 and shows average rate of bank storage during selected time intervals measured from the time of arrival of the release at the Colorado Canal. The nomograph shows that although the rate at which reservoir-release water enters bank storage decreases rapidly, large amounts of release water continue to enter bank storage days after the release has arrived at Colorado Canal. Early in the release period, all release water may enter bank storage.

## Inadvertent Diversions

It has long been recognized that the increase in river stage during a reservoir release caused ditches along the river to divert more water. This additional water which ditches divert during a release is termed inadvertent diversion.

Ditches upstream from Salida, Colo., are especially subject to inadvertent diversions. Ditch systems along this reach of the Arkansas River typically consist of a manmade rock and gravel diversion dike, a wooden sluicing structure some distance down the ditch, and a Parshall measuring flume downstream from the sluicing structure. As a result of the unsophisticated nature of these diversion structures, many of the ditches are unable to divert their legal water right when the river stage is low. When the stage of the river rises during a reservoir release, the ditch diverts additional water, but since the total diversion is usually less than the ditch's legal right no attempt is made to reduce the diversion to the original rate.

Although diversions downstream from Salida are also subject to inadvertent diversions, these ditches generally have elaborate diversion structures which reduce the magnitude of the inadvertent diversion.

Table 4.--*Bank storage for releases from Twin Lakes Reservoir to Colorado Canal*

| Flow at Wellsville before release (in cubic feet per second) | Release discharge (in cubic feet per second) | Positive head change in river, $s_o$ (in feet) | Rate of bank storage at indicated time since release arrived at Colorado Canal (in cubic feet per second) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | ½ hour | 2 hours | 7 hours | 16 hours | 2 days | 8 days |
| 400 | 500 | 0.85 | 705 | 354 | 189 | 125 | 72 | 36 |
| | 400 | .72 | 572 | 287 | 153 | 102 | 59 | 29 |
| | 300 | .57 | 440 | 221 | 118 | 78 | 45 | 23 |
| | 150 | .29 | 240 | 121 | 65 | 43 | 25 | 12 |
| | 50 | .10 | 83 | 42 | 22 | 15 | 8 | 4 |
| 1,000 | 500 | .62 | 514 | 258 | 138 | 91 | 53 | 26 |
| | 400 | .45 | 406 | 204 | 109 | 72 | 42 | 21 |
| | 300 | .34 | 282 | 142 | 76 | 50 | 29 | 14 |
| | 150 | .18 | 149 | 75 | 40 | 26 | 15 | 8 |
| | 50 | .06 | 50 | 25 | 13 | 9 | 5 | 3 |
| 2,500 | 500 | .39 | 323 | 162 | 87 | 57 | 33 | 17 |
| | 400 | .30 | 249 | 125 | 67 | 44 | 25 | 13 |
| | 300 | .20 | 166 | 83 | 44 | 29 | 17 | 9 |
| | 150 | .11 | 91 | 46 | 24 | 16 | 9 | 5 |
| | 50 | .04 | 33 | 17 | 9 | 6 | 3 | 2 |

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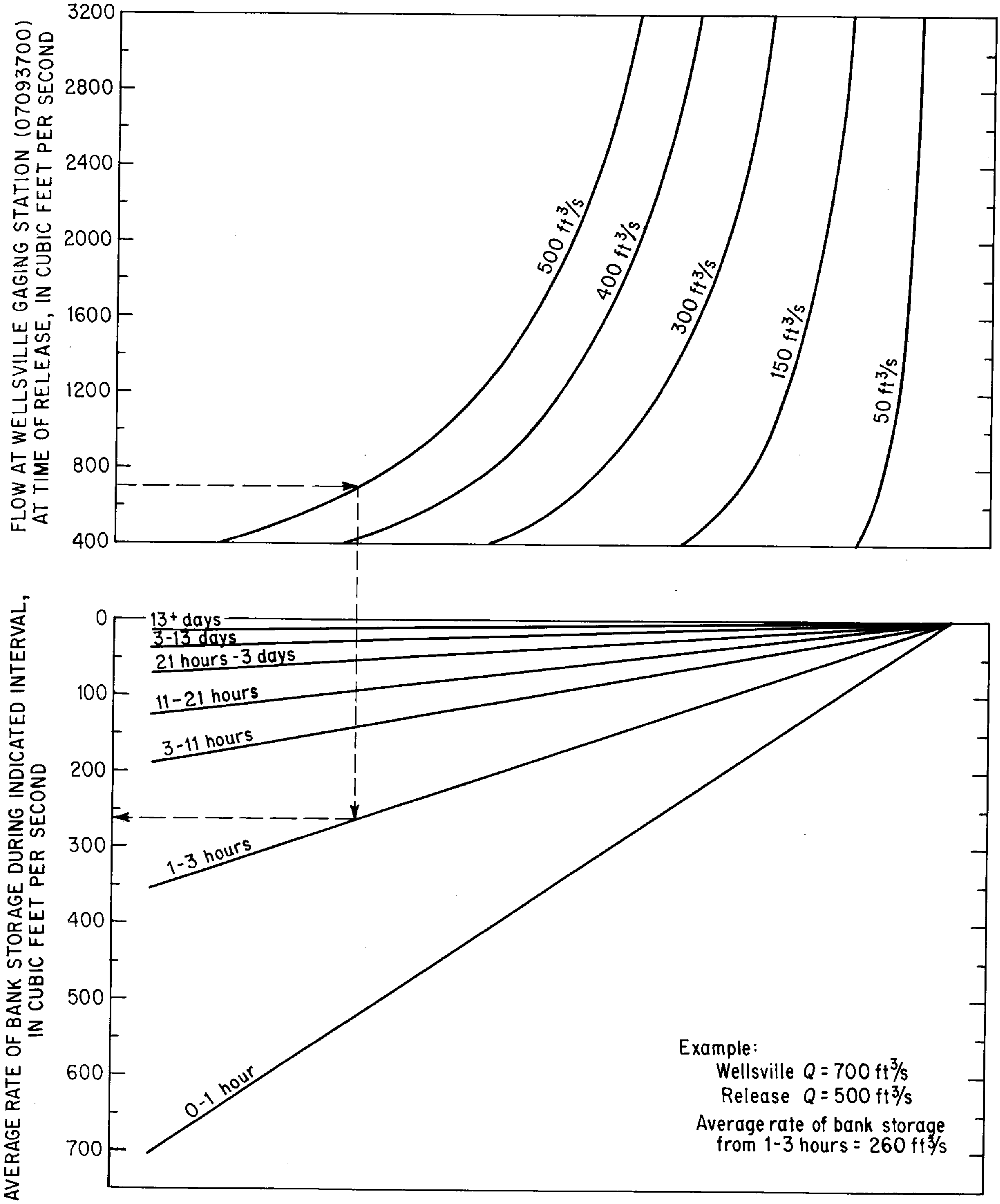



Figure 6.--Rate of bank storage during releases from Twin Lakes Reservoir to Colorado Canal.

These ditches can also be controlled to obtain the desired diversion even during low river flows, and adjustments are usually made when an increase occurs during a reservoir release.

The amount of water inadvertently diverted by a particular ditch can readily be determined through analysis of the ditch's diversion record during reservoir releases. Following a brief study of the diversion records for 21 ditches along the upper Arkansas River (table 5), 14 ditches were selected to be examined in detail during 15 reservoir releases. These releases ranged from about 225 $ft^3/s$ to about 500 $ft^3/s$ and were made during the years 1965, 1966, 1970, 1971, and 1972. The average reservoir release was about 400 $ft^3/s$.

It is emphasized that data in table 5 are averages of diversions during reservoir releases only. They do not represent the diversion during any one release, and they do not report average diversions during all types of river conditions.

Analysis of these data consisted of simple graphical techniques and multiple regression using the following variables:

(a) Dependent variables:

(1) Total inadvertent diversion by the 14 ditches, in cubic feet per second, and

(2) Inadvertent diversion by a selected ditch, in cubic feet per second.

