

# [***ARTICLE: 1969-2019: HOW HAVE THE SCIENCE AND ENGINEERING OF GROUNDWATER AND SURFACE WATER HYDROLOGY CHANGED IN 50 YEARS AND HOW HAVE THESE CHANGES AFFECTED WATER CASES?***](https://advance.lexis.com/api/document?collection=analytical-materials&id=urn:contentItem:5XBK-6JB1-F7VM-S42M-00000-00&context=1516831)

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**Reporter**

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**Author:** BY MARK R. PALUMBO [[1]](#footnote-2)1, JOE TOM WOOD P.E. [[2]](#footnote-3)2, STEVE WITTE P.E. [[3]](#footnote-4)3, AND CRISTYN R. RADABAUGH P.E. [[4]](#footnote-5)4

**Highlight**

This paper represents the efforts of four authors. Steve Witte authored the introduction section of the paper, Joe Tom Wood authored the surface water section, Mark R. Palumbo authored the ground water hydrology section, and Cristyn R. Radabaugh authored the accounting section. Each author also contributed to the "Are We Better Off Now Than We Were?" section.

**Text**

**[\*537]**

I. Introduction

In the months leading up to the ***Colorado*** legislative session in which the Water Right Determination and Administration Act of 1969 (or, the "69 Act) was enacted, almost certainly there was a great deal of angst concerning the social order that was to be governed by this body of law in the future. Now, looking back over the past half century, we can see how this innovative piece of legislation has been applied and how it has evolved. We can see how those involved in its creation relied upon our historical moorings in this state's experiment with the prior appropriation doctrine and their manifest faith in technology to provide solutions for the future, which was a hallmark of that era. This paper will primarily focus on the role of science and engineering on two of the three primary innovations of the 1969 Act; 1) the integration of ground water and surface water in ***Colorado***'s water allocation system and 2) the revolutionary concept of allowing out-of-priority diversions pursuant to an approved plan for augmentation. The third innovation, creation of water courts, to exclusively deal with "water matters", will receive less attention, except to note the fact that this new venue has given rise to a specialized type of expert witness to explain relevant technical matters to Water Judges as the triers of fact.

***Colorado*** was growing throughout the decade of the 1960s. From 1,753,947 residents in 1960, the population reached 2,207,259 a decade later. The interstate highway system, while not yet completed, was rapidly progressing. While the Cold War continued and school children throughout the state routinely practiced evacuating classrooms into ubiquitous fall-out shelters, there was a prevailing sense that we were winning the space race challenge set before us by President Kennedy early in his term and that we would indeed put a man on the moon before the end of the decade. Elsewhere in the country, racial tensions were mounting, and political assassinations were becoming almost commonplace. While their sons were agonizing over their personal involvement in another conflict, twenty-some years after returning home from Europe, the South Pacific and Korea, the "Greatest Generation" was attaining the height of their influence and political power. Business in ***Colorado*** was good. Reclamation continued throughout the West and the extension of rural electrification provided access to ***Colorado***'s ground water resources as never before and particularly so with respect to areas underlain by the Ogallala Aquifer and from the alluvium along the Arkansas and South Platte ***Rivers***.

As has been previously noted elsewhere, "Technology always precedes the law" and the ***Colorado*** legislature began to recognize the limitations of pre-existing law, first by enacting the ***Colorado*** Groundwater Management Act in 1965. In this legislation, the traditional (and constitutional) policy requiring the **[\*538]**beneficial use of water through appropriation was affirmed with respect to the "designated groundwaters of the state" and with respect to "nontributary groundwater." The legislature also declared that the doctrine of prior appropriation was to be modified to permit full economic development of "designated groundwaters" but found this doctrine to not be applicable with respect to "nontributary groundwater." Finally, this legislation retained or established permitting procedures to regulate the allocation process for tributary groundwater, "designated groundwaters" and "nontributary groundwater outside of designated basins" but without providing a definition of "nontributary groundwater" until 1985.

One of the principle objectives for the Water Rights Determination and Administration Act is evident from the language of the "69 Act itself:

Recognizing that previous and existing laws have given inadequate attention to the development and use of underground waters of the state, that the use of underground waters as an independent source or in conjunction with surface waters is necessary to the present and future welfare of the people of this state, and that the future welfare of the state depends upon a sound and flexible integrated use of all waters of the state. [[5]](#footnote-6)5

With a growing demand for water from already over-appropriated water sources by ***Colorado***'s existing population and with an ever-growing population, the need to utilize ground water resources conjunctively with surface water resources could not be overlooked and a just system of regulation was needed. However, at that time...and perhaps up to including the present, the physical interactions between ground water and surface water were (and are) not well understood by most people. People often applied what they knew or had observed regarding surface water to arrive at incorrect conclusions about ground water and imagined the existence of vast underground lakes or ***rivers***. Clearly, the need for a more sophisticated level of understanding of the movement of fluids through porous media of various properties and around and through various types of geologic structures was needed to accurately predict the effect of ground water withdrawals on surface water and to appropriately regulate the conjunctive use of both types of water among competing claimants.

Although the originator of the concept of a "plan for augmentation" may be lost to history and the credit for this innovation, which first appeared in the annals of ***Colorado*** law upon the enactment of the "69 Act, may forever remain unclaimed, it is but an extension of the earlier concept of an exchange of one type of water for another in equal amounts so as to not cause injury to other water right owners. Nevertheless, this is an ingenious concept intended to allow for more extensive beneficial uses of finite water resources shifting the emphasis from entitlement by right to entitlement subject to non-injury to superior rights. The key to implementing this concept is based on one's ability to demonstrate non-injury to senior water rights. This often involves analysis of the historical use of multiple water rights to determine not only the quantity of water that can be expected to be yielded by the water right to be changed to be used as a substituted supply, but also to determine the legitimate expectations to be preserved **[\*539]**in order to prevent any injury to a senior water right. The general standard that proposed changes of water rights must not injure the vested water rights of others has existed throughout most of the 20th century. An even finer point on this standard has existed in case law for most of that time:

An order permitting a change in point of diversion does not, and cannot, in any way, enlarge the right of its recipient by conferring upon him the power to divert a greater quantity of water from the stream than he theretofore took, nor permit him to use it for a longer length of time than he was previously entitled to. [[6]](#footnote-7)6

However, as will become apparent, it was not until the dawn of The Age of Limits, that this principle received meaningful application. Historical use analysis are now commonly used in changes of water right proceedings to quantify and more effectively constrain the use of changed water rights to conform with historical practices. Over time these analyses and the methods used have become increasingly sophisticated and this paper will explore various aspects and implications of these methods over time.

As we now stand on the eve of the 50th Anniversary of the Water Rights Determination and Administration Act, ***Colorado***'s population now stands at around 5.8 million people, or roughly 2.65 times as many as were here in 1970. We stand awestruck at how men of vision, acting without, cell phones, computers or email, were able to fashion a framework anchored to the foundations set by their predecessors and yet able to withstand yet unseen storms to provide security for future generations. We will now examine how the "69 Act has withstood the test of time from the perspective of the changes in tools, techniques and tactical revisions needed to implement it. We shall also offer opinions regarding whether we are actually better off now than we would have been using the system that existed more than half a century ago.

II. Changes of Water Rights, Appropriative Rights of Exchange, and Plans for Augmentation

The purpose of this paper is to describe and compare the engineering from the early years of the 1969 Act with the engineering that engineers commonly practice and see in recent times (today), insofar as changes of water rights (changes), appropriative rights of exchange (exchanges), and plans for augmentation (augmentation plans) are concerned.

In doing so, I asked several colleagues to provide me, as a favor, with copies of engineering reports for early (early to mid-1970s) changes, exchanges, and augmentation plans, and I used the Division of Natural Resources Weblink to obtain other engineering reports. Because I found or received from colleagues only a few actual early engineering reports, I also reviewed transcripts of trial or hearing testimony, transcripts of deposition testimony, and decrees themselves that informed me on how the engineering was performed. I would like to acknowledge and thank the following colleagues for their efforts in providing me, or attempting to provide me, with early engineering reports and/or early **[\*540]**engineering tools: Doug Clements of Spronk Water Engineers; Patricia Flood and Bill Lorah of Wright Water Engineers; Bruce Kroeker of TZA Water Engineers; Bill Warmack of Applegate Group; Bret Swiggle and Gary Thompson of W. W. Wheeler and Associates; and Steve Witte, recently retired Division Engineer for Water Division No. 2 (the Arkansas ***River*** basin). I would also like to thank Kate Ryan and Tia Gerung of Berg, Hill, Greenleaf, and Ruscitti for providing me with the ***Colorado*** statutes for changes of water rights, exchanges, and plans for augmentation, and confirming dates for the first *Wyoming v* ***Colorado*** lawsuit over the Laramie ***River***, and Cristy Radabaugh of Martin and Wood Water Consultants for reviewing and editing an early draft of this paper.

For decrees for today's changes, exchanges, and augmentation plans, I felt confident that I could describe the engineering methods and even characterize them to some extent.

I shall first describe engineering practices from the early years under the 1969 Act (early to mid-1970s) by describing one or a few cases from that time. Then I shall describe the engineering methodologies that engineers commonly practice today. Finally, I shall identify changes that have taken place from the early years to the present. I start with changes, then address exchanges, and lastly deal with augmentation plans, because this order resembles the chronological order in which these three types of adjudications proceeded (with changes and exchanges preceding the plans for augmentation that the 1969 Act added to ***Colorado***'s overall water scheme).

A. Decrees for Change(s) of Water Rights

Just as a reminder, the 1969 Act, as amended, defines a change of water rights, as follows:

(a) Means a change in the type, place, or time of use, a change in the point of diversion except as specified in section 37-86-111 (2), a change from a fixed point of diversion to alternate or supplemental points of diversion, a change from 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 except as specified in section 37-87-101 (3), 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; and

(b) Includes changes of conditional water rights as well as changes of water rights. [[7]](#footnote-8)7

B. Early 1969 Act Change Decrees

1. Crystal Lakes Development Company's Change Decree [[8]](#footnote-9)8

The Company filed its applications in Case Nos. W21 and W22 in late **[\*541]**1969, and then refiled the applications in 1970 in what became W275. The Division 1 Water Court entered its W275 decree in December of 1971.

The decree identified the water rights by quantity, location of point of diversion, prior decree, and as used for the purpose of irrigation. The decree granted the Company's claim to allow portions of the water rights decreed to the Currie Ranch Irrigation Ditches No. 11 and No. 12 to be diverted at a new point of diversion, the headgate of the Panhandle Ditch, to be used for domestic purposes, including for storage in a structure that would inundate the points of diversion of the two Currie Ditches. Giving few, if any, engineering details, the decree found that the historical diversions by the two ditches were 330 acre-feet per year, and that "(T)he present consumptive use of the water from Currie Ranch Ditches No. 10 and 11, is 66 acre feet per year and the probable consumptive use of the proposed Crystal Lakes Development will be about 20 percent of its total water usage." The decree then found that "(T)o obtain a consumptive use of 66 acre feet per year at a 20 percent rate, the Crystal Lakes Development will be able to divert a total of 330 acre feet per year." (According to the testimony on January 26, 1950, of Engineer Royce J. Tipton, in the trial concerning a transfer of water rights by the City of Englewood in Douglas County Civil Action 1706, "(T)he term itself, "consumptive use," was coined during the first Laramie ***River*** Suit, Wyoming versus ***Colorado***.' [Transcript page No. 770] This origination of the term would have occurred sometime in the period between May 29, 1911, when the suit was filed, and June 5, 1922, when the suit was decided by the United States Supreme Court.)

The decree then ordered the 330 acre-feet value be the annual limit to the diversion of the changed rights, and that, "except during times of "free water'," the Currie Ranch Ditch No. 10 divert no more than the flowrate previously decreed to it (2.20 cfs), that the Currie Ranch Ditch No.11 divert no more than the flowrate previously decreed to it (2.40 cfs), that the changed rights may be stored and used for domestic purposes, and that the ditches maintain their originally decreed priority dates.

While I can't tell much from the decree about the engineering, the decree's introductory paragraph mentions that "the Referee, desiring more specific information, requested that an Affidavit on the amount of water to be consumptively used be submitted by Applicant..."

The DNR Web-link contained an affidavit by Engineer M. W. (Mort) Bittinger which appeared to be the affidavit requested by the referee. The affidavit noted the ditches' consumptive use of 66 acre-feet per year and the 20% consumptive nature of the development's use of water. I believe that this affidavit summarizes Mr. Bittinger's engineering and that it, therefore, can stand *in lieu* of an engineering report for our purposes. Unfortunately, all that Mr. Bittinger states about his engineering practices is "THAT in accordance with accepted engineering practices, the net annual irrigation water requirement of pasture grass in the vicinity of the Currie Ranch has been computed as 0.91-0.96 acre-feet per acre, depending upon the dates of commencement of spring thaw and autumn frost;" and "THAT an average annual irrigation water requirement of 0.94 acre-feet per acre, when applied to the 70 acres which have historically been irrigated from the ditches, indicates that the historical average consumptive use by pasture of irrigation water delivered from the subject ditches amounts to approximately 66 acre-feet per year..."

