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Engineering and Hydrologic Issues in Changing Water Uses

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INTRODUCTION

Under the Colorado System of Appropriation, water historically used for one purpose may be changed in the type, time and place of use and from direct flow diversion and use to storage and later use. To accomplish such a conversion, the applicant must demonstrate to the Water Court that the proposed new use and method of operation will not adversely impact the stream system or injure other vested water rights. Based on the evidence presented by both the applicant and objectors wishing to protect their rights, the Court may grant the application as filed or with certain conditions governing the future exercise of the water rights involved.

To assist the Court in evaluating applications and to inform objectors of the effect the change will have on the stream system, it is necessary to document the historic use of the water rights and define the proposed method of operation. While this is primarily an engineering task involving generally accepted procedures and analytic techniques, the results are not always (or usually) readily accepted by engineers representing objectors and state administrative officials. This is because although the procedures and techniques may be widely used and understood, their use involves areas of judgment that can lead to valid differences among qualified and experienced engineers and hydrologists.
This paper discusses some of the factual issues involved in changes of water rights and plans of augmentation and the factors that must be considered and resolved in establishing non-injury.

DETERMINATION OF INJURY

When an appropriator of a water right desires to change the manner in which the right is exercised, there are a number of factors that must be considered. These include the types of changes that are allowed, the procedures which must be followed to obtain the change, and the principles that govern the manner in which the changed water right may be exercised. The most important principle is that the exercise of the water right, after it has been changed, must not cause injury to any other water right, particularly junior water rights.

Traditionally, changes have been concerned with transfers of the point of diversion of an irrigation right from one place on the stream to another. As the demand for water increases in magnitude and changes in the type of use required occur in response to urbanization and industrial growth, the need to convert water historically used for irrigation and mining to other purposes, including municipal, manufacturing, energy development and recreation, becomes more common. Recognizing this need in 1969,
the State of Colorado enacted the Water Rights Determination and Administration Act, which defined a change of water right as follows:

"Change of water right means a change in the type, place, or time of use, a change in the point of diversion, a change from a fixed point of diversion to alternate or supplemental points of diversion to a fixed point of diversion, a change in the means of diversion, a change in the place of storage, a change from direct application to storage and subsequent application, a change from storage and subsequent application to direct application, a change from a fixed place of storage to alternate places of storage, a change from alternate places of storage to a fixed place of storage or any combination of such changes. The term change of water right includes changes of conditional water rights as well as changes of water rights."

This broad definition recognizes that the expeditious use of water necessitates flexibility in changing water rights corresponding with the need to maximize beneficial use of the state's water resources. This was emphasized in the 1969 act by the provisions for establishing a plan of augmentation which is defined below:

"Plan for Augmentation means a detailed program to increase the supply of water available for beneficial use in a division or portion thereof by the development of new or alternate means or points of diversion, by a pooling of water resources, by water exchange projects, by providing substitute supplies of water, by the development of new sources of water, or by any other appropriate means. Plan for Augmentation does not include the salvage of tributary waters by the eradication of phreatophytes, nor does it include the use of tributary water collected from land surfaces which have been made impermeable, thereby increasing the runoff but not adding to the existing supply of tributary water."
The flexibility allowed in changing water rights and implementing plans of augmentation is, however, limited by the principle that injury to the rights of others must be avoided. Injury can occur as an enlargement of use in either time (period of diversion), quantity (greater amounts diverted under the changed priority), or degradation of quality, by the exercise of the changed water right as compared to its historic use.

The determination of injury is a matter of fact and requires that the historic beneficial use of the water right be defined and compared with the future use to identify potential alterations in the flow regime of the river that would adversely affect other rights. The techniques applicable to identifying injury and evaluating proposed mitigating terms and conditions include hydrologic modeling and the analysis of historic beneficial consumptive use.

Once the potential for injury has been defined, terms and conditions designed to eliminate possible injury can be developed and incorporated in the application for the change of water rights or plan of augmentation. These terms and conditions become negotiable between the applicant seeking the change and the objectors to the change and will be included in the decree granting the change of water rights or the plan of augmentation. The general nature of terms and conditions that may be proposed are stated in the 1969 act as follows:
"Terms and conditions to prevent injury may include:

(a) A limitation on the use of the water which is subject to the change, taking into consideration the historic use and the flexibility required by annual climatic differences;

(b) The relinquishment of part of the decree for which the change is sought, or the relinquishment of other decrees owned by the applicant which are used by the applicant in conjunction with the decree for which the change has been requested, if necessary to prevent an enlargement upon the historic use or diminution of return flow to the detriment of other appropriators;

(c) A time limitation on the diversion of water for which the change is sought in terms of months per year;

(d) Such other conditions as may be necessary to protect the vested rights of others."