(b) Independent variables:

(1) Amount of reservoir release, in cubic feet per second,

(2) River flow at Wellsville gage at time of release, in cubic feet per second,

(3) River flow at Wellsville gage at time release arrived at the Wellsville gage, in cubic feet per second, and

(4) River flow at Wellsville gage 6 hours after release arrived at the Wellsville gage, in cubic feet per second.

Results of this analysis indicated the simple relation of total inadvertent diversion to river flow at the Wellsville gage at time of release was well defined and the most useful for administrative purposes. This relationship is shown on figure 7. Figure 7 shows that inadvertent diversions range from 48 to 4 $ft^3/s$ for antecedent river flows of from 350 to 3,200 $ft^3/s$, respectively. Although intuitively one would expect that the amount of the release affects inadvertent diversions, available data were insufficient to adequately define this effect. Inadvertent

Table 5.--*Ditches studied in defining inadvertent diversion losses*

| Ditch or diversion | Total water right (in cubic feet per second) | Average inadvertent diversion for 15 reservoir releases (in cubic feet per second) | Average diversion prior to the 15 reservoir releases (in cubic feet per second) |
|---|---|---|---|
| Langhoff Ditch------------- | 4.80 | [1]0.8 | 0.80 |
| Dryfield Ditch------------- | 6.20 | .6 | 1.98 |
| Riverside-Allen Ditch------ | 34.00 | 3.3 | 11.6 |
| Helena Ditch--------------- | 36.00 | 2.4 | 20.3 |
| Bray-Allen Ditch----------- | 11.00 | 1.4 | 4.51 |
| Salida Ditch--------------- | 20.00 | 1.7 | 16.8 |
| Kraft Ditch---------------- | 5.00 | 1.1 | 3.24 |
| Sunnyside Ditch------------ | 39.17 | 1.2 | 14.1 |
| Williams-Hamm Ditch-------- | 17.00 | 1.4 | 15.9 |
| Pleasant Valley Ditch------ | 10.00 | ([2]) | ----- |
| Canon City Ditch----------- | 22.50 | ([3]) | ----- |
| South Cannon City Ditch---- | 34.51 | .8 | 31.5 |
| Hydraulic Ditch------------ | 77.00 | 3.0 | 66.7 |
| Oil Creek Diversion-------- | 24.73 | 2.1 | 23.5 |
| Fremont County Ditch------- | 17.93 | 1.0 | 14.8 |
| Minnequa-Union Ditch------- | 220.00 | ([4]) | ----- |
| Hannenkratt Ditch---------- | 5.16 | .3 | 2.48 |
| Lester-Atteberry Ditch----- | 10.74 | 1.2 | 1.89 |
| Johns-Mansville Diversion-- | .30 | ([3]) | ----- |
| Bessemer Ditch------------- | 392.65 | ([5]) | ----- |
| Booth-Orchard Grove Canal-- | 30.30 | ([5]) | ----- |
| Total----------------- | 1,018.99 | 22.3 | 230.10 |

[1]Average for six reservoir releases.
[2]No changes detected.
[3]Diversion record not usable.
[4]Only small changes which are adjusted within a few hours.
[5]Changes evident, insufficient data to define inadvertent diversion.

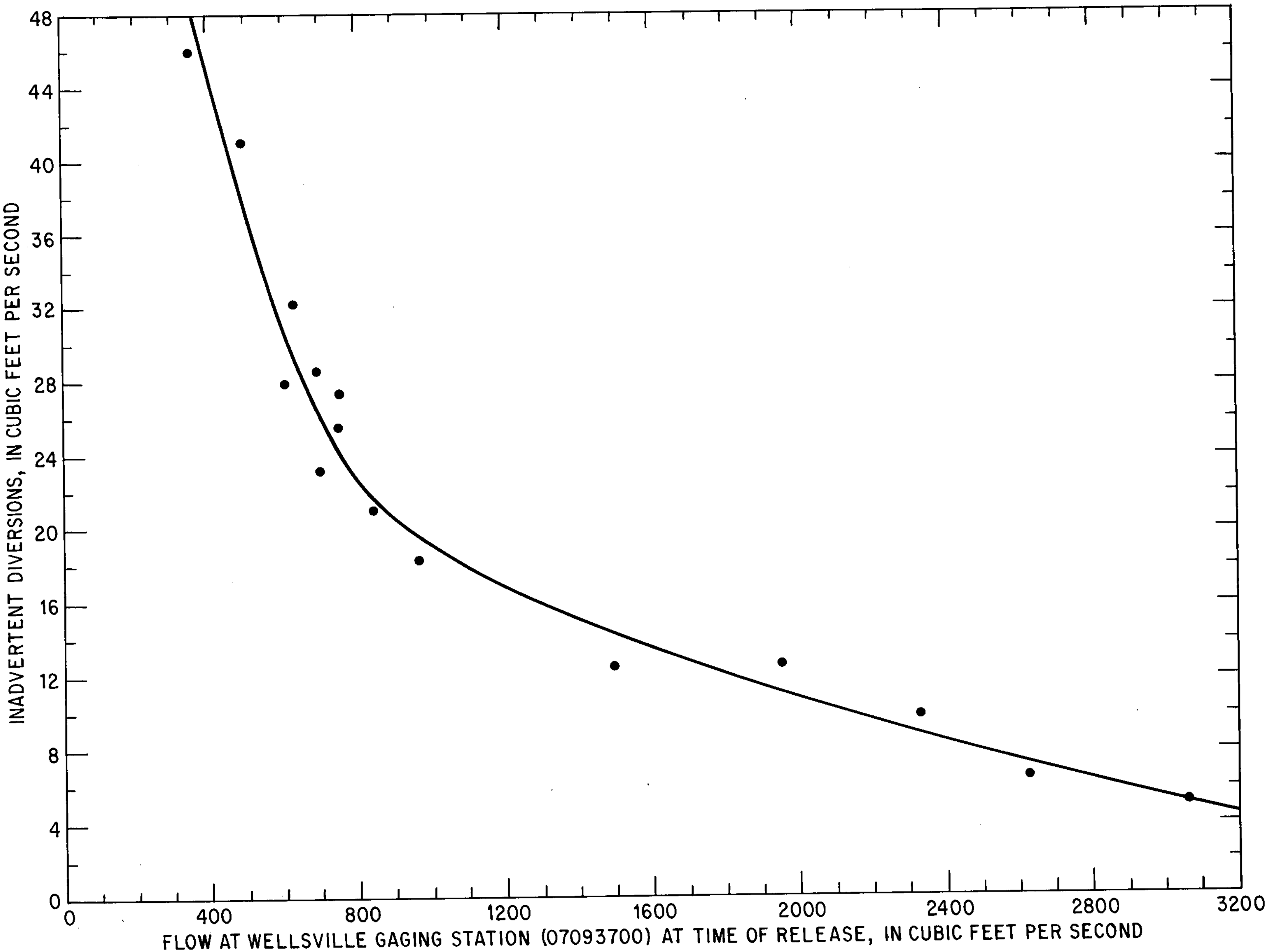



Figure 7.--Inadvertent diversions from Arkansas River as a result of releases from Twin Lakes Reservoir to Colorado Canal.

diversions during releases considerably greater or less than 400 $ft^3/s$ may differ from that given in figure 7. They may be estimated by assuming a direct relationship between release discharge and inadvertent diversions (inadvertent diversions during a 100-$ft^3/s$ release would be about 25 percent of that given in fig. 7).

Although the detailed chart study involved only 14 of about 40 diversions above the Colorado Canal, the brief examination of the charts for many of the other ditches indicated only minor response to the reservoir releases.

Data are not available to evaluate return flow as it might affect inadvertent diversions and for this reason it was not considered in the preceding analysis. However, return flow in general, and specifically its effect on inadvertent diversions, is an area in which further study is needed.

## Evapotranspiration

Evapotranspiration is the process by which water is evaporated from wet surfaces or transpired by plants (Veihmeyer, 1964). A brief discussion of each of the two processes involved in evapotranspiration, evaporation and transpiration, follows.