**[\*542]**Even though I cannot detail the engineering practices that Mr. Bittinger employed in this change case, I can identify the *types* of engineering analyses for this case as: (1) quantifying the area historically irrigated by the two ditches whose water rights were to be changed at 70 acres; (2) calculating the historical *annual* consumptive use requirement at 0.91 to 0.96 acre-feet per acre; (3) calculating the historical *annual* consumptive use of 66 acre-feet; and (4) balancing the *annual* historical consumptive use of 66 acre-feet per year with a future *annual* domestic consumptive use of 20% of 330 acre-feet per year, or 66 acre-feet per year, of domestic use.

2. Melvin C. Rich's Change Decree [[9]](#footnote-10)9

Rich filed his application in Case No. W445 on December 31, 1970, and the Division 1 Water Court entered its W445 decree in late 1971.

Rich sought to change his interests in two ditches diverting from Cherry Creek (in Water District 8) to two wells as alternate points of diversion.

The decree references an engineering report, but I could not obtain a copy. The decree reflects the following engineering results and methods.

The decree stated that the engineering report concluded that the consumptive use of crops previously raised would be approximately 17 inches to 24 inches each *year*, and that "for purposes of a solution to the overall problem, 21 inches of water per *year* will be used in the analysis." The decree went on to state that the report found that 123 acres had been historically irrigated, and that the applicant's lands consumptively used 215 acre-feet per *year*.

I note that the decree itself contained, for each of the two ditches being changed, a summary of historical diversions that included, for each year, the year, the number of days of diversion from the beginning date each year to the ending date each year, total days of diversion, the acres irrigated, the average daily amount (cfs) diverted, and the acre-feet diverted.

The decree introduces these tables by saying, "Records filed in the State Engineer's Office reflect the following," and I imagine that the referenced engineering report was the source of the tables.

Once again, I really don't know the engineering methods or their details, but I do have an idea of what the engineer *did* for this change case, which include: (1) quantifying the area historically irrigated by the two ditches whose water rights were to be changed at 123 acres; and (2) calculating the historical *annual* consumptive use of 215 acre-feet.

3. Genesee Associates' Change Decree [[10]](#footnote-11)10

Genesee Associates filed its application in Case No. W1564 on November 1, 1971, and the Division 1 Water Court entered its decree on October 30, 1972. Genesee Associates sought to change the water rights appurtenant to seven shares in the Warrior Ditch Company, whose ditch by the same name now diverts from Bear Creek within the Town of Morrison, and from Turkey **[\*543]**Creek near the Town, in Water District 9.

Although I found no engineering report for this change, I did find a transcript of the testimony of Engineer Bill Lorah, of Wright Water Engineers, in a hearing before the court in this case. As I can tie most of Mr. Lorah's quantitative results to values in the decree, I shall take the hearing transcript to stand for the engineering methods that he employed for this case.

Mr. Lorah, in describing the four water rights decreed to the Warrior Ditch, testified that although a portion of the Simonton Ditch priority had previously been transferred to the Warrior Ditch, the Simonton Ditch was not involved in Genesee Associates' change.

Mr. Lorah described the amounts (cfs) of Warrior Ditch Priorities 4, 14, and 16 that had previously been transferred out of the Warrior Ditch by the Town of Morrison, and he described the amounts of these three priorities that Genesee Associates was transferring.

Mr. Lorah "agreed" (1) that his proposed change would keep the stream whole; (2) to leave 20% of Genesee Associates' interests in the ditch to compensate for ditch loss; (3) to leave Genesee Associates' interest in Priority No. 8 (from Turkey Creek) in the ditch; (4) that the changed interest in Priority 4 should be divertible on a year-round basis; and (5) that there should be an *annual* limit of 186 acre-feet on Genesee Associates' diversion of its changed rights.

As to Mr. Lorah's proposed year-round diversion of Priority 4, the decree stated that "(As) to the No. 4 Priority, applicant should restore any depletions (difference between diversion and return) which may be necessary so that conditions on the stream at the headgate of any ditch. other than the Warrior Ditch, whose lawful diversions would be impaired by this depletion, are the same as they would have been if the No. 4 Priority had not been transferred." [[11]](#footnote-12)11Yet, the decree included no specific terms and conditions to effectuate this restriction.

He also testified that (1) 70 acres had been historically irrigated, (2) that these 70 acres should not continue to be irrigated with the water rights transferred to Genesee Associates; and (3) that he believed "that this transfer will not injure the vested rights of other water users on Bear Creek."

Mr. Lorah also testified that a central wastewater treatment plant would serve almost all the development, that most of the in-house use of water would return to the stream, and that the proposed development would have a very small amount of water used for irrigation.

Mr. Lorah testified that Genesee Associates should continue to pay the assessments on its shares to the ditch company, which term and condition the decree included.

Although Mr. Lorah did not speak directly to the details or results of any historical consumptive analysis, he did add to our discussion by testifying that the change decree should include: (1) leaving portions of the applicant's interests in the ditch to compensate for ditch loss; (2) allowing applicant's interest in one particular priority to be used beyond its historical season of use; and (3) a prohibition of a double use of applicant's changed interests on lands historically irrigated.

**[\*544]**

4. City of Lafayette's Change Decree [[12]](#footnote-13)12

Lafayette filed its application in Case No. W8346-A-76 (henceforth W8346) on November 1, 1971, and the Division 1 Water Court entered its decree on August 28, 1979.

Lafayette sought to change the water rights represented by 18.22 shares in the Howard Ditch, which diverts from South Boulder Creek in Boulder County. Bruce Kroeker of TZA Water Engineers provided me a copy of an engineering report by Zorich-Erker Engineering, Inc., dated November 1979, prepared for Lafayette's change in W8346, and I shall describe the engineering methodologies principally from this report.

The report's introduction begins by stating that Lafayette purchased the 18.22 shares for the purpose of developing a water supply capable of meeting the City's "future growth *needs*." The introduction states that the City "is seeking to change the point of diversion and type of use...," and that "(I)n order to prevent injury to other water rights owners in the South Boulder Creek Drainage Basin, the City of Lafayette has agreed to limit future diversions that will be associated with these shares to the historic consumptive use."

After describing the water right originally decreed to the Howard Ditch, the report noted that five prior transfers had occurred, leaving 70.53 out of 100 original shares, and 25.6392 cfs out of 36 cfs originally decreed to the ditch, remaining in Howard Ditch.

Using 1941 aerial photographs obtained from the Agricultural Stabilization and Conservation Service (ASCS) in Salt Lake City, Zorich-Erker plotted the legal descriptions of the lands owned by the prior owners of Howard Ditch stock. Then Zorich-Erker determined the irrigated acreages based on visual examination of the photographs, followed by field inspection of the parcels of land, and confirming the acreages with the former Ditch Superintendent and Ditch Rider for the Howard Ditch. Zorich-Erker concluded that the 18.22 Howard Ditch shares historically irrigated 123.5 acres.

The report then stated that the vegetation historically irrigated by the 18.22 Howard Ditch shares consisted of alfalfa and native hay, with native hay being very similar to alfalfa in respect to "the amount of water that is annually consumed for growth."

The report next addressed the "net potential consumptive use," which the report defined as being "the net amount of water, in addition to rainfall, which can be fully utilized by the vegetative growth of a given area for plant transpiration and building of plant tissue plus the net amount of water, in addition to rainfall, which is evaporated from plant surfaces and from adjacent soil." The report states that the method chosen to determine "consumptive use" was "the Blaney-Criddle method as outlined in Soil Conservation Service Technical Release #21, September 1970 edition. This method was used because of its universal acceptance and because of the existence of readily available data." (I note that the proper term for this method is the " *Modified* Blaney-Criddle Method," because the report's results are in the form of monthly values as per the 1970 version referenced by the report; the original Blaney-Criddle method produced **[\*545]**only annual values.) The report's term "net potential consumptive use" appears to me to be what engineers today alternatively call "irrigation water requirement (IWR)," or "crop irrigation requirement (CIR)," or "irrigation consumptive use requirement (ICUR)." The report concluded that the average annual net potential consumptive use for the alfalfa-native hay crop averaged 2.15 acre-feet per acre, or 265.5 acre-feet for the 123.5 irrigated acres.

The report summarized the Howard Ditch's historical diversions in a table, listing by year the first and last days of diversion, the number of days of diversion, the average and maximum daily rates of diversion, and the amount of water diverted for the year (acre-feet), as well as the amount of water diverted per share. The report stated that the annual diversions per remaining share averaged 30.63 acre-feet, that the annual diversion for Lafayette's 18.22 shares averaged 558.08 acre-feet, and that the average annual diversion of 558.08 acre-feet amounted to 2.1 times the average annual net potential consumptive use of 265.5 acre-feet.

The report then posited that because the available water supply is greater than the net potential consumptive, the average annual beneficial consumptive use for Lafayette's 18.22 Howard Ditch shares averaged 265.5 acre-feet. The report further justified the resultant average annual consumptive use of 265.5 acre-feet by going through an explanation of how a farmer's "water supply is not delivered in even doses," that a farmer will cease his irrigation to dry out the crop before it is harvested, and how the plants draw water from the "pore spaces of the underlying soil," and that when delivery of the water resumes, the delivered water "is used for meeting the plants' net watering requirements and for refilling the empty pore spaces in the underlying soil."

The report said that "Lafayette plans on fully using the historical consumptive use of 265.5 acre-feet per year through the processes of use, reuse, and exchange..." From an analysis of records of the water treated at the Marshall Filter Plant and records of the locations of use of said treated water, the report found that 77.7% of the water treated at the plant became return flow, but only 11.2% of the treated water was located in the South Boulder and Dry Creek Basins. Thus, the report concluded that 8.7% of the water treated at this plant became return flow to the South Boulder and Dry Creek Basins.

The report then stated that the diversion for the changed Howard Ditch water should be increased to 290.8 acre-feet per year, with 265.5 acre-feet per year being the fully consumable amount for Lafayette's use, and the remaining 25.3 acre-feet per year being needed to maintain historical return flows to the South Boulder and Dry Creek Basins (25.3 af/yr = 290.8 af/yr X 8.7%). The report also proposed a season of diversion of April 1 through October 31 for Lafayette's changed Howard Ditch rights.

Last, the report proposed monthly maximum diversions equal to the product of each month's average annual consumptive use and the factor 1.5. On this issue, the decree provided for the use of the factor of 1.3, not 1.5, to be applied to the monthly values, totaling 290.8 acre-feet for the year, in Paragraph 31 of the W8346 decree.

The decree contained other provisions not evidenced in the Zorich-Erker report, including the following.

The decree reduced Lafayette's diversion entitlement at the City's alternate **[\*546]**points of diversions for its Howard Ditch shares from 6.56 cfs to 3.28 cfs, abandoning 2.624 cfs to the stream, and leaving 0.656 cfs of Lafayette's Howard Ditch water for the Howard Ditch to divert, and reducing the total diversion entitlement at the Howard Ditch to 19.7352 cfs.

The decree required Lafayette to continue to pay the Howard Ditch Company's assessments on the City's shares.

Due to objectors' questioning Lafayette's contention that discontinuance of Howard Ditch diversions of Lafayette's water would revert the irrigated lands to their natural state, the court retained jurisdiction on dry up for three years.

The decree required daily accounting, *recorded in an appropriate format*, to include point and amount of diversion, and the amount of water for which return flow credit may be taken. The decree provided a table of monthly return flow percentages, to be applied to the respective amount of (changed Howard Ditch) diversion.

Wow! What a change decree! Look at all the bells and whistles! I am not asserting that this paper concludes that change decrees continued to mature overall in any sensible or logical or cumulative manner, but I am going to continue to describe what new engineering issues and methods that Lafayette's W8346 change of Howard Ditch shares add to our "pot."

These new engineering issues and methods include: (1) a statement of need for the Howard Ditch water to meet the City's "future growth needs;" (2) an overt overall purpose of the change to prevent injury to certain other water rights; (3) an accounting of shares and and amounts of the water right (usually cfs or acre-feet) previously transferred; (4) use of a specifically referenced source of information for aerial photographs (notably, as we shall see later, from Salt Lake City, Utah), together with field inspection of the historically irrigated lands; (5) identification of the specific irrigated crops; (6) the definition of "net potential consumptive use, "as well as identification of the specific method of calculation of consumptive use, the Soil Conservation Service's 1970 Technical Release #21, and the resulting *monthly*, and annual, values thereof; (7) a detailed summary of *monthly*, and annual, diversions by the subject ditch; (8) a verbal engineering justification for the entire net potential consumptive use being the resultant historical consumptive use; (9) a detailed engineering analysis to maintain historical return flows to the South Boulder Creek and Dry Creek Basins; (10) a proposed limitation to a specific season of use, April 1 through October 31; (11) a proposed set of monthly maximum diversions with the annual consumptive use diversion capped at 265.5 acre-feet; and (12) reductions to Lafayette's diversion entitlement for an amount abandoned to the stream (which might possibly have been an effort to maintain historical return flows in the main) and an amount to be left in the ditch, with a commensurate reduction to the total amount (cfs) of water that the ditch can divert in the future. [[13]](#footnote-14)13

**[\*547]**

C. Today's Change Decrees

1. Summary of Case No. 12CW73 [[14]](#footnote-15)14

I have chosen the change of water rights represented by shares in the Farmers Independent Ditch Company (FIDCo) in Case No. 12CW73 as representative of a change decree in today's time (or recent period), because I believe that it reflects many of today's engineering methodologies (and today's legal approaches) employed in change decrees. I realize that it is probably impossible for a single change decree of today to be representative of all change decrees throughout ***Colorado***, but I select the 12CW73 change decree, because it contains all, or most all, of the engineering analyses of historical use and the terms and conditions necessary to implement the change (that is, all of the "bells and whistles"). I also note that the engineering behind today's changes of water rights may vary across ***Colorado***, but as more of my experience lies in Division 1 than in other Water Divisions, I am heavily influenced by my Division 1 experience.