The nature and extent of potential injury liable to result from a proposed change of water rights varies with the type of change sought. Table 1 summarizes the principal types of water right changes encountered with examples and the corresponding nature of potential injury and some commonly applied terms and conditions for mitigation. In practice, a change of water rights or plan of augmentation will most likely involve one or more types of change and may require the imposition of a combination of the terms and conditions listed in Table 1, plus other conditions limited only by the imagination of the applicants and objectors. In some cases, provisions may be included in the decree for monitoring of the changed water rights or plan of augmentation over a period of years to ensure the terms and conditions do in fact prevent the injury anticipated.
The factual determination of potential injury and the definition of appropriate terms and conditions should be based on analysis of historic consumptive use under average and dry year conditions. This includes determination of the quantity, timing and location of return flows, the extent to which the rights involved have historically been exercised in priority and the degree to which junior rights have been dependent upon the availability of return flow from the rights to be changed or augmented. It is also necessary to consider the possibility that the change, if granted, will increase the frequency of junior rights being called out by the changed right.

The last consideration requires analysis of the relative location and priority of water rights on the stream system involved, usually facilitated by means of a straight-line diagram as illustrated by Figure 1, and an awareness of the possibility for so called rebound calls which occur when a transferred senior is, as a result of the transfer, in a position to call out a junior not previously affected. This call may then rebound from the newly affected juniors, who as a result, will be called out more frequently then before the change and thereby suffer a diminishment of their supply.

One final consideration that must be incorporated in a change or water rights or plan of augmentation that is not
directly related to injury is that the terms and conditions proposed be administrable by the State Engineer. This involves a recognition on the part of the parties involved in the proceeding when negotiating and specifying terms and conditions to recognize the limits of water commissioners and others making measurements and recording data. There have been cases where the final document became so complex, in terms of monitoring, data collection and administrative requirements, that the applicant was required to pay to the State the cost of an additional water commissioner required to administer the plan.

DETERMINATION OF HISTORIC CONSUMPTIVE USE

Historic beneficial consumptive use is the measure of a water right and its determination is important in the appraisal of the value of water rights and in establishing the basis for developing terms and conditions to be imposed on water right changes to prevent injury to other vested water rights. Consumptive use is defined as diversions less returns, the difference being the amount of water physically removed (depleted) from the stream system through evapotranspiration by irrigated crops or consumed by industrial processes, manufacturing, power generation and municipal uses. Stream depletions include both beneficial and non-beneficial consumptive uses.
The determination of historic consumptive use involves analysis of a number of factors, all of which are subjected to engineering judgment and legal interpretation. The first factor to be established is usually the study period which is selected to represent historic conditions. This is the period of record to be analyzed and should be representative of the conditions under which the water rights were exercised. In selecting a study period, it is important that streamflow and climatological records be available for analysis and that the period contain at least one critically dry year. Recent years are more likely to have better records available and will also reflect current administrative practices. Older periods, however, are often more representative of the extent of past irrigation, which in recent times in many areas has receded in the face of urbanization and other factors leading to the decline of irrigated agriculture.

By far the most common need for determining historic consumptive use involves an irrigation water right that is to be changed to some other time, type or place of use. To do this without allowing an enlarged use or causing injury to others water rights means that both the quantity and timing of the consumptive use under historic exercise of the right must be determined. This involves defining the type of crops irrigated, the diversions available under the right when in priority and the potential and actual irrigation and consumptive use occurring as a result of the irrigation.
The potential consumptive use is that which the crop would consume if a full supply of water were available to meet plant growth needs. The actual consumptive use is the amount the plant consumed of the available irrigation water. Irrigation consumptive use is the amount of consumptive use supplied by irrigation water applied in addition to the natural precipitation which is effectively available to the plant. Irrigation consumptive use in some cases may be supplied by natural sub-irrigation, which is generally not included in the amount of beneficial historic consumptive use available for transfer or conversion to other uses.

Figure 2 is a schematic representation of a stream and irrigation system showing the various components that must be analyzed and quantified in determining historic consumptive use. The principal components displayed in Figure 2 are discussed below by number.