### Evaporation losses

Evaporation takes place both from free-water surfaces and from soil surfaces. The increase in evaporation from soil surfaces due to bank storage during a reservoir release was assumed to be insignificant.

Evaporation from free-water surfaces is commonly determined from estimates of lake evaporation. Lake evaporation can be estimated by a number of methods. Three of these methods were used in this phase of the study and are only briefly described herein:

*Method 1.* Standard pan evaporation method (Veihmeyer, 1964). By this method, average monthly pan evaporation for the entire reach was determined by correlating observed pan evaporation with elevation and mean monthly temperature at appropriate U.S. Weather Bureau stations. The average monthly lake evaporation was then computed as

$$E_{lake} = 0.7E_{pan}. \tag{4}$$

*Method 2.* Modified pan evaporation method (World Meteorolog. Organization, 1966). This method converts observed pan evaporation to lake evaporation based on climatic and topographic considerations. Calculations were made for both the Pueblo and Twin Lakes U.S. Weather Bureau stations and averaged.

*Method 3.* Empirical method (Harbeck, 1962). According to Harbeck, reservoir evaporation in feet per day can be calculated using the equation

$$E = Nu_2(e_o - e_a) \qquad (5)$$

where N is 0.00028 for a 1-acre surface area, $u_2$ is wind speed at 2 meters above water surface in miles per hour, $e_o$ is the saturation vapor pressure in millibars, corresponding to the temperature of the water surface, and $e_a$ is the vapor pressure of the air, in millibars. Mean monthly river temperatures were estimated from data provided by the following:

Northside Waterworks, Pueblo;
Southern Colorado Power Company, Canon City;
Colorado Game Fish and Parks Department, Salida;
Otero Pumping Station, Homestake Project, Granite.

The evaporation rates determined by this method were much lower during midsummer than rates determined by the other methods. The reason is the importance of the wind factor in this method and the fact that May, early June, and late September are relatively windy above Canon City.

All lake evaporation rates determined by these methods were multiplied by a factor of 1.7 which, according to Delay and Seaders (1963), allows for higher evaporation rates from streams. Table 6 shows the results of these determinations for the five common irrigation months.

Table 6.--*Summary of Arkansas River evaporation calculations*

| Method | Mean monthly river evaporation, in feet per day | | | | |
|---|---|---|---|---|---|
| | May | June | July | August | September |
| Standard pan evaporation-- | 0.026 | 0.030 | 0.030 | 0.026 | 0.022 |
| Modified pan evaporation-- | .030 | .032 | .032 | .027 | .021 |
| Empirical----------------- | .034 | .026 | .018 | .018 | .022 |
| Average-------------- | .030 | .029 | .027 | .024 | .022 |

*Surface area increases due to reservoir releases.*--An evaporation loss can be determined for the increase in the river's surface area with a reservoir release. This increase in surface area for various release discharges is shown as a function of the river flow at the Wellsville gage in figure 8. Figure 8 shows that the increase in river surface area resulting from an average reservoir release of 400 ft$^3$/s ranges from 250 to 10 acres for antecedent river flows of from 280 to 3,200 ft$^3$/s, respectively. These curves were developed from aerial photographs, U.S. Geological Survey topographic maps, and gaging station discharge measurements.

Based on the average monthly evaporation rates shown in table 6, figure 9 shows the increase in evaporation with an increase in river surface area. It indicates evaporation from the Arkansas River is increased by a maximum of 4.5 ft$^3$/s due to increase in surface area resulting from a reservoir release. Used in conjunction with figure 8, these curves can be used to determine the incremental evaporation loss due to the increase in river surface area during reservoir releases.

*River temperature increases due to reservoir releases.*--An increase in evaporation also occurs when reservoir releases increase the temperature of the river. Temperature profiles for lower Twin Lakes obtained by D. B. Hoffman (written commun., 1971) and Nolting (1968), and Twin Lakes river temperatures obtained daily by the Otero Pumping Station, indicate Twin Lakes release water to be from 5°F to 6.5°F warmer than average river temperature during June, July, August, and September. Data were not available for Turquoise Lake or Clear Creek Reservoirs.

To calculate this component of the evaporation loss during releases from Twin Lakes, the difference between river evaporation before and during a reservoir release was computed for the length of river required for temperature equilibrium. Although the average monthly evaporation rates shown in table 6 were used in these calculations, the results showed insensitivity to monthly variations in evaporation and only averages were used. Evaporation due to the increase in river temperature during releases from Twin Lakes Reservoir made in June, July, August, or September is given in figure 10. Figure 10 shows this increase in evaporation to be as much as 1.3 ft$^3$/s during low antecedent river flows.

For releases from Turquoise Lake or Clear Creek Reservoirs, this component of evaporation loss is insignificant. Due to the physical nature of Twin Lakes Reservoir, the lower lake from which releases are made is fed from the surface waters of the upper lake and is, therefore, unusually warm. The temperature of Turquoise Lake and Clear Creek Reservoir release water will be considerably nearer the river's temperature.

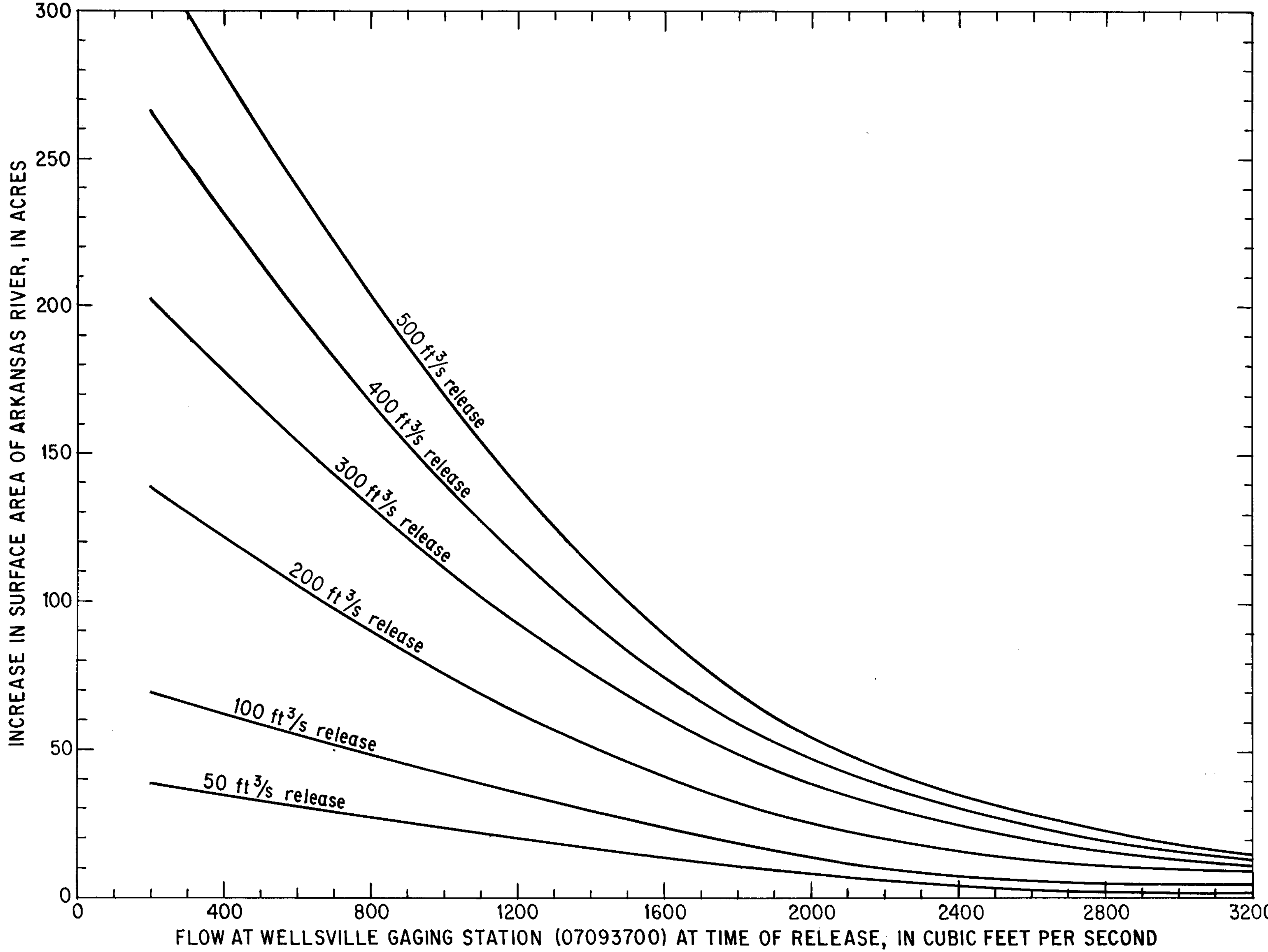



Figure 8.--Increase in surface area of Arkansas River as a result of releases from Twin Lakes Reservoir to Colorado Canal.