In 2012 ACWWA, ECCV, and United filed an application to change a total of 37.5 shares in the Farmers Independent Ditch Company (FIDCo), whose ditch by the same name diverts from the right (east) bank of the South Platte ***River*** between the Cities of Fort Lupton and Greeley. These three applicants filed several reports on the changes sought for the ditch's rights, which were originally decreed for irrigation. Opposers also filed reports on the changes sought. Using the final decree as a template for the engineering matters in this change, and referring to the reports themselves when necessary, the following are what I believe are the typical engineering practices in today's change decrees.

2. Descriptions of the Water Rights to be Changed [[15]](#footnote-16)15

The 12CW73 decree describes the water rights to be changed by identifying the name of the structure for which the change(s) is being sought; the original decree, its case number, its court of jurisdiction, and its date of entry; a legal description for the decreed point of diversion (and in other cases that I've seen, legal descriptions for any undecreed points of diversion); the source of water for the changed rights (in this case, the South Platte ***River***); the priority dates and amounts (cfs) for the whole of the two rights to be changed in this case, and for each party's interest in the two rights; and the use or uses originally decreed to the water rights. The 12CW73 decree also provided the number of FIDCo shares that ACWWA was changing (20 shares), the number of shares that ECCV was changing (17.5 shares), and the total number of outstanding shares in the ditch company (800 shares). Whether all of these matters constitute engineering may be arguable, but engineers typically assist in providing this information, particularly the calculations of the amounts (cfs) of the rights to be changed based on the share-pro-rata portions of the ditches' rights.

**[\*548]**The 12CW73 decree then proceeded by including a series of findings of fact for the change of ACWWA's 20 FIDCo shares, as I shall describe, and then it included a very similar or parallel series of findings of fact for ECCV's 17.5 FIDCo shares. The following describes the findings of fact for the change of ACWWA's 20 FIDCo shares. [[16]](#footnote-17)16

The 12CW73 decree identified the farm, by name (the Ruggles Farm), where ACWWA's shares were historically used, the share certificate number for the shares that ACWWA acquired, and identified the location and the number of acres historically irrigated by the shares with a figure attached to the decree.

This may be where the decree really begins to rely on engineering.

Paragraph 12 of the decree puts forth a general engineering method by which ACWWA's historical consumptive use of its FIDCo water was determined. Paragraph 12 reads as follows.

Accordingly, to quantify the historical consumptive use of ACWWA's FIDCO Shares, ACWWA assumed that the monthly farm headgate delivery to ACWWA's FIDCO Shares was the lesser of the pro-rata share of the South Platte ***River*** headgate diversions less ditch loss, or the on-farm water demand taking into account the consumptive demand for the crops, irrigation efficiency, and soil moisture. For purposes of estimating farm headgate deliveries of ACWWA's FIDCO Shares, the consumptive use was divided by a farm efficiency that was five percentage points less than the maximum irrigation efficiency.

The Applicants' preliminary engineering report, by Brown & Caldwell (B&C), dated May 1, 2013, states the following about sources of general information on historical use on page 2-1.

Information regarding the historical use of the subject shares was gathered from various available sources, including *statements of historical use that were acquired during acquisitions of the shares, personal interviews with farmers having knowledge of the farming practices on the various parcels*by either Duane Helton Consulting or Brown and Caldwell, and *publicly available information regarding irrigated lands in the South Platte Basin, including the State of* ***Colorado****'s South Platte Decision Support System (SPDSS).*

In the preceding quotation, and in the quotation that next follows, I have italicized the engineering methods that I believe form the heart of quantifying the area historically irrigated.

In discussing historical irrigation practices, including the area irrigated, the B&C preliminary report adds a footnote 2 to the bottom of page 2-2 that states the following.

Brown and Caldwell verified the information in the D. Helton Consulting reports *by reviewing and/or analyzing aerial and satellite imagery;* publicly recorded surveys, *deeds*, and legal documents; *statements of historical use*; and publicly available information regarding irrigated lands in the South Platte Basin, including the South Platte Decision Support System (SPDSS). Brown and **[\*549]**Caldwell also *reviewed notes from personal interviews by D. Helton Consulting with individuals having knowledge of the farming practices on the various parcels*.

I want to emphasize the large bodies of aerial and satellite photography available today from the Internet ( *e.g*., NRCS (National Resources Conservation Service) and NAIP (National Agriculture Imagery Program)). A fairly popular practice for the determination of historically irrigated area, bottom line, is to acquire aerial or satellite photography at a frequency of about one every decade, interview the historical irrigator and get him/her to delineate his/her irrigated areas on a copy of the aerial/satellite photo, preferably then perform a field visit with the historical irrigator to determine if his/her statements can be corroborated in the field, and then return to one's office or motel room and cleanly depict the irrigated areas on another copy of the photo, and measure the irrigated area(s) in acres. After all of this is said and done, then compare this result against other available sources of information to determine the reasonableness of the irrigated area developed from the photo, the interview, the field visit with the historical irrigator, and the result of this series of steps.

Some engineers believe that the determination of historically irrigated area includes both engineering and art.

Paragraphs 12 and 13.3 of the decree together state that historical farm headgate deliveries were the lesser of (1) share-pro-rata diversions, less ditch loss, and (2) the on-farm water demand taking into account the consumptive demand for the crops, irrigation efficiency, and soil moisture. For purposes of estimating farm headgate deliveries of ACWWA's FIDCO Shares, the consumptive use was divided by a farm efficiency that was five percentage points less than the maximum irrigation efficiency. (I note that several fairly recent Division 1 change decrees have relied on engineers' demand-based analyses, one of the earliest of which was PSCo's change of Water District 2 rights in a 2001 Division 1 application. From my experience, engineers have generally employed demand-based analyses of historical use for ditches that have been generally water-long.) I see no indication from the 12CW73 decree or engineering that any effort was made to reduce excess historical FIDCo ***river*** headgate diversions when the FIDCo water rights were out of priority.

The statements in Paragraph 12 related to taking the farm headgate delivery as the lesser of share-pro-rata diversions, less ditch loss, and the on-farm water demand effectively require us engineers to determine ditch loss, the consumptive demand for the crops, irrigation efficiency, and soil moisture.

Paragraph 13.1 states that the study period of 1950 through 2010 "was selected to represent the longest period of reliable diversion, cropping, and climate data for the subject farm. The study period is sufficiently representative of wet, average, and dry years, and is reliable for the purpose of this Decree. The study period ended in 2010 because that was the end of irrigation on the Ruggles Farm."

Paragraph 13.3 characterizes the historical ***river*** headgate diversions, but it does not state the source of same. Page 2-2 of the preliminary report advises us that B&C relied on HydroBase for ***river*** headgate diversions. Steve Witte notes that HydroBase is the State Engineer's current repository for historical diversion records, the keeping of such records being statutorily required.

**[\*550]**Paragraph 13.4 states that "(A) ditch conveyance loss was assessed evenly for all FIDCO Shares and was assumed to be 25 percent of the total ***river*** headgate diversions. This is a reasonable estimate of ditch loss and was taken from engineering analyses for prior change cases for the Farmers Independent Ditch."

As to the consumptive demand for the crops, Paragraph 13 states that "ACWWA used the Integrated Decision Support Consumptive Use model developed by ***Colorado*** State University to analyze the historical consumptive use of ACWWA's FIDCO Shares. The Modified Blaney-Criddle method (USDA-SCS Technical Release 21) and locally calibrated crop coefficients were used to determine the crop irrigation water requirement." Pages 2-1 and 2-3 of the B&C report reveal that the crop water requirement results utilizing locally calibrated coefficients using the Penman-Monteith method were, in fact, used to calibrate coefficients for the Modified Blaney-Criddle method, the latter method being used for the whole 1950-2010 study period.

Paragraph 13.5 of the 12CW73 decree states that "(T)he maximum irrigation efficiency for the Ruggles Farm is 70 percent for gravity irrigation based on historical irrigation practices, soil characteristics, leveling, and tail water reuse, and 80 percent for sprinkler irrigation."

Paragraph 2.2.3 of the preliminary B&C report states the following.

Farmers practiced flood irrigation on most fields in this analysis, with the exception of a portion of the Ruggles farm where sprinkler irrigation was used beginning in 2008. The maximum "base" irrigation efficiency used for flood irrigation was 60% and for sprinkler was 80%. These values are based on common values cited in the SPDSS Task 56 - Conveyance and Application Efficiencies Technical Memorandum (Leonard Rice, 2006). However, the Ruggles farm had a tailwater collection system that captured end-of-field flows from approximately 58 percent of the irrigated area. It is estimated that approximately 11.6 percent of the farm headgate delivery was pumped back and re-applied via this system. At an efficiency of 60 percent, the practice boosted the overall farm efficiency by 6 or 7 percent. Accordingly, flood irrigation on the Ruggles farm was modeled using a maximum efficiency of 65 percent. [[17]](#footnote-18)17

Paragraph 13.6 of the decree describes the historically irrigated crops as including "a mix of corn, beans, sugar beets, small vegetables, some sunflowers, and winter wheat." Pages 2-2 and 2-3 of the B&C preliminary report describe the crop mix as coming from an initial assessment of the Ruggles Farm prepared previously by Duane Helton Consulting. Footnote 2 on page 2-2, quoted previously herein, elaborates on the determination of the historical crop mix. [[18]](#footnote-19)18

**[\*551]**Paragraph 13.8 displays Table 1, depicting average monthly historical consumptive use resulting from the use of ACWWA's 20 FIDCo shares, totaling 190.08 acre-feet as an average for a year.

Paragraph 13.9 states that annual demand-based farm headgate deliveries *averaged* 273.11 acre-feet, and it includes Table 2, displaying *maximum monthly* demand-based farm headgate deliveries.

Paragraphs 13.10, 13.10.1, and 13.10.1.1 state that all of the return flows from the Ruggles Farm were by way of groundwater, that these return flows averaged 83.18 acre-feet per year, and that the on-farm return flows were lagged back to the South Platte ***River*** using the Alluvial Water Accounting System (AWAS). Later, in Paragraph 15.4.3.1, the decree provides Table 3, which is a set of monthly return flow factors, which are to be multiplied by (the future) monthly farm headgate deliveries, and then divided by the number of days in the given month, to obtain ACWWA's daily return flow obligation to maintain historical levels of return flow. (These factors in Table 3 derive from Table 17 of the B&C supplemental report of February 9, 2015. The location on the South Platte ***River*** to which the groundwater return flows accrue is given on Figure 2 of yet another B&C report for the 12CW73 case, and it is based on flow directions using historical groundwater contours.) The 12CW73 decree copied B&C's Figure 2 and re-named it Exhibit 2.

The 12CW73 decree then included other terms and conditions regarding ACWWA's use of its changed 20 FIDCo shares, including the following.

As ACWWA's FIDCo water would continue to be diverted by the Farmers Independent Ditch and delivered to an ACWWA augmentation station(s) on the ditch, ditch losses would continue as they had historically, and no particular term and condition for ditch loss was needed. [[19]](#footnote-20)19

The 12CW73 decree limited the season of diversion for ACWWA's FIDCo water to April 1 through October 31, adopting the season proposed in the preliminary B&C report.

The decree stated that if return flows are made upstream of the location of historical return flows, the Division Engineer shall determine transit losses. I saw nothing on transit loss in the engineering reports that I reviewed.

The decree requires ACWWA to maintain historical levels of return flow on a daily basis, "including on days when there is no call downstream of the historical return flow location...," while the preliminary report was silent on what would trigger a return flow obligation.

Table 3 in the decree sets forth monthly return flow factors, which the decree requires to be applied to the average annual augmentation station deliveries (tantamount to farm headgate deliveries), the product of which is to be divided by the number of days in the given month to obtain the required daily amount of return flow. The preliminary report proposed the use of total farm headgate deliveries from the prior irrigation season. The factors in Table 3 derive from **[\*552]**Table 17 of a subsequent B&C engineering report, dated February 9, 2015, said table being a summary of B&C's final report that set forth the values that the 12CW73 decree adopted.

Paragraph 15.7 of the decree imposed the following augmentation station volumetric limits on ACWWA's FIDCo shares.

The decree limited the maximum annual augmentation station delivery to 381 acre-feet, and it limited the maximum annual consumptive use to 267 acre-feet, both values presumably coming from B&C's last engineering report of February 9, 2015.

The decree's Table 4 lists maximum monthly delivery limits, all but those for June, July, and August being the same as the monthly values in decree Table 2. I do not remember or know the reason for Table 4's values for June, July, and August being larger than those months' values in Table 2.

Last, the decree limited ACWWA's augmentation station deliveries to a cumulative value of 5,428.4 acre-feet over any 20 consecutive years, and to a cumulative value of 2,714.2 acre-feet over the first 10 years after entry of the 12CW73 decree. I can track these values to very close to the values in the last B&C report of February 9, 2015. What I do not see in the 12CW73 decree is a 20-year cumulative limit on deliveries on a month-to-month basis, which is what I have seen in other recent Division 1 change cases, and which I believe is appropriate and needed in change cases to maintain historical levels of return flow.