1. **River flow** upstream of the point of diversion represents the physical supply available at the ditch headgate. Since surface runoff records are rarely available at the point of interest, it is necessary to establish the flow available by extrapolation from data for gages upstream or downstream or by correlation of records from hydrologically similar basins.
2. The amount diverted for irrigation is referred to as the 
stream headgate diversion and represents what is normally 
recorded by the state water official (water commissioner). 
This amount should not be confused with the farm headgate 
delivery which is the amount actually applied to the area 
irrigated and will be less that the stream headgate diversion 
by the net value of canal losses due to (4) evaporation, (8) 
seepage and (9) bypasses and canal gains from (5) precipitation 
and (6) inflow from surface runoff.

3. Undiverted river flow is the flow bypassing the irrigation 
headgate and may be supplemented by (15) ground water 
contributions which will be positive in gaining streams and 
negative in stream reaches that lose flow to the ground 
water system, (16) surface runoff from non-irrigated lands, 
(17) industrial and municipal discharges and (18) natural 
inflow from tributaries.

7. Water applied to irrigation is partially taken up by (10) 
evapotranspiration, usually considered synonymous with 
consumptive use, and which includes transpiration or building 
of plant tissues plus evaporation of soil moisture, snow and 
intercepted precipitation associated with vegetal growth. 
This is the water that has, through exercise of the water 
right, historically been depleted from the stream system and
thus is not available for diversion and use by downstream appropriators.

14. *Irrigation return flow* includes, in addition to (8) canal seepage and (9) bypasses, (11) deep percolation, which is water migrating below the plant root zone and returned to the stream system as subsurface flow and (12) tail water which returns to the stream as overland flow. Tail water normally returns to the stream within a matter of days, whereas deep percolation flows through the soil at a much lower rate, in many cases taking several months to reach the stream, thereby contributing significantly to winter flows.

13. Other losses to the atmosphere occur as a result of the irrigation operation, but in most cases are too small to be quantified individually and are grouped within the other major losses.

When evaluating the historic operation of irrigation water rights it is useful to calculate the irrigation efficiency by dividing the consumptive use by the amount diverted. The result for normal flood irrigation practice will generally range between 40 to 60 percent, meaning that 60 to 40 percent of the water diverted at the stream headgate returns to the stream. Other methods of irrigation using center pivot or linear sprinklers and drip irrigation systems will have higher efficiencies on the order of
80 to 95 percent. Table 2 shows how headgate diversions can be broken down into various kinds of conveyance and farm losses, including recoverable and irrecoverable losses, to arrive at the operating efficiency.

Diversions to a single ditch may be made under one or more separate decrees with different priorities and water from several ditches may be delivered to the same land. Ditches may also divert from more than one source and may carry both direct flow and storage water. This often creates problems in identifying and quantifying the land irrigated by individual water rights. Figure 3 illustrates a system of ditches and reservoirs used to irrigate lands on a ranch in western Colorado. For administrative purposes, it became necessary to determine and quantify the historic use of the water delivered by the McMahon Ditch from Red Dirt Creek to irrigated lands also served by other ditch and reservoirs as shown. The McMahon Ditch had decrees from Red Dirt Creek and Deer Creek and also carried storage water released from McMahon Reservoir. The parcels could also be supplied by water diverted from Pinto Creek, through the Heini Ditch and Reservoir system and from Lewis Reservoir.

To resolve this problem, it was necessary to evaluate aerial photographs for six different years, covering a period of 45 years, interview operators of the ditch and reservoir systems, the local water commissioner and the managers responsible for
irrigating the various parcels. In addition, computations were made of the consumptive use of the irrigated lands, which, when applied to irrigation efficiencies, indicated the quantity of water that was needed at the McMahon Ditch, Red Dirt Creek and Deer Creek headgates. This information was compared to the natural flow available, after satisfaction of obligations to downstream senior water rights, based on estimates from an existing surface runoff gage on Red Dirt Creek and estimates of the flows in Deer Creek and Pinto Creek derived by extrapolation from similar basins, to derive the amount of water that had historically been supplied from McMahon Reservoir. The results of an investigation such as this must be thoroughly documented and substantiated for use in negotiation with other water users and state officials or presentation to an administrative or judicial proceeding.

The unit consumptive use of irrigation water (volume of consumptive use per unit of area, commonly expressed as acre-feet per acre or simply feet or inches) by crops can be either measured or computed. Measurement is accomplished by instruments called lysimeters, which are tanks filled with soil in which crops can be grown under controlled conditions to measure the quantity of water lost by evaporation and transpiration. Measurement by lysimeters can provide site-specific data for deriving the coefficients needed in various computational procedures. The installations are costly however, and require regular maintenance.
At least two seasons of operation are necessary to obtain reliable data. Selection of location and method of operation are equally important to provide usable and acceptable data.