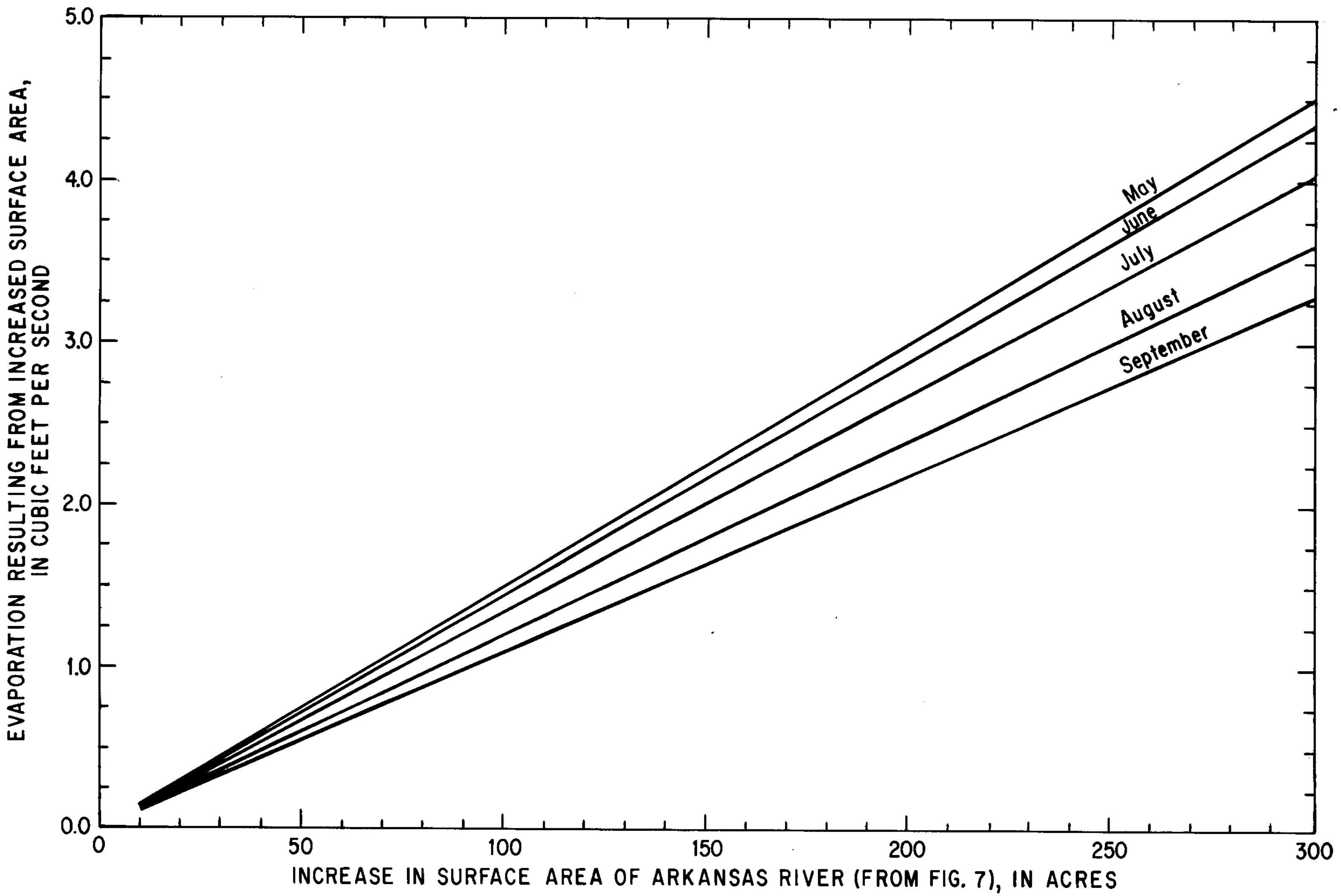



Figure 9.--Arkansas River evaporation due to increases in surface area resulting from releases from Twin Lakes Reservoir to Colorado Canal.

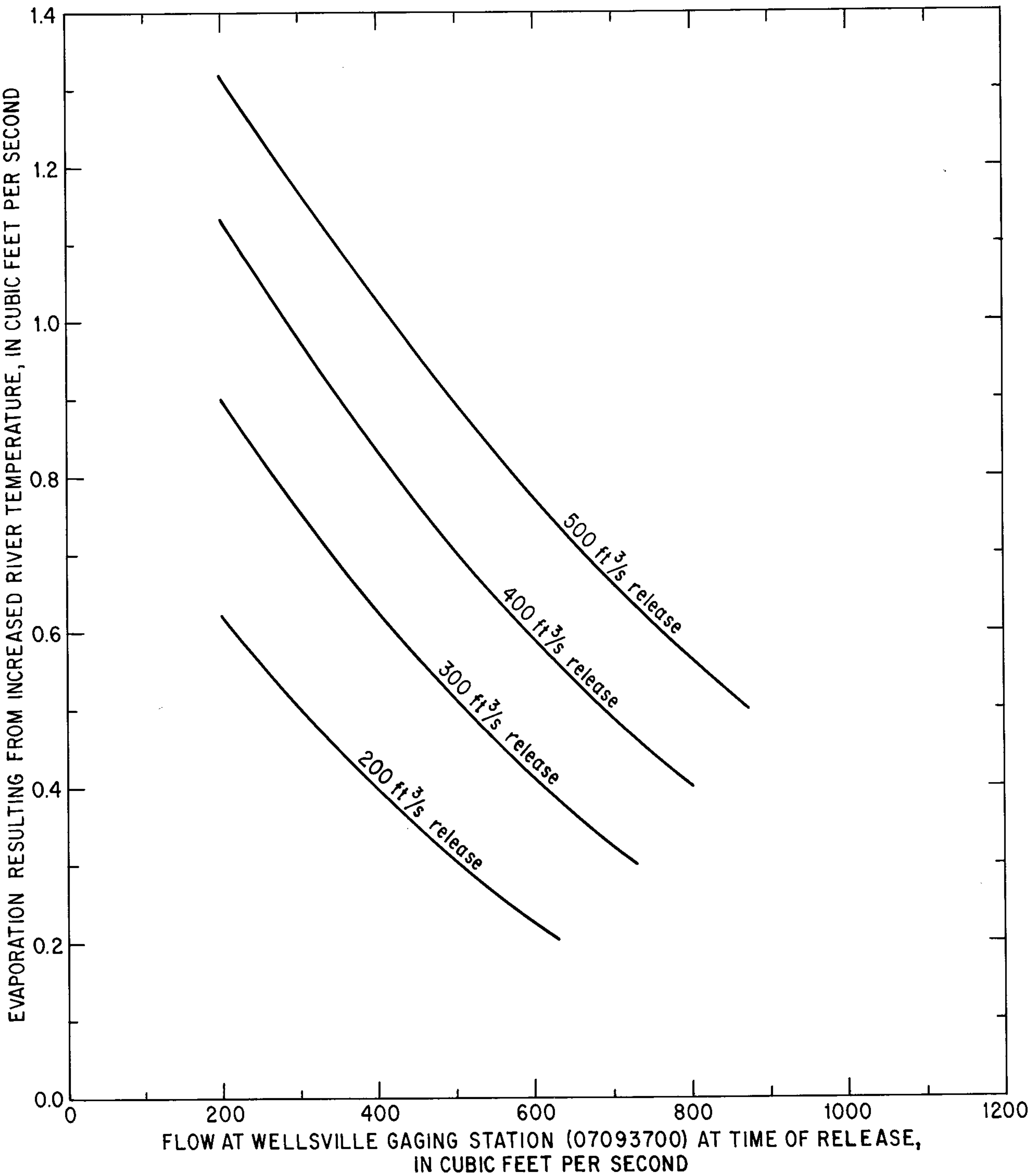



Figure 10.--Arkansas River evaporation due to increases in river temperature resulting from releases from Twin Lakes Reservoir to Colorado Canal (June, July, August, and September).