I am next going to list the engineering elements of the 12CW73 change decree that I consider as reflecting today's change decrees, and then characterize each element, and today's engineering methodology for same, if appropriate, and also compare each engineering element and methodology with the early 1969 Act element and methodology. When I characterize an early change decree below, I am taking all of the characteristics from the three old change cases that I have previously described herein as if there were a single decree that contained all of the characteristics from these three early 1969 Act decrees.

D. Engineering Elements and Methodology of Change Cases - Early 1969 Act Period and Today

1. General Description Of Water Right To Be Changed And Location Of Use

Not much difference exists here, except that if a map of the farm or place where the water right was historically used is created, today an engineer is likely to use software and a map electronically produced, if this element is really considered to be engineering. [[20]](#footnote-21)20

**[\*553]**

2. Historical Demand-Based Deliveries

None of our three early change decrees used a demand-based delivery method. The analog to early change decrees would be their use of diversions from a ***river*** or stream. The difference here would be that today we obtain historical diversion from an electronic source, such as HydroBase or CDSS. In the early days, engineers had to travel to the eighth floor of the Centennial Building at 1313 Sherman Street in Denver and copy, and pay for, diversion records printed from microfilm or microfiche, which engineers then put into a report table(s) and/or used in computer programs.

3. Historically Irrigated Area

There's not much difference insofar as the use of a ditch company stock records and deeds, the use of field inspections, and interviews with either a prior irrigator or someone else with knowledge of how and where the water was used. The big difference today is the widespread availability of quick and inexpensive aerial or satellite photography. In the early days, I had to contact someone in Utah or Georgia and get an index of aerial photographs for the general area of interest, and when I identified the specific photos that I wanted, I ordered them and paid for them. It might well be months before I had these critically needed documents in hand. I could also obtain aerial photography from local commercial sources, such as ***Colorado*** Aerial Photography, located in Denver. The availability and access to aerial photography and satellite imaging have continued to improve.

4. Study Period

None of our three early change decrees mentioned the phrase "study period." Today's change decrees and the engineering behind the decrees specify a specific study period and usually give some justification for its selection, as the 12CW73 decree and engineering do. [[21]](#footnote-22)21

5. Ditch Loss

There's nothing really new here, as Genesee Associates' W1564 decree and Lafayette's W8346 decree both deal with ditch loss much as engineers do today.

6. Identification Of Irrigated Crops And Crop Mix

Little has changed in how engineers deal with types of irrigated crops and crop mix, except (1) that Farm Service Agency offices hold records more tightly **[\*554]**than they used to, most often requiring individual land owner's (farmer's) consent, and (2) we have newer sources that were not available during the early years of the 1969 Act, such as the ***Colorado*** Decision Support System.

7. Calculation of Irrigation Consumptive Use Requirements

The main difference here is that today engineers give an exceedingly detailed description of the method they use, very importantly including the selection of crop growth stage coefficients. As these determinations require numerous calculations, today engineers use computer programs to make these calculations. While the Modified Blaney-Criddle method likely remains the most commonly used manner by which to calculate irrigation consumptive use requirements in ***Colorado***, the use of the Penman-Monteith method to come up with crop growth stage coefficients for the Modified Blaney-Criddle method appears to be growing in favor. Also, today engineers use specialized programs or spreadsheets, including STATECU and IDSCU, which allow calculations to be performed on a monthly basis throughout the entire study period, rather than just for selected types of years, such as average, hot-and-dry, and cold-and-wet. In the early 1969 Act days, engineers mainly used slide rules, or perhaps crank "adding machines." Long ago I also used templates on 8 [fr1/2] by 11 inches sheets, with the column headings for the elements of the Modified Blaney-Criddle method already typed in neatly.

8. Maximum Irrigation Efficiency

None of the documents for our three early change decrees contained the word "efficiency." Today's engineers have been using the phrase and values for maximum irrigation efficiency since we began performing historical use analyses for changes of irrigation water rights, usually on the basis of engineering judgement or from past engineering and/or decrees for similar conditions. In the past ten years or so, use of such methods as the Farm Irrigation System Index (FIRI) has increased.

9. Volumetric Limits

In today's decrees, particularly when the changed water continues to be diverted in the same ditch as it was historically diverted, terms and conditions place two kinds of limits on monthly and annual augmentation station deliveries (analogous to historical farm headgate deliveries). The first kind of volumetric limits consists of both monthly and *annual maximum* deliveries. The second set of volumetric limits provides a long-term throttling of deliveries down to an *average annual* and *average monthly* delivery by setting, say, a 10-or 20-consecutive-year value not to be exceeded within that span of years. [[22]](#footnote-23)22For example, if the historical average *annual* farm headgate delivery was 113 acre-feet, then a consecutive 20-year value of 2,260 acre-feet (2,260 acre-feet = 20 years X 113 acre-feet/year) could be applied. (While the ACWWA\ECCV\United 12CW73 decree had maximum monthly and annual limits, and a 20-year limit on *annual* deliveries, it did not contain the 20-year limits on monthly deliveries that several recent Division 1 decrees contain.)

**[\*555]**

E. Maintenance Of Historical Levels Of Return Flows

One of the biggest differences from the way early 1969 Act changes treated return flows is today's decree requirement that historical levels of return flows be "completely" maintained; yet the use of the adverb "completely" begets trouble. Some early 1969 Act change decrees (other than the three that I have described) simply allowed the applicant to divert his/her changed rights in the form of consumptive use, usually with a portion of the water right "abandoned to the stream." This did not provide for any lagged return flows, such as those during the non-irrigation season, or direct return flows when the changed water right was not being diverted. In some early cases, this "abandonment" may amount to something like today's decrees that require the applicant to produce physically the water for the maintenance of return flows; in other cases, I can't see how any semblance of maintaining historical return flows would occur.

As to today's "complete" maintenance of return flows, I have seen three primary ways that change decrees have dealt with this issue. The first method involved requiring the applicant to maintain historical levels of return flow only when there was a downstream call on the ***river*** senior to the applicant's date of filing his/her application for a change of water rights. [[23]](#footnote-24)23

The second method allowed the applicant to keep the return flow if the applicant had included in his/her application for change a claim for an appropriative right to the return flow. [[24]](#footnote-25)24Then, if the call on the ***river*** was junior to the applicant's date of appropriation for the claim for return flow, the applicant could keep the return flow, and, if the call were senior to the applicant's date of appropriation for the return flow, the applicant would have to maintain the historical level of return flow.

The third and last method of dealing with return flow is to do what the ACWWA\ECCV\United 12CW73 decree required: make return flows at all times, even when no call at all exists on the ***river***. [[25]](#footnote-26)25

Last but not least is the use of the bounded Glover methodology to obtain the timing of the lag from the irrigated area to the nearest flowing stream, in most cases in Division 1 performed using the Alluvial Water Accounting System (AWAS). The three-dimensional MODFLOW model is sometimes used to develop lagging factors, but the SDF factor approach, once quite popular in Division 1, seems to have gone the way of the dinosaurs. [[26]](#footnote-27)26

The four most significant developments that I've seen in change decrees, from the early 1969 Act period to today's time, include: (1) the plethora of electronic information available, from aerial photography to decrees, diversion and climatological data, to software that expedites calculations of irrigated areas, historical use, and so on; (2) the application of multiple volumetric limits to **[\*556]**constrain future use to historical use; (3) demand-based historical use analysis for systems that tend to be water long; and (4) the calculation of delayed or lagged return flow obligations using AWAS.

I would be remiss if I failed to state two other conclusions, which some might deem to be heresy, and which do not stem from my comparisons of engineering methodologies from early 1969 Act days to today's time. From prior and extensive research into *PRE*-1969 Act transfer decrees (what we now call "change decrees") and, in some cases, the engineering behind such transfer decrees, I conclude that pre-1969 Act transfer decrees preponderantly (1) were *not* limited to historical consumptive use and, in fact, (2) were *not* limited to historical use in any meaningful way. Which begs the question in my mind of to what extent did the 1969 Act cause most post-1969 Act change decrees to be based on historical consumptive use? To elaborate upon these questions, I wish to share the following background and conclusions.

In 1988 I studied each of the 1,053 transfer decrees contained in the State Engineers Office "card files." These card files contained references to the transfer decrees that had been entered by ***Colorado***'s numerous district courts prior to the promulgation of the 1969 Act, going back to 1890. At that time, I was interested in how many of these pre-1969 Act transfer decrees (1) contained any sort of true volumetric limits ( *e.g*., an annual diversion of a given number of acre-feet), (2) contained any express seasonal limit, and (3) included any reduction in maximum rate of diversion. Due to the fact that some of these transfer decrees were not, in fact, decrees at all ( *e.g*., some were orders by the State Engineer) or defied my ability to interpret them, my list of eligible pre-1969 Act transfer decrees decreased to 919 decrees.

I concluded that none of the 919 pre-1969 Act transfer decrees had a true volumetric limit. [[27]](#footnote-28)27Not only did none of the 919 transfer decrees have a volumetric limit, but 814 of the 919 transfer decrees had no reduction in maximum rate of diversion, 906 of the 919 transfer decrees had no express seasonal limit, and 810 of the 919 transfer decrees had no express seasonal limit and no reduction in maximum rate of diversion.

With what I had come to know in the post-1969 Act time of the types of terms and conditions that we use today to limit the changed water right to historical use, and to historical consumptive use, in particular, it is actually what I did not see in the pre-1969 Act transfer decrees that began to lead me to conclude that preponderantly the pre-1969 Act transfer decrees were ***not*** *quantitatively* or *temporally* based upon either historical use or historical consumptive use. [[28]](#footnote-29)28

Later, I became involved on behalf of the City of Golden in a complaint against Golden by several parties diverting from Clear Creek in Division 1, Case No. 95CW205. One of Plaintiffs' arguments was "that consumptive use is also **[\*557]**one of the implicit terms and conditions in every water decree and others are entitled to reopen such decrees to convert such implicit terms and conditions into expressed volumetric terms and conditions." [[29]](#footnote-30)29That got me to thinking again and wondering how consumptive use could have been, or could not have been, part and parcel to pre-1969 Act transfer decrees. [[30]](#footnote-31)30

But I wasn't done yet. I wondered about the origin of the term "consumptive use," when the term first arose, who raised it, and what and when were its early methodologies, which, of course, led to my self-publication on March 14, 1997, of *The Term Consumptive Use, Its Origin, And The Early Development of Its Methodologies*. [[31]](#footnote-32)31

I concluded that (1) the term "consumptive use" first arose, in the western United States, sometime between 1910 and 1920, but I couldn't at that time pin down just who coined the term, and (2) that the first method for the calculation of consumptive use was likely that in 1924 by Charles R. Hedke.

My paper included a Figure 1, reproduced herein, that plotted on a year-by-year basis, from 1890 through 1990, the cumulative number of pre-1969 Act transfer decrees that had been entered by the year shown, along with "markers" placed by each year when something of significance had occurred in regard to consumptive use, *e.g.*, the Hedke method of 1924.

If, and I repeat if, the Plaintiffs against the City of Golden argued or stated that historical consumptive use has been the basis of transfer or change decrees in ***Colorado*** from the get go. *i.e.*, since 1890, how can such be possible if the term "consumptive use" did not exist prior to 1910, and if there was no engineering method for the calculation of historical consumptive use?

With so much of my career spent on changes of water rights, I began to wonder about when various elements of today's change decree came about. For example, when was the first transfer decree that required the petitioner for change to leave in the ditch a certain amount of the water that the petitioner was changing to a new point of diversion, in order to protect remaining shareholders in the ditch from injury. So, I self-published yet another paper on November 24, 2014, entitled *Thoughts on "Changes In Change Decrees" Or "You Cannot Step Twice Into The Same Water, For Other Waters Are Continually Flowing In.*" [[32]](#footnote-33)32I was careful to note in this paper that my identification of transfer decrees (case numbers and dates of entry of decrees) derived from my experience, and did not represent absolute claims of the first transfer decree to require this or that.

In this paper, I stated that the first transfer decree, to my knowledge, to be based on limiting future use of the changed rights to historical consumptive use was the City of Englewood's transfer of its rights in the Nevada Ditch and Platte Canyon Ditch, both of which historically diverted from the South Platte ***River*** in the southern Denver Metropolitan area. The Douglas County District Court **[\*558]**entered its decree approving the changes on February 9, 1950, in Civil Action 1706. Because defendants (today, opposers or objectors) appealed the court's decree, the transcript of the trial's testimony was preserved, and in the transcript, I could see that Englewood's engineer, R. J. Tipton used the 1942 Lowry-Johnson method to calculate the historical consumptive use from Englewood's interests in the Nevada and Platte Canyon Ditches. This paper further noted that by 1950, the year of entry of Englewood's CA1706 decree, over 600 of the 919 pre-1969 Act transfer decrees had been entered, casting a dark cloud over the prospect that transfer decrees have always limited future use to historical consumptive use.

This paper then identified four other pre-1969 Act transfer decrees where the same Pete Wheeler engineered the transfer decrees based on his quantification of historical consumptive use and "balanced," or limited, future municipal consumptive use to historical consumptive use. The paper identified one additional pre-1969 Act transfer decree that appeared to have involved the same balancing that Pete Wheeler used in the other five cases, making a grand total of six pre-1969 Act transfer decrees that I could show that were based on limiting future use to historical consumptive use. Said six transfer decrees represent less than 1% of the 919 pre-1969 Act transfer decrees.