Numerous methods for computing the consumptive use of irrigation water by crops have been developed and are described in the technical literature. In the western United States, the most commonly used and recognized methods are the Blaney-Criddle and the Jensen-Haise formulas. The development and application of these two methods are described in detail in publications of the American Society of Civil Engineers (1) and the Soil Conservation Service (2). Both methods have distinct advantages and limitations.

The problems most commonly encountered in using either method involve selection of an appropriate study period considered to represent historic conditions, the identification of the crops irrigated under historic operation and the determination of crop coefficients, all compounded by the lack of data needed for application of the method selected. The results obtained may vary significantly depending on the method of computation selected, even when identical parameters are used. This is illustrated by Figure 4.

The resolution of these problems depends heavily on the judgment of the investigator and is often the result of negotiations between the parties involved in the proceeding. Once the unit
consumptive use has been calculated, it is applied to the area irrigated to arrive at the total volume of historic consumptive use.

EXAMPLE OF CHANGE IN PLACE OF STORAGE AND TYPE OF USE

In 1955, the City of Broomfield acquired title to storage decrees in the Zang Reservoir No. 1, Zang Reservoir No. 2 and Nissen Reservoir No. 6 from a development corporation. The development corporation had acquired title to land that is now downtown Broomfield and proceeded to develop the land occupied by the reservoir and irrigated by water from the three reservoirs and an irrigation ditch. Between 1955 and 1983, the City of Broomfield obtained its raw water supply by diverting directly out of an irrigation ditch and pumping the water into its Great Western Reservoir. Water from the reservoir was delivered to the City's water treatment plant and distribution system by gravity. In 1982, the City applied for a change in the place of storage from the three reservoirs to the Great Western Reservoir and a change in use from irrigation to municipal purposes. Protest to the application were filed by several objectors citing three principal issues:

1. Abandonment, since no record of use had been made since 1955.
2. Injury to junior water rights due to an expansion of use if the three senior reservoir priorities were exerted against appropriations made subsequent to 1955.

3. Loss of return flows historically accruing to the stream system from the use of water for irrigation purposes.

Aerial photographs taken in 1937 and 1941 were used to quantify the area irrigated by the original appropriators and subsequent users of the Zang and Nissen storage decrees. Through interviews with the people who farmed the land, representative cropping patterns were derived and used to compute the consumptive use under average, dry and wet year conditions. The consumptive use was converted to a farm headgate diversion by applying a farm headgate efficiency based on local practice and interviews with the former farmers of the land. The farm headgate diversion required to support the documented historic irrigation was then compared to the quantity of water available to the property from all sources, including direct flow ditch rights and storage in Zang and Nissen Reservoirs.

This analysis demonstrated that the water stored in Zang and Nissen Reservoirs was essential to support the historic level of irrigation and established the historic use of the reservoir decrees. These data were used to establish that the rights had
not been abandoned and to define terms and conditions that would allow the City to utilize its storage decrees while at the same time protecting vested water rights. The terms and conditions adopted were as follows:

1. Sixty-five percent of the total amount decreed to the reservoirs was transferred to Great Western Reservoir and changed to municipal use.

2. Thirty-five percent of the total amount decreed was abandoned to the stream to account for historic return flows.

3. Diversions under the Zang and Nissen priorities were limited to the period April 21st to August 1st to protect junior rights.

4. The maximum rate of diversion under the decrees was limited to 40 cfs, which represented 58 percent of the originally decreed rate of diversion.
REFERENCES