### Transpiration losses

An increase in transpiration losses along the Arkansas River is associated with bank storage during a reservoir release. This process, however, is extremely complex. Because evaporation losses, which are probably of the same magnitude as transpiration losses, are not a signigicant source of transit loss, transpiration losses were assumed to be negligible.

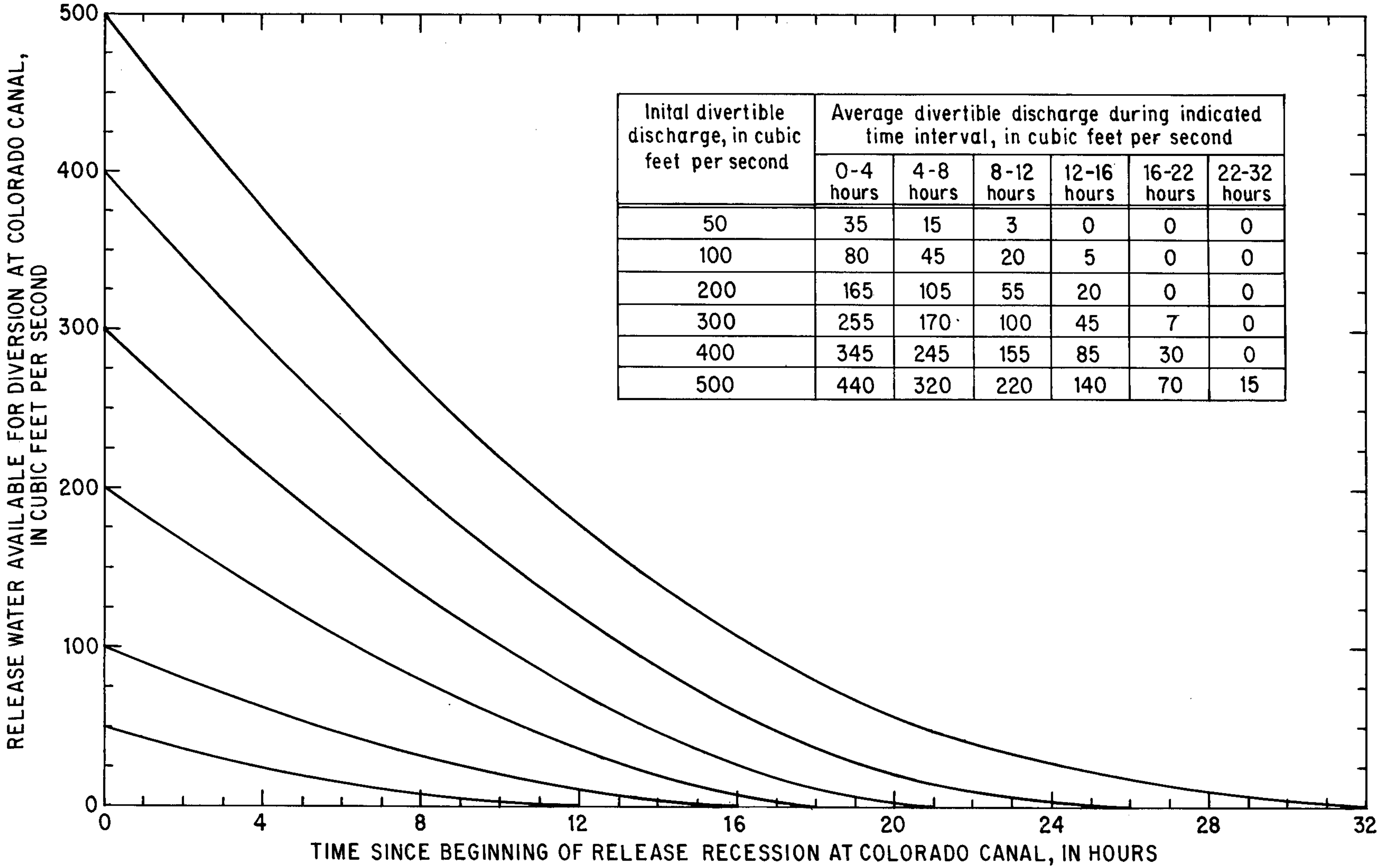
## RECESSION FOLLOWING RESERVOIR RELEASES

The previous discussions of the four potential sources of transit loss have shown that evaporation and inadvertent diversions remove release water throughout the release period. Channel and bank storage, on the other hand, have temporarily stored release water at a rate which, although initially high, rapidly decreases with time. When the stage declines, channel and bank storage will release the stored water to the stream in a similar fashion. Obviously, canal operation during this recession period will determine how much of the stored water is recovered.

The recessions at the Avondale and Pueblo gaging stations for many reservoir releases to Colorado Canal were studied to determine how much of the water in channel and bank storage is divertible. Average recessions for various river flows at Colorado Canal are shown in figure 11. The recessions have been modified slightly to represent only release water which the Colorado Canal can economically and practically divert. For example, figure 11 indicates that 400 $ft^3/s$ reservoir release water will require about 26 hours to recede following the initial decrease in stage beginning the recession. After 26 hours, the release water still in the river is not divertible by the canal.

The discharge shown in figure 11 includes water released from both channel storage and bank storage. Comparison with figure 4 indicates that all water in channel storage arrives at the Colorado Canal headgate soon enough to be diverted. Therefore, there is no transit loss due to channel storage assuming water will enter and leave channel storage at about the same rate. This is probably a valid assumption.

Figure 6 can represent water leaving bank storage if the assumption is made that water leaves bank storage at the same rate as it enters. This assumption is theoretically invalid because (1) the short duration of increase in river stage causes nonequilibrium effects, (2) river stage decreases are more gradual than stage increases, and (3) saturated thicknesses may change aquifer transmissivity. Because sufficient data were not available, figure 6 was not adjusted for this phenomena.




| Inital divertible discharge, in cubic feet per second | Average divertible discharge during indicated time interval, in cubic feet per second | | | | | |
|---|---|---|---|---|---|---|
| | 0-4 hours | 4-8 hours | 8-12 hours | 12-16 hours | 16-22 hours | 22-32 hours |
| 50 | 35 | 15 | 3 | 0 | 0 | 0 |
| 100 | 80 | 45 | 20 | 5 | 0 | 0 |
| 200 | 165 | 105 | 55 | 20 | 0 | 0 |
| 300 | 255 | 170 | 100 | 45 | 7 | 0 |
| 400 | 345 | 245 | 155 | 85 | 30 | 0 |
| 500 | 440 | 320 | 220 | 140 | 70 | 15 |

Figure 11.--Recession curves of releases from Twin Lakes Reservoir to Colorado Canal.

Transit loss due to bank storage can be determined on an hourly basis from figures 5 and 11. However, since calculations for various release and river conditions indicate the loss will normally be between 65 and 75 percent of the total bank storage, it is sufficiently accurate to simply reduce the total bank storage by 70 percent.

## SAMPLE COMPUTATIONS

The computation of time of travel, transportation losses, and diversion schedules can be computed using the tables and figures given in this report. Sample computations for several release conditions are given in the following pages.