F. Exchanges

***Colorado***'s statutes say the following, among other things, about exchange.

When the rights of others are not injured thereby, it is lawful for the owner of a reservoir to deliver stored water into a ditch entitled to water or into the public stream to supply appropriations from said stream and take in exchange therefor from the public stream higher up an equal amount of water, less a reasonable deduction for loss, if any there be, to be determined by the state engineer. The person or company desiring such exchange shall be required to construct and maintain, under the direction of the state engineer, measuring flumes or weirs and self-registering devices at the point where the water is turned into the stream or ditch taking the same or as near such point as is practicable so that the division engineer may readily determine and secure the just and equitable exchange of water. [[33]](#footnote-34)33

§ 37-83-104 (4) also provides that "a practice of substitution or exchange pursuant to law may constitute an appropriative right and may be adjudicated and otherwise evidenced as any other right of appropriation." [[34]](#footnote-35)34

Steve Witte notes the earliest appropriative right of exchange in the Arkansas ***River*** basin of which he is aware is the exchange decreed for 756.28 cfs from Lake Meredith to the ***Colorado*** Canal, with a date of appropriation of March 9, 1898, as confirmed by the decree entered on November 25, 1916, in Pueblo County District Court Case No.13693. Our point in referring to this early exchange decree is that the 1969 Act did not create the ability to adjudicate appropriative rights of exchange; such ability pre-dated the enactment of the 1969 Act.

One would also do well to bear in mind what the ***Colorado*** Supreme Court **[\*559]**has said about exchanges, for example, in its opinion in the *Empire Lodge Homeowners' Association v Moyer*. [[35]](#footnote-36)35Quoting Casey Funk and Amy Cavanaugh, the Supreme Court defined in *Empire Lodge* the four required elements of an exchange, as follows.

Four critical elements of an exchange are that (1) the source of substitute supply must be above the calling water right; (2) the substitute supply must be equivalent in amount and of suitable quality to the downstream senior appropriator; (3) there must be available natural flow at the point of upstream diversion; and (4) the rights of others cannot be injured when implementing the exchange. [[36]](#footnote-37)36

1. Early 1969 Act Exchange Decrees

*i. City and County of Denver Exchange Decree in Douglas County Civil Action 3635* [[37]](#footnote-38)37

This decree was actually entered under the pre-1969 Act statutes, but I choose it because the decree was entered in 1972, shortly after the enactment of the 1969 Act, and because to many of us in the water community, this exchange is known as "the mother of all exchanges," probably due to its enormous maximum decreed rate of 3,000 cfs. Once again, I do not have any of Denver's engineering, but I do have both the decree and a transcript of the testimony of Denver's witnesses on October 7, 1971, in a hearing before the water referee, the late Mr. Monte Pascoe.

The decree informs us that the name of this appropriative right is "Exchange within Denver Water System." The decree lists seven points of diversion by exchange (Cheeseman Reservoir, Risborough Diversion Facility, Denver Platte Canyon Intake, High Line Canal Diversion Works, Marston Reservoir, and Farmers and Gardeners Ditch. [[38]](#footnote-39)38Interestingly to me, the decree does not explicitly identify exchange-from points, nor sources of substitute supply by name. The CA3635 decree found that Denver had made 454 cfs of the exchange absolute, leaving the remaining 2,546 cfs conditional. While the CA3635 decree made 454 cfs of the exchange absolute, the decree did *not* identify the upstream point of diversion for this exchange of 454 cfs (what we typically refer to today as the "exchange-to" point), did *not* identify the location of the point of introduction to the stream of 454 cfs of the substitute supply for the exchange (what we today would refer to as the "exchange-from" point), and did *not* identify the source or character of the water used for the substitute supply. The decree made July 4, 1921, the date of appropriation for the exchange, "except to the extent the diversion is made by means of a structure ... which has a decreed priority later than July 4, 1921," in which case the priority of the exchange shall take on the priority date of the structure at which the diversion by **[\*560]**exchange occurs.

The transcript of the testimony of Denver's two witnesses allows us to take a peek at the engineering lying behind Denver's claims. Mr. Robert Fischer's testimony identifies the two exhibits that Denver used at the hearing. Mr. Fischer described Exhibit 1 as "a more or less pictorial drawing of the water supply system present, and parts of those proposed features of it." He then described Exhibit 2 as "a scheme, a straight-line diagram of the South Platte ***River*** primarily of the tributaries entering it, and some of the points of diversion and storage facilities of the Denver Water Department to generally - primarily Water District 8." (I think that the transcript's "scheme" probably meant "schematic.")

Mr. Fischer also testified about each of the structures where diversion by exchange would take place, the types of uses that Denver would make of the water exchanged, and the various sources of water for the exchange, including transmountain waters from the Frasier and Williams Fork ***Rivers***, waters stored in the Bear Creek basin, and "releases" from sewage treatment plants.

In response to a question from Referee Pascoe, Mr. Fischer made very clear that Denver's intent was to establish "a priority for this type of use of the waters of the Platte" that "would be senior to later claims."

Mr. Fischer also explained how the exchange would operate, as follows.

"Well, the right really we are claiming here is the right to make use of the waters that would flow in the Platte ***River*** through this stretch of the ***river*** located in Water District 8.

The right to make use of those waters by diverting them, or storing them, thereby depleting the flow of the ***river*** to Water District 8, or below the point of diversion or storage, and at some point downstream, introduce an equivalent amount of water to meet the requirements of the ***river***, to meet the calls of the ***river*** on downstream."

I find Denver's second witness to be very unusual. Prior to the testimony of Mr. Fischer, Denver's Special Counsel Glenn G. Saunders asked Referee Pascoe if he (Saunders) could withdraw, because he (Saunders) will be a witness in the hearing, and because another attorney for Denver could proceed during the hearing. Referee Pascoe granted the withdrawal of Mr. Saunders.

By the time of this hearing in 1971, Mr. Saunders had garnered quite a reputation in ***Colorado*** water law, to say the least, and he added to that reputation in his later years. He was quite a force to be reckoned with.

In his testimony, Mr. Saunders claimed to be the person who originated the claim for the exchange, while also stating that the "claim drew out of thinking by August P. Gumlick, who was a member of the Board for many, many yearsFalse" (the Board meaning the Denver Board of Water Commissioners).

In explaining to Referee Pascoe his long involvement with Denver's water affairs, and after having identified Mr. Malcolm Lindsay as having been a special water counsel to the Board, Mr. Saunders rendered, in my experience, one of most profound pieces of testimony I have ever seen or heard, as follows.

One of the things that was found when Mr. Lindsay was employed in 1925, the Denver Union Water Company for whom I worked in 1917 had its water rights were sort of shamble. They had a man by the name of Walter P. Miller - he is the greatest water thief - that is a compliment - that is, anyway, at that time **[\*561]**it was thought pardonable to steal a lot of water, and he was the best.

Along with Mr. Fischer, Mr. Saunders stressed what was thought to be a future competition for appropriative rights of exchange, while briefly addressing Denver's need for the CA3635 exchange, as follows.

If this is in competition with another appropriator, we want the first crack at that water for our needs.

*ii. Pinewood Springs Municipal Water System's Exchange Decreed in Division 1 Case No. W8001-75* [[39]](#footnote-40)39

The Pinewood Springs Municipal Water System filed an application in July 1975, for a decree approving a plan for augmentation including exchange. The resulting W8001-75 decree also involved a change of water right, but, for the purpose of this paper, all I am going to address is the exchange that was "approved" by the W8001-75 decree. Once again, I do not have any engineering report in support of the claims, so I describe the engineering by interpretation of the decree.

The decree involved a plan for augmentation for a subdivision located in Larimer County, some eight miles northwest of Lyons, ***Colorado***. Portions of a changed water right would be stored, by exchange, in a reservoir, from which releases to the Little Thompson ***River*** would be made to augment the subdivision's winter depletions.

Paragraph 8(C), in pertinent part, describes the exchange, as follows.

Water will be stored in Pinewood Springs Reservoir in exchange for portions of said 16.32 acre-feet for subsequent release to the Little Thompson ***River*** at the direction of the Division Engineer for Water Division No. 1 to replace depletions resulting from water usage by the Pinewood Springs Subdivision. There are no appropriators between the point at which releases from Pinewood Springs Reservoir will reach the Little Thompson ***River*** and the headgate of the Culver Lateral, approximately eight miles downstream.

While approving the plan for augmentation including exchange, the decree assigned no maximum rate of diversion for the exchange and no date of appropriation for the exchange.

2. Today's Exchange Decrees

I have chosen one relatively recent exchange decree in Division 1, Case No. 09CW283, because its engineering contains several bells and whistles that today's exchange decrees commonly have.

Arapahoe County Water and Wastewater Authority's (ACWWA) and United Water and Sanitation District's (United) Exchanges Decreed in Division 1 Case No. 09CW283 [[40]](#footnote-41)40

United filed its application on December 31, 2009, for a series of exchanges on a 130-mile reach of the South Platte ***River***, and a much shorter reach on St. **[\*562]**Vrain Creek, and on August 26, 2010, ACWWA intervened as a ***co***-applicant. The Division 1 Water Court entered its decree in this case on September 18, 2014.

Our approach in describing the engineering performed in support of this decree will be to start with the decree itself, and then describe the engineering analyses. I note that the primary engineering supporting the exchanges sought began with a report dated June 4, 2012, by Duane Helton of D. Helton Consulting, LLC (Helton 2012 report). Then, in January of 2014 and in June of 2014 Daniel Gillham of Helton & Williamsen, PC, authored supplemental expert reports with revised engineering (Gillham January 2014 report and Gillham June 2014 report, respectively). Also, Alan Leak of WRC Engineering, Inc., and Andrew Damiano of United prepared expert reports that, among other things, demonstrated ACWWA's need for the water supply to be generated from the exercise of the 09CW283 exchanges.

The 09CW283 decree confirmed conditional appropriative rights of exchange from a series of exchange-from points to a series of exchange-to points, whose general locations were provided by the 2012 Helton report.

Exhibit 2 to the 09CW283 decree presents a matrix of all of the maximum rates of exchanges. The Helton 2012 report first calculated the maximum rates of exchange *per share* for the direct flow supplies by taking the quotient of each ditch's total decreed rate of diversion divided by the number of shares in the ditch company, and then multiplying said quotient by a series of factors: an estimated canal efficiency; an estimated lateral efficiency; an estimated depletion factor; and an estimated transit loss. For the maximum rate of exchange *per share* for ACWWA's storage sources, the Helton 2012 report took the same approach, but used the physical capacity of the release structure from the storage vessel instead of a stream diversion. For both direct flow and storage sources, the Helton 2012 report multiplied the maximum rate of exchange *per share* by the number of shares ACWWA had for each source. For accretions from ACWWA's 70 Ranch recharge, the Helton 2012 report took the maximum accretion of 11.0 cfs from the 02CW404/03CW442 decree and prorated it to 6.11 cfs based on ACWWA's contractual right for the use of this facility. The Gillham January 2014 report made slight adjustments to some of these maximum rates of exchange and became the source of the maximum rates of ACWWA's exchange in the 09CW283 decree's Exhibit 2.

The 09CW283 decree placed a maximum, cumulative-for-all-exchanges, annual volumetric limit of 6,981 acre-feet at all exchange-to points, based on the sum of estimates of the maximum annual historical consumptive use for each source made by D. Helton Consulting, LLC, Brown & Caldwell, and Helton & Williamsen, PC, as given in the Gillham January 2014 report. The 09CW283 decree also placed a 10-year maximum diversion of 44,000 acre-feet at all exchange-to points, based on the Gillham January 2014 report's recommendation to incorporate ACWWA's contractual right with United for delivery of an average annual amount of 4,400 acre-feet.

The 09CW283 decree confirmed three separate dates of appropriation for various of the exchanges.

The Helton report and the two Gillham reports supported the 09CW283 **[\*563]**decree's terms and conditions regarding the requirement for a live stream before an exchange could be exercised, the application of reasonable transit losses on releases and deliveries of water, the requirement for measuring equipment, and the requirements for accounting. The Gillham June 2014 report supported the decree's requirements for securing the water commissioner's permission before exercising exchanges and for bypassing water.

The 09CW283 decree also found the following.

ACWWA has demonstrated a specific plan for operation of the conditional appropriative rights of exchange described in this Decree, demonstrated a need for these water rights, and shown that unappropriated exchange potential exists for the described appropriative rights of exchange. ACWWA has demonstrated diligence during the period since filing the original Application in this case, that the appropriative rights of exchange can and will be diverted, and that the appropriative rights of exchange can and will be completed and water used for the described beneficial uses within a reasonable time.

I believe that a large part of the decree's finding of ACWWA's "can and will" rests upon the engineering of point flow modeling that the Helton and the Gillham reports described. The Helton June 2012 report presented forty-one tables of monthly volumes of water that its point flow model showed could have historically been diverted by exchange ( *i.e*., a form of analysis of exchange potential) in the 1970-2007 study period using the method that I refer to as "take the ***river*** as you historically find it" announced in the ***Colorado*** Supreme Court's opinion in *Arapahoe County v Crystal Springs HOA et al*. [[41]](#footnote-42)41What I mean by this phrase is that when engineers quantify what would have been historically available to the subject right, engineers base their quantification of availability using *historical* gaged streamflows, *historical* diversions, and other *historical* flows, such as discharges from a wastewater treatment plant.