# Table 1

**WATER RIGHTS CHANGES**

**SOURCES OF INJURY AND MITIGATING MEASURES**

<table>
<thead>
<tr>
<th>Type of Change</th>
<th>Example</th>
<th>Source of Injury</th>
<th>Terms &amp; Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Type of Use</td>
<td>Irrigation to municipal/industrial.</td>
<td>Extension of diversion period from seasonal to year-round.</td>
<td>Limit diversions to historic irrigation season. Limit seasonal volume diverted to historic consumptive use. Return a portion of the water available for use by the changed right to the stream when diverted to maintain historic conditions. Abandon portion of right to stream. Treatment of effluent.</td>
</tr>
<tr>
<td></td>
<td>Mining to irrigation recreation or municipal.</td>
<td>Increase in consumptive use (depletion). Degradation of quality.</td>
<td></td>
</tr>
<tr>
<td>2. Place of Use</td>
<td>Transfer point of diversion of ditch along river. Transfer ditch priority to well(s) as alternate points of diversion.</td>
<td>Increase in period and quantity of diversion due to greater availability of water at new or alternate point of diversion.</td>
<td>Limit diversions at new point or wells to periods when water physically available and in priority at original point of diversion. Assess stream conveyance losses against diversions at new point of diversion or wells.</td>
</tr>
<tr>
<td>3. Time of Use</td>
<td>Irrigation to snowmaking.</td>
<td>Diversion for snowmaking is 100% depletion in fall with return in spring reduced by losses to evaporation and sublimination and delayed by ground-water return portion.</td>
<td>Provision of replacement water from other sources, such as non-tributary wells or imported water. Subordination of changed right priority to downstream junior to insure juniors supply not diminished by call from senior placed outside of historic irrigation season.</td>
</tr>
<tr>
<td>Type of Change</td>
<td>Example</td>
<td>Source of Injury</td>
<td>Terms &amp; Conditions</td>
</tr>
<tr>
<td>--------------------------------------------------</td>
<td>-------------------------------------------------------------------------</td>
<td>---------------------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>4. Direct flow to storage, usually accompanied by a change in type, place or time of use.</td>
<td>Direct flow irrigation right changed to storage for municipal or industrial use.</td>
<td>Alteration of historic return flow available to downstream junior.</td>
<td>Limit amount stored to historic consumptive use.</td>
</tr>
<tr>
<td></td>
<td>Mining right stored for use as source of augmentation water.</td>
<td>Enlarged use and increased depletion due to difference in consumptive uses and timing of diversions and returns.</td>
<td>Require releases from storage to compensate for lost return flows.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Limit period when water can be diverted to storage.</td>
</tr>
</tbody>
</table>
Table 2

**DISTRIBUTION OF LOSSES AND RETURN FLOWS**

Distribution of Non-Recoverable Losses and Recoverable Return Flow For an Assumed Headgate Diversion of 100.00 Acre-Feet

<table>
<thead>
<tr>
<th>Function</th>
<th>Loss Expressed as A Percentage Of</th>
<th>Non-Recoverable</th>
<th>Recoverable</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Conveyance</td>
<td>25</td>
<td>25</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>Surface</td>
<td>25</td>
<td>30</td>
<td>1.88</td>
</tr>
<tr>
<td></td>
<td>Seepage</td>
<td>75</td>
<td>5</td>
<td>0.94</td>
</tr>
<tr>
<td></td>
<td>Sub-Total Conveyance</td>
<td></td>
<td></td>
<td>2.81</td>
</tr>
<tr>
<td>Crop Evapotranspiration</td>
<td>38</td>
<td>100</td>
<td>100</td>
<td>38.00</td>
</tr>
<tr>
<td>On Farm Application</td>
<td>37</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surface</td>
<td>50</td>
<td>15</td>
<td>2.78</td>
<td>85</td>
</tr>
<tr>
<td>Percolation</td>
<td>50</td>
<td>5</td>
<td>0.93</td>
<td>95</td>
</tr>
<tr>
<td>Sub-Total On Farm</td>
<td></td>
<td></td>
<td></td>
<td>3.70</td>
</tr>
<tr>
<td>Total Losses</td>
<td></td>
<td></td>
<td></td>
<td>44.51</td>
</tr>
<tr>
<td>Surface</td>
<td></td>
<td></td>
<td></td>
<td>4.65</td>
</tr>
<tr>
<td>Subsurface</td>
<td></td>
<td></td>
<td></td>
<td>1.86</td>
</tr>
<tr>
<td>Ditch Headgate Efficiency</td>
<td>38 %</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Farm Headgate Efficiency</td>
<td>51 %</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
FIGURE 2 - IRRIGATION RETURN FLOW

LEGEND

River Inflow and Outflow
Beneficial Consumptive Use
Irrecoverable Losses
FIGURE 3 - WESTERN COLORADO IRRIGATION DITCH AND RESERVOIR SYSTEM
FIGURE 4

AVERAGE IRRIGATION CONSUMPTIVE USE
CORN AT CHERRY CREEK 1960-1975

TEMPERATURE AND PRECIPITATION: NOAA AT CHERRY CREEK DAM
GROWING SEASON: CORN 55° MEAN-32° FROST
ALFALFA 50° MEAN-28° FROST
CROP COEFFICIENT: B-C TR21
J-H ASCE

R_s IN J-H USING S AT DENVER, R_s0 FOR LATITUDE 391/2°
B-C= BLANEY-CRIDDLE, TECHNICAL RELEASE NO. 21
J-H= JENSEN-HAISE, ASCE, 1973