EXAMPLE 1

RELEASE FROM Twin Lakes RESERVOIR TO Colorado Canal

Date of release: 5-1-68 Amount of release: 500 $ft^3/s$ Duration of release: 14 days (336 hours)

Flow at Wellsville gaging station prior to release: 400 $ft^3/s$
(Call 539-6487 for stage, obtain discharge from table 2)

Time of travel (fig. 3): 53 hours

TRANSPORTATION LOSSES
Bank storage (fig. 6)

| 1<br>Time interval (hours) | 2<br>Maximum time in hours | 3<br>Actual time in interval (hours) | 4<br>Average bank storage in interval ($ft^3/s$) | 5<br>Bank storage in time interval (col. 3 × col. 4, hours × $ft^3/s$) |
|---|---|---|---|---|
| 0-1 | 1 | 1 | 705 | 705 |
| 1-3 | 2 | 2 | 355 | 710 |
| 3-11 | 8 | 8 | 190 | 1,520 |
| 11-21 | 10 | 10 | 125 | 1,250 |
| 21-72 | 51 | 51 | 70 | 3,570 |
| 72-312 | 240 | 240 | 35 | 8,400 |
| 312+ | --- | 24 | 15 | 360 |
| Totals | | 336 | | 16,515 |

Charge for bank storage loss is 70 percent of column 5 divided by duration of release: 34.4 $ft^3/s$

Inadvertent diversions

Charge for inadvertent diversion losses (fig. 7): 45.0 $ft^3/s$

Evaporation

Surface area increase (fig. 8): 280 acres

Charge for change in surface area (fig. 9): 4.2 $ft^3/s$

Charge for change in river temperature (fig. 10): 0 $ft^3/s$

TOTAL TRANSPORTATION LOSS---------------------------------------------------------------- 83.6 $ft^3/s$

TOTAL TRANSPORTATION LOSS (percent of release)------------------------------------------ 16.7 %

DIVERSION SCHEDULES

Prior to recession at Colorado Canal

| 1<br>Time interval (hours) | 2<br>Maximum time in hours | 3<br>Release discharge ($ft^3/s$) | 4<br>Average bank storage (col. 4 above, $ft^3/s$) | 5<br>Inadvertent diversion ($ft^3/s$) | 6<br>Evaporation ($ft^3/s$) | 7<br>Channel storage (fig. 4, $ft^3/s$) | 8<br>Total (cols. 4-7, $ft^3/s$) | 9<br>Average divertible discharge ($ft^3/s$) |
|---|---|---|---|---|---|---|---|---|
| 0-1 | 1 | 500 | 705 | 45.0 | 4.2 | 395 | 1,149 | --- |
| 1-3 | 2 | 500 | 355 | 45.0 | 4.2 | 275 | 679 | --- |
| 3-11 | 8 | 500 | 190 | 45.0 | 4.2 | 125 | 364 | 136 |
| 11-21 | 10 | 500 | 125 | 45.0 | 4.2 | 40 | 214 | 286 |
| 21-72 | 51 | 500 | 70 | 45.0 | 4.2 | 2 | 121 | 379 |
| 72-312 | 240 | 500 | 35 | 45.0 | 4.2 | --- | 84 | 416 |
| 312+ | --- | 500 | 15 | 45.0 | 4.2 | --- | 64 | 436 |

Release arrived at 1500 hours

During recession at Colorado Canal

Final divertible discharge from column 9 above------------------------------------------------ 436 $ft^3/s$

Release recession began at 1100 hours

| Time interval from beginning of recession (hours) | Average divertible discharge (fig. 11, $ft^3/s$) |
|---|---|
| 0-4 | 379 |
| 4-8 | 272 |
| 8-12 | 178 |
| 12-16 | 105 |
| 16-22 | 44 |
| 22-32 | 5 |

0765

EXAMPLE 2

RELEASE FROM Twin Lakes RESERVOIR TO Colorado Canal

[D]ate of release: 6-5-71 Amount of release: 400 $ft^3/s$ Duration of release: 10 days (240 hours)

Flow at Wellsville gaging station prior to release: 500 $ft^3/s$
(Call 539-6487 for stage, obtain discharge from table 2)

Time of travel (fig. 3): 49 hours

TRANSPORTATION LOSSES
Bank storage (fig. 6)

| 1<br>Time interval (hours) | 2<br>Maximum time in hours | 3<br>Actual time in interval (hours) | 4<br>Average bank storage in interval ($ft^3/s$) | 5<br>Bank storage in time interval (col. 3 × col. 4, hours × $ft^3/s$) |
|---|---|---|---|---|
| 0-1 | 1 | 1 | 520 | 520 |
| 1-3 | 2 | 2 | 260 | 520 |
| 3-11 | 8 | 8 | 140 | 1,120 |
| 11-21 | 10 | 10 | 90 | 900 |
| 21-72 | 51 | 51 | 55 | 2,805 |
| 72-312 | 240 | 168 | 30 | 5,040 |
| 312+ | --- | --- | --- | ----- |
| Totals | | 240 | | 10,905 |

Charge for bank storage loss is 70 percent of column 5 divided by duration of release: 31.8 $ft^3/s$

Inadvertent diversions

Charge for inadvertent diversion losses (fig. 7): 37.5 $ft^3/s$

Evaporation

Surface area increase (fig. 8): 215 acres

Charge for change in surface area (fig. 9): 3.1 $ft^3/s$

Charge for change in river temperature (fig. 10): 0.7 $ft^3/s$

TOTAL TRANSPORTATION LOSS---------------------------------------------------------- 73.1 $ft^3/s$

TOTAL TRANSPORTATION LOSS (percent of release)------------------------------------------ 18.3 %

DIVERSION SCHEDULES

Prior to recession at Colorado Canal

| 1<br>Time interval (hours) | 2<br>Maximum time in hours | 3<br>Release discharge ($ft^3/s$) | 4<br>Average bank storage (col. 4 above, $ft^3/s$) | 5<br>Inadvertent diversion ($ft^3/s$) | 6<br>Evaporation ($ft^3/s$) | 7<br>Channel storage (fig. 4, $ft^3/s$) | 8<br>Total (cols. 4-7, $ft^3/s$) | 9<br>Average divertible discharge ($ft^3/s$) |
|---|---|---|---|---|---|---|---|---|
| 0-1 | 1 | 400 | 520 | 37.5 | 3.9 | 315 | 876 | --- |
| 1-3 | 2 | 400 | 260 | 37.5 | 3.9 | 215 | 516 | --- |
| 3-11 | 8 | 400 | 140 | 37.5 | 3.9 | 100 | 281 | 119 |
| 11-21 | 10 | 400 | 90 | 37.5 | 3.9 | 30 | 161 | 239 |
| 21-72 | 51 | 400 | 55 | 37.5 | 3.9 | 0 | 96 | 304 |
| 72-312 | 240 | 400 | 30 | 37.5 | 3.9 | --- | 71 | 329 |
| 312+ | --- | --- | --- | ---- | --- | --- | --- | --- |

Release arrived at 0630 hours

During recession at Colorado Canal

Final divertible discharge from column 9 above------------------------------------------------ 329 $ft^3/s$

Release recession began at 0730 hours

| Time interval from beginning of recession (hours) | Average divertible discharge (fig. 11, $ft^3/s$) |
|---|---|
| 0-4 | 281 |
| 4-8 | 192 |
| 8-12 | 116 |
| 12-16 | 57 |
| 16-22 | 14 |
| 22-32 | 0 |

EXAMPLE 3

RELEASE FROM Twin Lakes RESERVOIR TO Colorado Canal

Date of release: 5-19-72 Amount of release: 450 $ft^3/s$ Duration of release: 16 days (384 hours)

Flow at Wellsville gaging station prior to release: 800 $ft^3/s$
(Call 539-6487 for stage, obtain discharge from table 2)