3. Comparison of Early 1969 Act Exchange Decrees and Today's Exchange Decrees

Today's exchange decrees rely on a great deal more engineering than early 1969 Act exchanges, particularly the two early decrees that I described. In these two early exchange decrees, taken separately and at their worse, I saw no engineering evidence concerning applicant's need for the water to be diverted by exchange; no explicit descriptions of exchange-from point or of the source of the substitute supply for the exchange; no maximum rate of diversion for the exchange; no date of appropriation for the exchange; no demonstration that the applicant can and will exercise the exchange within a reasonable period of time; no volumetric limits on the exchange; no requirements for a live stream, for transit loss, for measuring devices, and for accounting; and, in the case of a decree for multiple exchanges, no exchange matrix.

G. Plans for Augmentation

As a second reminder, the 1969 Act, as amended, defines a plan for augmentation, as follows.

**[\*564]**

"Plan for augmentation" means a detailed program, which may be either temporary or perpetual in duration, 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 that have been made impermeable, thereby increasing the runoff but not adding to the existing supply of tributary water. [[42]](#footnote-43)42

1. Early 1969 Act Plans for Augmentation

In researching early plans for augmentation, I ran across numerous "augmentation plans" that really were changes of ditch rights to wells as alternate points of diversion. Many of these so-called augmentation plans were decreed for very large irrigation systems in Division 1, such as that decreed in Case No. W7921-75 to the Cache la Poudre Water Users Association. It seems that in the early years of the 1969 Act, water practitioners weren't quite sure just what a plan for augmentation was. One case in point would be the application by the O'Briens in Division 1 Case No. W1782. The application styled itself as "Application for Change ***Or*** Augmentation of Water Rights of Charlotte M. and Warren H. O'Brien." The resulting decree reads as a change of water right; the decree does not contain the word "augment" or any derivative thereof.

Also lending credence to the proposition that water professionals in the early years of the 1969 Act did not really know what a plan for augmentation is/was are the following statements from an article in the 1971-1972 University of ***Colorado*** Law Review by Attorney David Harrison.

A major tool of the Act is the concept of a plan of augmentation. There is no clear agreement on just what an augmentation plan is, but apparently any sensible plan of water management which increases the supply available for beneficial use will qualify. In fact, the provision may be characterized as a grant of power to the courts permitting them to allow any intelligent plan, thus promoting experimentation and inventiveness.

Later in his article, Mr. Harrison adds the following.

Judicial standards for categorizing applications as "plans for augmentation" or alternate points of diversion will have to be evolved in a case by case procedure on the basis of the necessity of judicially imposed regulation.

Now I shall select a few early augmentation plans and describe them.

Gordon Sonnenberg Farms, Inc., Plan for Augmentation Decreed in Division 1 Case No. W8186-76 [[43]](#footnote-44)43

Sonnenberg Farms filed its application in March of 1976, and the court entered its W8186-76 decree in December of 1976. Sonnenberg had earlier obtained a decree in Case No. W124 for a groundwater right for the Sonnenberg Well No. 10425-FA for 3 cfs for the irrigation of 140 acres. In the W8186-76 case, Sonnenberg sought to enlarge the area irrigated by the well by 53.5 **[\*565]**acres and to augment the irrigation of such enlarged area. The decree noted that the irrigation of the well's original 140 acres was "covered by other Plans for Augmentation and decrees of this Court." The application in Case No. W8186-76 for approval of the plan for augmentation of the enlarged 53.5 acres noted that irrigation of the original 140 acres was augmented by the Groundwater Appropriators of the South Platte (aka GASP). The decree's *modus operandi* for augmentation consisted of using 1 cfs of Sonnenberg's ownership of water decreed to the Lone Tree Ditch, as follows.

At times of a valid downstream senior call applicant shall provide 1.0 cubic feet per second of replacement water from the priority of the Lone Tree Ditch.

The W8186-76 application states that the Lone Tree Ditch water will be left in the ***river*** and provides a little more on the supporting engineering.

It is expected that the additional acreage under the well will consume 1.5 acre feet per acre or 80.25 acre feet per year. This amount represents to ( *sic*) net annual depletion of the South Platte ***River***. Sprinkler irrigation will produce an efficiency of 70% consumed and it will therefore be necessary to pump approximately 114.6 acre feet per year from the alluvium of the South Platte ***River*** by means of the subject well.

Neither the W8186-76 application nor the resulting decree provides any information on the adequacy of the 1 cfs of the Lone Tree Ditch water right to balance the application's 80.25 acre-feet per year of consumptive use from the enlarged 53.5 acres. However, the application includes the following strange statement.

Applicant's implementation of this Plan for Augmentation will result in an increase in the supply of water available for beneficial use in Water Division No. 1 by the elimination of nonbeneficial consumption of water associated with surface diversion.

Also, the W8186-76 decree made no statements about: the historical consumptive use of Sonnenberg's 1 cfs of the Lone Tree Ditch water right; any requirement for dry up of the land irrigated by the 1 cfs of Lone Tree Ditch; and the timing of depletions from the well to the South Platte ***River***.

Columbine Country Club's Plan for Augmentation in Division 1 Case No. W8521-77 [[44]](#footnote-45)44

The Club filed its application for approval of a plan for augmentation of its alluvial wells (the Columbine wells) in March of 1977, and the court entered its decree in November of 1982. [[45]](#footnote-46)45

I find this early augmentation decree to be interesting in that it includes as a source of augmentation the water produced by the Columbine wells themselves, in addition to the "normally" expected sources of the Club's interests in the two ditches and two nontributary wells. Is this perhaps the first plan, or at least a very early augmentation plan, that includes "augmentation wells?" I know of a few augmentation decrees in Division 1 that include the use of augmentation wells, but such cases have drawn a lot of attention from opposers and their engineers, due to their fear that the use of augmentation wells will be **[\*566]**abused, in the sense of an irresponsible use of a credit card, leaving a "hole in the ***river***" due to unreplaced well depletions, resulting in injury to other water rights.

The Club's decree references an Exhibit B, which is described as "a table which shows how the Columbine augmentation plan will operate." I take this to mean the plan's accounting, although I did not obtain a copy of it.

While I could not obtain any engineering report in support of the Club's decree, I note from the decree that the court appeared really persuaded by the engineering before it, five times referencing the Club's "competent engineering," as follows.

According to *competent engineering* testimony, the ultimate depletive effect to the South Platte ***River*** from the Columbine Wells is the consumptive use of the water pumped, or 80 percent of the total well diversions under present operations. The annual depletions then, based upon the years 1977 through 1980, average 423 acre feet per year. 80 percent of the 5-year mean annual irrigation pumping number from Column (1), Exhibit B, will be entered in Column (2).

*Competent engineering* evidence establishes that, because of this delayed and spread depletive effect, it is appropriate to use the average of several years of prior pumping to determine the resulting depletion. Initially, Columbine will use the mean of the four years of available detailed data (1977-1980). This will be entered in Column (1) of Exhibit B. As additional years' data become available, Columbine will use the mean of the most recent five years and will enter this number in Column (1) of Exhibit B.

According to *competent engineering* evidence, the depletive effect of pumping Columbine's Wells is distributed monthly in accordance with following percentages:

Month Percentage Month Percentage

January 2.6 July 14.5

February 2.2 August l5.6

March 2.3 September l5.5

April 3.7 October 12.4

May 8.0 November 6.7

June 12.6 December 3.9

These percentages are entered in Column (4) on Exhibit B. Applying them to the annual irrigation depletion reported in Column (2) produces the monthly irrigation depletions, to be entered in Column (5).

According to *competent engineering* evidence, approximately 50 percent of the historic Last Chance Ditch diversions have been consumed in the beneficial irrigation of crops. Therefore, it is appropriate to use 50 percent of the water to which Columbine is entitled from the Last Chance Ditch as the amount available for augmentation credit.

*Competent engineering* evidence demonstrates that approximately 50 percent of the diversions historically made through the Brown Ditch have been consumed in beneficial irrigation of crops or in year-around industrial (gravel operation) uses. Therefore, it is appropriate to allow Columbine credit against monthly depletions for 50 percent of the amount of water available to Columbine **[\*567]**under the Brown Ditch right, subject to the limitations described hereinafter.

Some may choose to chuckle at these mentions of *competent engineering*, but even at the risk of getting ahead of ourselves, I am impressed with some of the modernity of the above findings of the court, and of even more to be described herein. So far, I note the use of water produced from an augmented well for the purpose of augmentation, the decree's attention to detailed accounting, the use of an average of several years of pumping for the purpose of calculating the depletions to be augmented in the current period of time, the use of a monthly pattern of groundwater depletions, and the specificity of the means of taking as an augmentation credit 50% of the diversions *available* from the two ditches.

Also, note the volumetric limits on the Club's pumping of its alluvial wells as set forth in Paragraph 17 of the W8521-77 decree.

17. Limitations upon the amounts pumped through the Columbine Wells will assure other water users that the depletive effects of pumping will not exceed the replacement water available from Columbine, and thus will protect such water users from injury. Accordingly, pumping through the Columbine Wells for irrigation shall not exceed 125 percent of the recent mean of 528 acre feet, i.e. 660 acre feet, in any one calendar year nor an aggregate of 2,880 acre feet in any consecutive five calendar years.

The last fairly modern term and condition that the decree imposes on the Club consists of limiting the Club's augmentation credits from the Brown Ditch to the period from March 15 through November 15 of each year. Why the W8521-77 decree did not limit the Club's augmentation from the Last Chance Ditch to a specific period of time lies beyond me. This is perhaps just another example of how loosey-goosey some early 1969 Act decrees were in comparison with many of today's decrees.

2. Indian Hills Water District's Plan for Augmentation Decreed in Division 1 Case No. W8549-77 [[46]](#footnote-47)46

Indian Hills Water District filed its application for (1) approval of a plan for augmentation, (2) including exchange, and (3) for a change of water right on May 26, 1977. The District filed an amended application, concerning Bear Creek Reservoir and various details, on December 21, 1979, and the District filed another amendment seeking a priority date for its exchange on December 27, 1982, which date *followed* the court's entry of its decree on March 30, 1982. In this one section of my paper, in order to keep these three pieces together, I am going to address aspects of the augmentation plan, the change of water right, and the exchange. Also, while I can trace several, but not all, parts of the engineering report to the decree, I am going to focus primarily on the engineering, and not the decree.

I obtained a copy of an engineering report from Patricia (Trish) Flood of Wright Water Engineers, dated September, 1980 (report). A two-page letter of **[\*568]**transmittal to the District by Chief Engineer Ralph L. Toren of Wright Water Engineers notes changes made to an earlier report of May 17, 1977. I do not have a copy of the 1977 report.

The report begins by stating "the purpose of this report is to develop the necessary background information to formulate a water augmentation plan for the Indian Hills Water District." The report then describes the District's present and future water facilities, assets, and needs. The District's facilities included several new wells in the Turkey Creek alluvium, as well as several other wells in Parmalee Gulch, all of which were to be augmented by the plan. The report describes the augmentation plan as providing "a vehicle by which the alluvial wells, belonging to the District, will become alternate points of diversion to certain of the present Warrior Ditch water rights." On the other hand, the report's discussion of an exchange is limited to (1) an exchange of the District's changed Warrior Ditch interests that *would have* occurred to small reservoirs in the vicinity of or within the District, but which were then negated by the District's acquisition of storage space in Bear Creek Reservoir from the ***Colorado*** Water Conservation Board (CWCB), and (2) a general description of the exchange of water released from Bear Creek Reservoir to augment depletions from the District's wells.

When I go to the W8549-77 decree itself, I find the word "exchange" once, and only in the caption on the first page of the decree. The decree contains no description of a stream reach for any exchange, no exchange-to or exchange-from points, no source of substitute supply for an exchange, no maximum rate of diversion for an exchange, and no date of appropriation or priority date for any exchange. Rather, the decree describes the augmentation plan as involving the storage of the District's changed Warrior Ditch interests in Bear Creek Reservoir, and the release of same to augment the depletions from the District's Turkey Creek and Parmalee Gulch wells.

To confuse augmentation/exchange matters a bit more, the original, 1977 application includes the word "exchange" in its caption, but does not provide any real details of any exchange. The 1979 amended application adds nothing to any claimed exchange. But, finally, the post-decree second amendment of 1982 sheds a rather dark light upon the subject of an exchange. After giving grounds for the dates of initiation of exchanges both to the Parmalee Gulch wells and to the Turkey Creek wells, the second amended application stated that at the time of the initial application, it was "known that such wells could not be used without an exchange." Then the second amended application states that at the time of the 1977 application, "it was not clear whether a priority date could be obtained for an exchange pursuant to [*C.R.S. 1973 § 37-92-101*](https://advance.lexis.com/api/document?collection=statutes-legislation&id=urn:contentItem:61P5-WY01-DYDC-J3FM-00000-00&context=1516831) et seq." This amended application then stated that "(I)n 1981, [*C.R.S. 1973 § 37-92-305(10)*](https://advance.lexis.com/api/document?collection=statutes-legislation&id=urn:contentItem:61P5-WY01-DYDC-J3G3-00000-00&context=1516831) was added specifically providing that the original priority date of exchange shall be recognized and preserved. This statute makes possible the amendment filed herein." Last, after stating that the decree had already been entered, this amended application asked the court either to add the exchanges to the decree under the decree's provisions for retained jurisdiction, or, in the alternative, to add the exchange as a matter of making a correction to a substantive error to the decree. I have not come upon any decree entered by the court other than that entered on March 30, 1982, even though the court's register of actions shows activity going beyond 1990.