Time of travel (fig. 3): 42 hours

TRANSPORTATION LOSSES
Bank storage (fig. 6)

| 1<br>Time interval (hours) | 2<br>Maximum time in hours | 3<br>Actual time in interval (hours) | 4<br>Average bank storage in interval ($ft^3/s$) | 5<br>Bank storage in time interval (col. 3 × col. 4, hours × $ft^3/s$) |
|---|---|---|---|---|
| 0-1 | 1 | 1 | 500 | 500 |
| 1-3 | 2 | 2 | 250 | 500 |
| 3-11 | 8 | 8 | 135 | 1,080 |
| 11-21 | 10 | 10 | 90 | 900 |
| 21-72 | 51 | 51 | 50 | 2,550 |
| 72-312 | 240 | 240 | 25 | 6,000 |
| 312+ | --- | 72 | 10 | 720 |
| Totals | | 384 | | 12,250 |

Charge for bank storage loss is 70 percent of column 5 divided by duration of release: 22.3 $ft^3/s$

Inadvertent diversions

Charge for inadvertent diversion losses (fig. 7): 23.0 $ft^3/s$

Evaporation

Surface area increase (fig. 8): 185 acres

Charge for change in surface area (fig. 9): 2.8 $ft^3/s$

Charge for change in river temperature (fig. 10): 0.5 $ft^3/s$

TOTAL TRANSPORTATION LOSS------------------------------------------------------------ 48.6 $ft^3/s$

TOTAL TRANSPORTATION LOSS (percent of release)------------------------------------------ 10.8 %

DIVERSION SCHEDULES

Prior to recession at Colorado Canal

| 1<br>Time interval (hours) | 2<br>Maximum time in hours | 3<br>Release discharge ($ft^3/s$) | 4<br>Average bank storage (col. 4 above, $ft^3/s$) | 5<br>Inadvertent diversion ($ft^3/s$) | 6<br>Evaporation ($ft^3/s$) | 7<br>Channel storage (fig. 4, $ft^3/s$) | 8<br>Total (cols. 4-7, $ft^3/s$) | 9<br>Average divertible discharge ($ft^3/s$) |
|---|---|---|---|---|---|---|---|---|
| 0-1 | 1 | 450 | 500 | 23.0 | 3.3 | 355 | 881 | --- |
| 1-3 | 2 | 450 | 250 | 23.0 | 3.3 | 245 | 521 | --- |
| 3-11 | 8 | 450 | 135 | 23.0 | 3.3 | 112 | 273 | 177 |
| 11-21 | 10 | 450 | 90 | 23.0 | 3.3 | 35 | 151 | 299 |
| 21-72 | 51 | 450 | 50 | 23.0 | 3.3 | 1 | 77 | 373 |
| 72-312 | 240 | 450 | 25 | 23.0 | 3.3 | --- | 51 | 399 |
| 312+ | --- | 450 | 10 | 23.0 | 3.3 | --- | 36 | 414 |

Release arrived at 0200 hours

During recession at Colorado Canal

Final divertible discharge from column 9 above---------------------------------------------------- 414 $ft^3/s$

Release recession began at 2300 hours

| Time interval from beginning of recession (hours) | Average divertible discharge (fig. 11, $ft^3/s$) |
|---|---|
| 0-4 | 258 |
| 4-8 | 255 |
| 8-12 | 164 |
| 12-16 | 93 |
| 16-22 | 36 |
| 22-32 | 2 |

EXAMPLE 4

RELEASE FROM Twin Lakes RESERVOIR TO Colorado Canal

Date of release: 7-20-71 Amount of release: 400 $ft^3/s$ Duration of release: 10 days (240 hours)

Flow at Wellsville gaging station prior to release: 2,500 $ft^3/s$
(Call 539-6487 for stage, obtain discharge from table 2)

Time of travel (fig. 3): 30 hours

TRANSPORTATION LOSSES
Bank storage (fig. 6)

| 1<br>Time interval (hours) | 2<br>Maximum time in hours | 3<br>Actual time in interval (hours) | 4<br>Average bank storage in interval ($ft^3/s$) | 5<br>Bank storage in time interval (col. 3 × col. 4, hours × $ft^3/s$) |
|---|---|---|---|---|
| 0-1 | 1 | 1 | 235 | 235 |
| 1-3 | 2 | 2 | 120 | 240 |
| 3-11 | 8 | 8 | 65 | 520 |
| 11-21 | 10 | 10 | 40 | 400 |
| 21-72 | 51 | 51 | 25 | 1,275 |
| 72-312 | 240 | 168 | 15 | 2,520 |
| 312+ | --- | --- | --- | ----- |
| Totals | | 240 | | 5,190 |

Charge for bank storage loss is 70 percent of column 5 divided by duration of release: 15.1 $ft^3/s$
Inadvertent diversions
Charge for inadvertent diversion losses (fig. 7): 9.0 $ft^3/s$
Evaporation
Surface area increase (fig. 8): 30 acres
Charge for change in surface area (fig. 9): 0.4 $ft^3/s$
Charge for change in river temperature (fig. 10): 0 $ft^3/s$

TOTAL TRANSPORTATION LOSS---------------------------------------------------------------------- 24.5 $ft^3/s$
TOTAL TRANSPORTATION LOSS (percent of release)------------------------------------------------ 6.1 %

DIVERSION SCHEDULES

Prior to recession at Colorado Canal

| 1<br>Time interval (hours) | 2<br>Maximum time in hours | 3<br>Release discharge ($ft^3/s$) | 4<br>Average bank storage (col. 4 above, $ft^3/s$) | 5<br>Inadvertent diversion ($ft^3/s$) | 6<br>Evaporation ($ft^3/s$) | 7<br>Channel storage (fig. 4, $ft^3/s$) | 8<br>Total (cols. 4-7, $ft^3/s$) | 9<br>Average divertible discharge ($ft^3/s$) |
|---|---|---|---|---|---|---|---|---|
| 0-1 | 1 | 400 | 235 | 9.0 | 0.4 | 315 | 559 | --- |
| 1-3 | 2 | 400 | 120 | 9.0 | .4 | 215 | 344 | 56 |
| 3-11 | 8 | 400 | 65 | 9.0 | .4 | 100 | 174 | 226 |
| 11-21 | 10 | 400 | 40 | 9.0 | .4 | 30 | 89 | 311 |
| 21-72 | 51 | 400 | 25 | 9.0 | .4 | 0 | 34 | 366 |
| 72-312 | 240 | 400 | 15 | 9.0 | .4 | --- | 24 | 376 |
| 312+ | --- | --- | --- | --- | --- | --- | --- | --- |

Release arrived at 1230 hours

During recession at Colorado Canal

Final divertible discharge from column 9 above--------------------------------------------------- 376 $ft^3/s$
Release recession began at 0600 hours

| Time interval from beginning of recession (hours) | Average divertible discharge (fig. 11, $ft^3/s$) |
|---|---|
| 0-4 | 323 |
| 4-8 | 227 |
| 8-12 | 142 |
| 12-16 | 75 |
| 16-22 | 24 |
| 22-32 | 0 |

EXAMPLE 5

RELEASE FROM Clear Creek RESERVOIR TO Colorado Canal

Date of release: 9-2-73 Amount of release: 100 ft$^3$/s Duration of release: 5 days (120 hours)

Flow at Wellsville gaging station prior to release: 1,000 ft$^3$/s
(Call 539-6487 for stage, obtain discharge from table 2)

Time of travel (fig. 3): 36 hours

TRANSPORTATION LOSSES
Bank storage (fig. 6)

| 1<br>Time interval (hours) | 2<br>Maximum time in hours | 3<br>Actual time in interval (hours) | 4<br>Average bank storage in interval (ft$^3$/s) | 5<br>Bank storage in time interval (col. 3 × col. 4, hours × ft$^3$/s) |
|---|---|---|---|---|
| 0-1 | 1 | 1 | 100 | 100 |
| 1-3 | 2 | 2 | 50 | 100 |
| 3-11 | 8 | 8 | 30 | 240 |
| 11-21 | 10 | 10 | 20 | 200 |
| 21-72 | 51 | 51 | 10 | 510 |
| 72-312 | 240 | 48 | 5 | 240 |
| 312+ | --- | --- | --- | --- |
| Totals | | 120 | | 1,390 |

Charge for bank storage loss is 70 percent of column 5 divided by duration of release: 8.1 ft$^3$/s