**[\*569]**Having broken my promise to focus primarily on the engineering, I now return to the engineering, because I found it to be somewhat surprisingly modern.

The report stated that it used a study period from 1952 through 1957, and that such period started with two average or above-average years (1952 and 1953), followed by three dry years (1954, 1955, and 1956), and ended with a wet year (1957). The report included detailed month/year tables of the historical use of the District's four Warrior Ditch shares.

While the report states that it used the Blaney-Criddle method to calculate the historical consumptive use of the four Warrior Ditch shares, the report's printouts of values for potential net consumptive use include the SCS Technical Release No 21 *monthly* values for the two coefficients used in the calculation. That means that the report used the *Modified* Blaney-Criddle method (of April 1967, as revised September, 1970), as the prior Blaney-Criddle method allowed only for calculations of *seasonal* consumptive use. (While it is true that the report also included calculations of crop consumptive use requirements using the Jensen-Haise method, the report used the Modified Blaney-Criddle method in the key "Bear Creek Operation Studies," which demonstrated how well the District would fare in satisfying its augmentation requirements.)

The report's analysis of the historical use of the four Warrior Ditch shares also used *a* Glover method to lag deep percolation return flow back to the stream. However, in contrast to most analyses that I've seen more recently that used a bounded Glover approach, the report used an unbounded (or infinite aquifer) approach. Nonetheless, this is one fairly early engineering analysis to use *a* Glover method for lagging return flows.

I saw nowhere in either the report or the decree any lagging of well pumping into a well depletion to a stream. My guess as to the reason for this is the report states that the wells were effectively in the streambeds of both watercourses and therefore may have been assumed to impact streamflow within a very short period of time.

Another thing that I noticed was the report's use of six preceding cycles of the 1952-1957 study period (in an operational study of how the plan for augmentation would operate) "so that the return flows from deep percolation could be fully reflected." I interpret this to mean that the reason for the six preceding cycles was to allow return flows to come to a steady state condition. Also, I see today's engineers as more likely to "wrap" return flows emanating from the latter part of a study period into the beginning of a study period, so that the sum of the parts equals the whole, something perhaps akin to steady state.

The report presented the number of days in certain months of the extremely dry years of 1954 and 1963 that the senior-most Warrior Ditch water right had been called out, likely tying into the report's assessment of the amount of storage space needed in Bear Creek Reservoir to make the augmentation plan more robust. The report also acknowledged that at certain times, the District would not have a sufficient amount of its changed Warrior Ditch interests stored in Bear Creek Reservoir that could be released to augment the wells' depletions. This led the report to propose that at such times, the District would "borrow" water from the CWCB's conservation pool, and then pay it back.

The report appears to have considered an operational mode going forward **[\*570]**that would involve ongoing detailed calculations that would resemble an historical use analysis. Rather than doing so, the report proposes the use of depletion percentages to be applied to the District's Warrior Ditch farm headgate deliveries.

3. Today's Plans for Augmentation

I have chosen the augmentation plan decreed to the Groundwater Management Subdistrict (GMS) of the Central ***Colorado*** Water Conservancy District in Division 1 Case No. 02CW335, because it deals with numerous issues that we commonly see in today's augmentation plan decrees.

*i. The Groundwater Management District's Plan for Augmentation Decreed in Division 1 Case No. 02CW335* [[47]](#footnote-48)47

The decree states that Central filed its application in this case on December 23, 2002. Although some fifty-three (53) parties filed statements of opposition, the case did not go to trial, but reached settlement, with the decree being entered on June 3, 2005. The decree did not approve of the changes of any water rights, but it did involve the use of some twenty (20) decreed sources of augmentation water, and some twenty-two other sources, that could be added to the augmentation supplies following procedures set forth in the 02CW335 decree, but this paper will generally not address these sources. The late Leo Eisel of Brown and Caldwell prepared a report, dated April 2004, in support of the application (report).

The report states that some 962 member wells will be augmented by the plan, and the decree's Table 1 lists 765 wells to be augmented. Although the report appears not to anticipate adding new member wells, the decree allows for the addition of new member wells, provided that depletions from pumping the wells prior to the well being added to the 02CW335 plans are replaced by either a court-approved decree or a substitute water supply plan approved by the State Engineer. Member wells may be deleted for the 02CW335 plan upon water court approval.

The report proposed that certain wells, called "augmentation wells," be used as a last-resort augmentation supply. The report acknowledges that depletions from the twenty-three (23) augmentation wells must also be augmented and states that use of said augmentation wells is not expected during average years. The decree includes twenty-five (25) augmentation wells and places certain restrictions upon their use, including requiring (1) that these wells be used only by GMS and its members to augment their well depletions and the well depletions covered by the decree in Case No. 03CW99 (which is the Well Augmentation District [WAS] of the Central ***Colorado*** Water Conservancy District), if such water rights are included as augmentation supplies in that case; (2) that GMS not lease, sell, or dispose of water produced by these wells for any other purpose; and (3) that GMS will not use these augmentation wells "unless its other sources of replacement water are insufficient."

**[\*571]**It is also notable that the 02CW335 decree requires that pumping of augmentation wells and the depletions therefrom be included in the projections.

I found the report not particularly clear on the location of depletions from member and augmentation wells. However, the report did identify four administrative reaches (A, B, C, and F) on the South Platte ***River***, one reach on Beebe Draw (D), and one reach on Box Elder Creek (E), and the report essentially identifies the location of a well's depletion by reach, to which the decree adheres. (This approach regarding ***river*** reaches is later used in the decree to demonstrate that all depletions will be accounted for and augmented, by reach, in the projection, which is described later herein. Also, this paper will deal with how the plan for augmentation is structured in the main, as the treatments for Reaches D and E differed from the South Platte ***River*** Reaches A, B, C and F.)

In the 02CW335 plan, depletions from member and augmentation wells needed to be calculated in two principal manners, the first being present and future depletions from "past" pumping, *i.e*., from pumping that occurred before the initiation of the plan, and the second being depletions that result from pumping going forward after initiation of the plan. Because the decree's methodology differs somewhat from the engineering, I shall only describe the decree's methodology.

Because records of *historical* pumping were practically nonexistent, "the volume of groundwater consumed is estimated as the amount needed to meet the net crop irrigation water requirement (NCIWR) minus any surface water available for irrigation supply purposes where the NCIWR is equal to the potential crop evapotranspiration requirement for the crops minus effective precipitation. The potential crop evapotranspiration requirement is estimated using the Blaney-Criddle evapotranspiration methodology. Each Member contract is treated as a farm unit with onsite alluvial groundwater consumptive use estimated for each of the 550 active irrigation contracts and 13 non-irrigation contracts. Therefore, the historical consumptive use for each Member well is estimated based on: (1) acres irrigated, (2) acres of specific crops to be irrigated, (3) irrigation method used and (4) physical and legal availability of surface water supply used for irrigation on each farm unit." Calculations for the consumptive use of groundwater covered historical well pumping back to 1974. This stands as a great example of engineers sometimes having to innovate approximate historical use when reliable records are unavailable. [[48]](#footnote-49)48

"The consumptive use model version 3.1.20 (IDSCU) developed by the Integrated Decision Support Group (IDS) at ***Colorado*** State University is used to estimate consumptive use of alluvial groundwater (via a water budget) for each Member Well. The IDSCU uses the modified Blaney-Criddle method to estimate potential crop evapotranspiration, and to calculate a monthly water **[\*572]**budget which includes effective precipitation, soil moisture, monthly surface water diversions, and estimated alluvial groundwater credited towards meeting the NCIWR." [[49]](#footnote-50)49

The decree anticipated that all wells would be metered by April 1, 2008, after which time the calculation of the consumptive use of groundwater would become much simpler. At that point, the consumptive use of groundwater would be the product of metered pumping and a factor. The decree specified the following factors: 60% for well water applied by flood irrigation; 80% for well water applied by sprinkler irrigation; 100% for well water applied by drip irrigation; 100% from well water used for supplying feedlots; and 100% for augmentation wells. The decree also described more complex calculations of consumptive use for any municipal use of groundwater.

The report proposed that the timing of each well's depletion to the ***river*** be determined by use of the Stream Depletion Factors (SDFs); however, the 02CW335 decree employs the ""alluvial aquifer' setting in the Integrated Decision Support Alluvial Water Accounting System ("AWAS') to complete the calculations of the stream depletions and recharge described in the Glover equation." (Although I was involved in negotiating the settlement of this case, I do not remember why this change from the SDF method to the AWAS method occurred.) The decree's Tables 1 and 3 contain values for "X", "W", and "T" for each member and augmentation well.

The report included two sets of tables, one for average-year conditions and the other for dry-year conditions, that compared, by reach, all of the augmentation supplies to the sum of all of the well depletions and return flow obligations. These tables also portrayed the net impact to each reach, by month, as well as the excess supply that would act as a credit to the next downstream reach. The dry-year set of tables formed the basis for the decree's projection tool.

The decree required GMS to make a projection on or before April 1 of each year for the next six years to include "the projected depletions from Member Wells and Augmentation Wells, return flows from replacement sources and the projected supply of augmentation water for replacing out-of-priority depletions and required return flow obligations." "The purpose of the projection by Reach is to demonstrate that Applicant will have sufficient augmentation supplies to replace all depletions and return flow obligations during the entire six-year projection period by Reach. The projection by Reach will be used to limit the pumping of Member Wells and Augmentation Wells, to assure that full augmentation will occur during the projection period for each Reach."

The decree required the following information for the projection.

Depletions from Previous Pumping. The depletions associated with previous pumping of the Member Wells and Augmentation Wells, by Reach.

Projected Member Well Depletions. The amount of pumping and resulting depletions from the Member Wells, by Reach, that can occur in the current year without causing unreplaced depletions over the six-year projection period.

Projected Augmentation Well Pumping. The amount, if any, of Augmentation **[\*573]**Well pumping, and resulting depletions, to be used to replace Member Well and Augmentation Well depletions under the plan during the projection period.

Recharge Accretions. The accretions resulting from Applicant's previous (prior to the current annual or monthly projection) recharge activities by Reach.

Storage and Direct Flow Water Right Deliveries. The projected deliveries of storage and direct flow water used for augmentation False by Reach.

Storage and Direct Flow Water Right Return Flow Obligations. The amount of return flow obligations attributable to Applicant's previous and projected use of storage and direct flow water released for augmentation, by Reach.

Additional or Alternate Supplies. Any additional or alternate net replacement supplies or credits that have been authorized for use in the plan False, by Reach, the amounts of which are known at the time the projection is made, that Applicant has secured for any or all of the years of the projection period.

Estimated ***River*** Transit Loss. Estimated ***river*** transit loss.

Also, I want to share Steve Witte's comments on the important role of projections.

The innovation of projection tools is perhaps one of the most proactive means of ensuring that plans for augmentation are effective in preventing injury to senior vested water rights and therefore represents something of a monument on the augmentation landscape over the past 50 years. Previously, it fell to water administration officials to recognize that plans had *ex post facto* injured or perhaps in the best-case scenario were injuring senior water rights, and then the only remedy available was curtailment, which then required defending such administrative action. Projection tools provide advance indication of future problems which then can be addressed in a more orderly and timely manner.

The decree also required the following limitations and assumptions.

A ***river*** call senior to the most senior of GMS's member and augmentation wells, requiring that well depletions and return flow obligations be replaced at all times for each reach

Detailed limitations on augmentation well pumping.

Projected recharge diversions of zero for all years, and accretions from recharge limited to diversions to recharge made prior to the April 1 date for the projection, less evaporation

The amount of projected storage for the current year of the projection period under any storage right which has a priority junior to May 25, 1910, shall be limited to the amount of water in storage before April 1 of the current year, less evaporation. The amount of projected storage diversions under such junior storage rights for years subsequent to the current year shall be projected to be zero.

For storage rights senior to May 25, 1910, the decree's Table 2B sets forth the dry-year release available for augmentation, and the decree provided the means by which to add augmentation supplies from other storage rights not **[\*574]**listed in the decree.

Table 2B also sets forth the dry-year yields from the direct flow sources identified in the decree as augmentation sources. For direct flow rights not identified in the decree, the decree provides that dry-year yields from an approved substitute water supply plan may be used until a change decree is entered, after which the change decree's dry-year yields will be used.

Last, the decree's Table 2C quantifies the amounts of water that GMS had available under leases at the time of entry of the 02CW335 decree. The decree also allowed GMS to include in its projection of available augmentation water any water its had leased under a "fixed and definite right."

The decree allows GMS to update its projection on a monthly basis, for example, if after the April 1 initial projection for the year, GMS had been able to divert water into recharge in, say, July, so that its accretions due to recharge would be larger in exceed debits; or (3) if GMS determines that any member has exceeded his/her pumping quota and the pumping quota for all member wells has been exceeded, or any member has exceeded his/her irrigated acreage, GMS shall issue an order to that member to terminate pumping.

The 02CW335 decree required detailed accounting, by reach.

While prohibiting GMS from aggregating its winter augmentation, the decree did allow for GMS to petition the court for such approval, upon including, at a minimum, several specific conditions.

4. Differences and Similarities Between Early 1969 Act Augmentation Plans and Today's Augmentation Plans

While it may not seem fair to take Columbine Country Club's augmentation plan as representative of early 1969 Act plans, due to the modernity of several aspects of it, this plan did come about in the early days of the 1969 Act. Some of the similarities between the Club's early augmentation plan and today's GMS 02CW335 plan include: (1) the need to calculate depletions from historical pumping that preceded the initiation of the augmentation plan; (2) the plans' detailed accounting; and (3) the use of water produced by wells themselves for the purpose of augmentation, with the corresponding need to augment depletions resulting from that pumping at some time.