Inadvertent diversions
Charge for inadvertent diversion losses (fig. 7): 19.0 ft$^3$/s

Evaporation
Surface area increase (fig. 8): 40 acres
Charge for change in surface area (fig. 9): 0.4 ft$^3$/s
Charge for change in river temperature (fig. 10): 0 ft$^3$/s

TOTAL TRANSPORTATION LOSS------------------------------------------------------------ 27.5 ft$^3$/s
TOTAL TRANSPORTATION LOSS (percent of release)---------------------------------------- 27.5 %

DIVERSION SCHEDULES

Prior to recession at Colorado Canal

| 1<br>Time interval (hours) | 2<br>Maximum time in hours | 3<br>Release discharge (ft$^3$/s) | 4<br>Average bank storage (col. 4 above, ft$^3$/s) | 5<br>Inadvertent diversion (ft$^3$/s) | 6<br>Evaporation (ft$^3$/s) | 7<br>Channel storage (fig. 4, ft$^3$/s) | 8<br>Total (cols. 4-7, ft$^3$/s) | 9<br>Average divertible discharge (ft$^3$/s) |
|---|---|---|---|---|---|---|---|---|
| 0-1 | 1 | 100 | 100 | 19.0 | 0.4 | 70 | 189 | -- |
| 1-3 | 2 | 100 | 50 | 19.0 | .4 | 55 | 124 | -- |
| 3-11 | 8 | 100 | 30 | 19.0 | .4 | 10 | 59 | 41 |
| 11-21 | 10 | 100 | 20 | 19.0 | .4 | 0 | 39 | 61 |
| 21-72 | 51 | 100 | 10 | 19.0 | .4 | -- | 29 | 71 |
| 72-312 | 240 | 100 | 5 | 19.0 | .4 | -- | 24 | 76 |
| 312+ | --- | --- | --- | ---- | --- | -- | --- | -- |

Release arrived at 1600 hours

During recession at Colorado Canal

Final divertible discharge from column 9 above---------------------------------------- 76 ft$^3$/s
Release recession began at 0330 hours

| Time interval from beginning of recession (hours) | Average divertible discharge (fig. 11, ft$^3$/s) |
|---|---|
| 0-4 | 58 |
| 4-8 | 31 |
| 8-12 | 12 |
| 12-16 | 3 |
| 16-22 | 0 |
| 22-32 | 0 |

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EXAMPLE 6

RELEASE FROM Clear Creek RESERVOIR TO Colorado Canal

Date of release: 6-19-72 Amount of release: 100 $ft^3/s$ Duration of release: 14 days (336 hours)

Flow at Wellsville gaging station prior to release: 1,000 $ft^3/s$
(Call 539-6487 for stage, obtain discharge from table 2)

Time of travel (fig, 3): 36 hours

TRANSPORTATION LOSSES
Bank storage (fig. 6)

| 1<br>Time interval (hours) | 2<br>Maximum time in hours | 3<br>Actual time in interval (hours) | 4<br>Average bank storage in interval ($ft^3/s$) | 5<br>Bank storage in time interval (col. 3 × col. 4, hours × $ft^3/s$) |
|---|---|---|---|---|
| 0-1 | 1 | 1 | 100 | 100 |
| 1-3 | 2 | 2 | 50 | 100 |
| 3-11 | 8 | 8 | 30 | 240 |
| 11-21 | 10 | 10 | 20 | 200 |
| 21-72 | 51 | 51 | 10 | 510 |
| 72-312 | 240 | 240 | 5 | 1,200 |
| 312+ | --- | 24 | 0 | 0 |
| Totals | | 336 | | 2,350 |

Charge for bank storage loss is 70 percent of column 5 divided by duration of release: 4.9 $ft^3/s$

Inadvertent diversions

Charge for inadvertent diversion losses (fig. 7): 19.0 $ft^3/s$

Evaporation

Surface area increase (fig. 8): 40 acres

Charge for change in surface area (fig. 9): 0.5 $ft^3/s$

Charge for change in river temperature (fig. 10): 0 $ft^3/s$

TOTAL TRANSPORTATION LOSS------------------------------------------- 24.4 $ft^3/s$

TOTAL TRANSPORTATION LOSS (percent of release)---------------------- 24.4 %

DIVERSION SCHEDULES

Prior to recession at Colorado Canal

| 1<br>Time interval (hours) | 2<br>Maximum time in hours | 3<br>Release discharge ($ft^3/s$) | 4<br>Average bank storage (col. 4 above, $ft^3/s$) | 5<br>Inadvertent diversion ($ft^3/s$) | 6<br>Evaporation ($ft^3/s$) | 7<br>Channel storage (fig. 4, $ft^3/s$) | 8<br>Total (cols. 4-7, $ft^3/s$) | 9<br>Average divertible discharge ($ft^3/s$) |
|---|---|---|---|---|---|---|---|---|
| 0-1 | 1 | 100 | 100 | 19.0 | 0.5 | 70 | 190 | -- |
| 1-3 | 2 | 100 | 50 | 19.0 | .5 | 55 | 125 | -- |
| 3-11 | 8 | 100 | 30 | 19.0 | .5 | 10 | 59 | 41 |
| 11-21 | 10 | 100 | 20 | 19.0 | .5 | 0 | 0 | 60 |
| 21-72 | 51 | 100 | 10 | 19.0 | .5 | -- | 30 | 70 |
| 72-312 | 240 | 100 | 5 | 19.0 | .5 | -- | 24 | 76 |
| 312+ | --- | 100 | 0 | 19.0 | .5 | -- | 20 | 80 |

Release arrived at 1430 hours

During recession at Colorado Canal

Final divertible discharge from column 9 above------------------------------ 80 $ft^3/s$

Release recession began at 0200 hours

| Time interval from beginning of recession (hours) | Average divertible discharge (fig. 11, $ft^3/s$) |
|---|---|
| 0-4 | 62 |
| 4-8 | 33 |
| 8-12 | 13 |
| 12-16 | 3 |
| 16-22 | 0 |
| 22-32 | 0 |

## CONCLUSIONS

1. The travel time of releases from Twin Lakes Reservoir to Colorado Canal ranges from 29 to 69 hours depending on the flow of the Arkansas River. Travel time of releases from Turquoise Lake is 4½ hours more while releases from Clear Creek Reservoir is 2½ hours less.

2. Releases from Twin Lakes Reservoir to Colorado Canal are modified by channel storage, bank storage, inadvertent diversions, and evapotranspiration.

3. For releases up to 500 $ft^3/s$, channel storage ranges from 0 to 440 $ft^3/s$ depending on the time since the release arrived at Colorado Canal and the amount of the release. During the release recession, all water in channel storage arrives at Colorado Canal headgate soon enough to be diverted. Channel storage, therefore, is not a source of transit loss.

4. For releases up to 500 $ft^3/s$, the average rate of bank storage ranges from 0 to 445 $ft^3/s$ depending on the flow of the Arkansas River at time of release, the amount of the release, and the time since the release arrived at Colorado Canal. During the release recession, 70 percent of the water in bank storage is not divertible. Bank storage, therefore, results in a transit loss which is generally about 7 percent of the release depending on the duration of the release.

5. Inadvertent diversions range from 5 to about 47 $ft^3/s$ depending on the flow of the Arkansas River at time of release and the amount of the release. Most inadvertent diversions are not compensated for during the release period. Inadvertent diversions, therefore, result in a transit loss which is generally about 8 percent of a typical release.

6. Evaporation loss occurs due to the increases both in river surface area and in river temperature during a release. Sources of transit loss due to evaporation depend on the flow of the Arkansas River at time of release, the month of the year, and the amount of the release. Evaporation due to increased surface area ranges from 0 to 4.5 $ft^3/s$ or about 1 percent of the release. Evaporation due to increased river temperature ranges from 0 to 1.3 $ft^3/s$ or less than 1 percent of the release.

7. Transpiration loss due to bank storage is assumed to be negligible.

8. Releases from Twin Lakes Reservoir to Colorado Canal are generally subject to a total loss of about 16 percent while in transit down the Arkansas River.

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