One of the largest differences between augmentation plans of the early 1969 Act period, like the Sonnenberg Farms plan, and today's plans is that the early plans sometimes balanced depletions and augmentation supplies on an *annual* basis while today's plans most often balance depletions and supplies on a *daily* basis. Other differences include (1) GMS's creation of ***river*** reaches, necessitated by the broad geographical coverage of the GMS plan, as opposed to the small geographical coverage of the Columbine Country Club plan; (2) today's availability of commonly used and commonly accepted engineering tools, such as IDSCU and AWAS; and (3) for plans involving delayed depletions from the use of groundwater, the use of a projection tool to attempt to prevent the "credit card" over-usage of groundwater pumping. [[50]](#footnote-51)50

**[\*575]**

H. How Have These Changes in Engineering Affected Water Court Cases?

Water court decrees, as well as pre-1969 Act state district court decrees, include a section on findings of fact, which, among other things, adopt the results of one party's or another party's engineering, or sometimes a Solomon-like split of the engineering baby. Today's decrees for all three of the types of water adjudication discussed in this paper - changes of water rights, appropriative rights of exchange, and plans for augmentation - generally include requirements for detailed daily accounting. Today's change decrees and exchange decrees usually involve some type(s) of volumetric limits and a *bona-fide*showing of need. Taken as a whole, but not solely the result of changes in engineering, the number of trees (think paper) required for a change decree has increased markedly from a one-page transfer decree entered in 1900 (Saguache County, Goodwin Ditch) to perhaps 80 or 100 pages today. But who but we olde guys use paper today anyway?

In my opinion, water engineering has always been in service to the law, or to the courts - prior to the 1969 Act, during the 1969 Act's early years, and continuously to the present. We employ our expertise to educate the water judges, who in terms of engineering, for the most part are lay people, at least in the beginning of their careers as water judges. Just as ***Colorado*** water law has evolved since statehood in 1876, water engineering has also evolved and will continuously evolve.

I. Bonus Section - Old Tools of the Trade

I actually started my engineering career fifty years ago, in 1969, on April 21, but not in ***Colorado***. Rather, I began my career at a place some 450 miles east of Denver, where you can smell it, and then some 450 more miles south, where you can step in it. But I began my practice in a field that I really loved, then and now - water resources engineering. The following include some of the tools of the trade from the old days

1. The Slide Rule

Photograph 1

**[\*576]**All of us engineers in 1969, young and old, used a slide rule to make our calculations. Photograph 1 is the slide rule that I used in 1969, made by the Keuffel & Esser Company of New York. In Photograph 1 he is calculating the product of 21 and 31. He puts the numeral 1 at the left end of the slide on top of the numeral 21 below the slide. Then he slides the transparent part with the vertical black line to the numeral 31 on the slide, and he sees a value of approximately 650 below the slide. Generally, the slide rule produces an answer to two or three significant digits. And, one of the funny things about a slide rule is that the numeral 21 in our example could have been 2,100 or 2,100,000 or 0.0000021. Taking 21 to be 2.1 X 10^1 and 31 to be 3.1 X 10^1 gives us an approximate answer of 6 X 10^2, or 600, which gives us the ballpark for the value of the result from our slide rule, 650. In other words, the user must properly account for where the decimal point belongs. While a slide rule does not add or subtract numbers, it does have all six of the trigonometric functions and allows one to take logarithms and such.

2. Electronic Calculators

Around 1972 or 1973, our slowly maturing engineer received a Texas Instruments SR-10 hand-held electronic calculator as a gift from his father, Joe Billy. The TI SR-10 calculator came out in November of 1972 and retailed for $ 175, according to Google research. It had the ability to add, subtract, multiply, and divide, and calculate square roots, but it had no memory and no trigonometric functions. It had several advantages over the slide rule, a liberal number of decimal places, not needing to approximate your answer as you had to do with the slide rule, and, according to another young engineer friend of our slowly maturing engineer, "It allowed you to make mistakes faster." [[51]](#footnote-52)51Repeating our slide rule example of multiplying 21 by 31, Photograph 2 shows that our first step after turning on the TI-30 is to enter the number 21.

Photograph 2

**[\*577]**Then we hit the "X" button, which means to multiply the 21 by some other number. In Photograph 3 we enter the "some-other" number 31.

Photograph 3

Then we hit the "=" button, and the result of "651." pops up in Photograph 4. Quiz of the Day - What did the "SR" in the TI SR-10 stand for?

Photograph 4

Around 1976 or 1977, our then young engineer obtained a Texas Instruments TI-30 calculator, which, according to Google, first came out in 1976 at a retail price of around $ 25. This little puppy could really dance - it had square root capability and the ability to square a number, along with raising a number to a given power, memory, and trigonometric functions. Its "screen" produced results in a tiny, red font - quirky.

3. Planimeter

Our young engineer learned how to use a planimeter in 1969, or 1970 at the latest. A planimeter allows one to measure the area of any shape of object **[\*578]**- a square, a circle, an oval, a rectangle, a pentagon, a slice of pie, or some irregularly shaped object, such as an irrigated area or the drainage area of a stream or dam at a given point.

For our example of how to use a planimeter (borrowed from Gary Thompson and Bret Swiggle of W.W. Wheeler and Associates), I start with Photograph 5, where I have chosen to locate Clayton Dam across an unnamed tributary to Plum Creek, on the east side of U S Highway 85, south of Denver near the old munitions town of Louviers (and near the home of a late Water District 8 water commissioner, Joe Clayton).

Photograph 5

The first thing that I had to do, by hand, is to draw in the drainage divide of the watershed upstream from our dam.

Then, in Photograph 6, I place the round glass magnifying half dome over a tick mark that I have placed on the drainage divide with its bubble directly above the point where the tick mark intersects the drainage divide. Unfortunately, when our now aged but completely matured engineer took the photo shown in Photograph 6, he focused on the readout of the planimeter and shot his photo at an oblique angle that made the bubble appear not to be directly over the intersection of the tick mark and the drainage divide. You'll just have to trust the olde engineer on that one. The beginning reading of the planimeter in Photograph 6 is 79.69 square inches.

**[\*579]** Photograph 6

Our engineer then makes his first circuit of the drainage divide until he reaches his starting point, and in Photograph 7 we see that his second reading of the planimeter is 81.10 square inches. The difference between these two readings is 1.41 square inches.

Photograph 7

He then makes a second circuit around the perimeter of the drainage divide back to his point of beginning, and his final reading in Photograph 8 is 82.50 squares inches, for a difference in the second circuit of 1.40 square inches. He **[\*580]**is happy that his readings of 1.41 and 1.40 square inches are so close to one another, because the closeness indicates that his engineer friend didn't bump his drafting table when he walked by smoking a Chesterfield and spilling coffee from his cup. So, our young engineer concludes that he'll use the average of 1.405 square inches. He's been using a planimeter on 15-minute USGS quadrangle maps for quite some time, and he knows that one square inch on the quad sheet represents approximately 91.83 acres. So, he multiplies his average planimeter reading of 1.405 square inches by 91.83 acres per square inch, and he concludes that the drainage area upstream from the Clayton Dam is approximately 129 acres. Did you notice the use of the Vernier scale to get the last significant digit in our readings of the planimeter?

Photograph 8

4. Map Wheel

The last quaint little tool that our young engineer learned to use was a map wheel, shown in Photographs 9 and 10.

**[\*581]** Photograph 9 and 10

A map wheel is like a smaller sister or brother to the measuring wheel used by employees of the San Mateo County Public Works department on August 28, 2018, to obtain a distance along 9th Avenue for the purpose of removing a sewer blockage (Photographs 11 and 12).

Photograph 11 and 12

If you can enlarge Photograph 12, note that the operator of the measuring **[\*582]**wheel has zeroed out the readout, located on the lower part of the wheel, between the word "Lufkin" and the operator's boots. A map wheel allows one to calculate the linear distance along a wiggling, squiggling line, such as the meandering Trinity ***River*** in Texas as it nears the Gulf coast.

Because our engineer spent the vast majority of his career working in ***Colorado***, we shall assume that we've been asked to calculate the approximate length of the Shoshone Power Plant's pipeline (or penstock) from its source on the ***Colorado*** ***River*** upstream of Glenwood Springs to its downstream discharge back to the ***River***. We pull out a 15-minute quad map, and after zeroing out our planimeter in Photograph 9, we run the map wheel along the route of the pipeline that shows up clearly on the quad. In Photo 10, our end reading is 6.5 inches. Because we just love the 15-minute quad sheets' scale of 1:24,000, or 1 inch equals 2,000 feet, we arrive at an approximate length of 13,000 feet for the Shoshone Power Plant's pipeline. Now we can answer the exam's question of what is the theoretical power that can be produced with a flow of 1,250 cfs through the pipeline and back to the ***river***, because we know everything else we need to know to answer the question, including, but not limited to, the type, size, age, and condition of the pipe.

III. Ground Water Hydrology

This section of the paper will discuss how the science of ground water hydrology has been applied to and has adapted to changes in ***Colorado*** water law from 1969 to 2019. Over this 50 year time period, ground water methods, techniques, and analyses have been developed for and applied to changes in ***Colorado*** water law. This paper will document in a summary manner the development and application of ground water practices for the 1969 to 2019 time period.

This paper will discuss the evolution of alluvial ground water and bedrock aquifer ground water in separate sections and, as appropriate, the commonality between alluvial and bedrock ground water practices will be discussed.

One question asked in this paper is, "With respect to ground water hydrology over the period 1969 to 2019, what is different and what has stayed the same?" A general answer to this question is that much is different and much is the same. The basic principles of ground water hydrology had their beginnings near the middle of the nineteenth century when Henry Darcy (1856) [[52]](#footnote-53)52described the physics of ground water flow in most alluvial and sedimentary formations. [[53]](#footnote-54)53This is known as Darcy's Law. On the other hand, in 1969 how many people foresaw "everyone" walking around with a smart phone capable of connecting to anywhere in the world, able to answer any factual question in seconds, and much, much more? Due to automated data collection tools and the legal and administrative requirements to collect data, the amount of available data that can be applied to projects is much greater now than in the past. The ability to **[\*583]**search for and obtain hydrogeologic reports and data in a straight-forward manner from an office computer or laptop have significantly increased the amount of hydrogeologic knowledge and data that is applied to water court cases. Specific examples of significant advances in ground water hydrology that have affected water consulting practice in respect to water rights cases in ***Colorado*** include the development of numerical ground water models and automated calibration techniques. Other technical advances such as the development and use of electronic, remote-reading pressure transducers and data loggers to measure and record changes in ground-water level have allowed for more detailed ground-water analyses and ground water models. These and many more advances in ground water have resulted in the advancement of ground water hydrology and its ability to meet the requirements of implementing the changes in ***Colorado*** water law that occurred between 1969 and 2019. Similarly, the availability of these powerful new tools in ground water consulting in the post-'69 Act era have enabled and, in some instances, have driven case law, statutes, and administrative regulations in ***Colorado*** water.

A. Alluvial Ground Water and Plans for Augmentation

Along with the integration of tributary ground water into the prior-appropriation system in ***Colorado***, the 1969 Act also directed development of augmentation plans to allow tributary wells, "... to operate outside of the priority system so long as a replacement source of water can be arranged so that one's out-of-priority stream depletions are fully replaced in the proper time, place, and quantity *.*" [[54]](#footnote-55)54

The significance and importance of the establishment of augmentation plans with respect to ground water hydrology consulting work cannot be overemphasized as these augmentation plans require the integration of many facets of ground-water hydrology and the technical aspects of ground water law. Over the past 50 years, an evolution has taken place: there has been increasing technical understanding, and a rising bar, set by the Water Courts and water administrators, the State Engineer's Office ("SEO") for minimum standards for what is included in an augmentation plan. It is very clear that tributary well augmentation plans and exchanges have become more detailed and more complicated over time, a development largely due to the general availability of more and better data, and more and better technical tools to process, analyze, and present those data. A heightened sensitivity to water rights protection and potential water rights injury issues, which are the result of increased water demand, have resulted in more work going into more detailed tributary well augmentation plans and exchange analyses.

The development of a "modern day" tributary well augmentation plan, even a relatively simple plan for one well, can include the following hydrogeologic, water rights administration, and water quality components:

Well site location analyses;

Test hole drilling, lithologic sample collection and analysis, and determination of the well's depth and depth to bedrock

**[\*584]**Well permitting

Development of well installation and pumping test contractor specifications and well construction documents

Well installation

Site-specific pumping tests to determine aquifer properties of transmissivity [[55]](#footnote-56)55and specific yield [[56]](#footnote-57)56, the well's pumping rate, and the amount of hydraulic connection with the stream system

Water quality sampling, laboratory testing, and water quality analyses

Quantification of the location, timing, and amount of stream depletion from well pumping

Development of a stream depletion unit response function [[57]](#footnote-58)57("URF") from well pumping that is integrated into the augmentation plan accounting

Research, identification, and quantification of the augmentation plan's replacement supply

Development of augmentation plan accounting and its approval by the Division Engineer

Analysis and development of any needed exchanges, either as part of, or in parallel with, the augmentation requirements.

The frequency of stream depletion replacement and augmentation plan accounting, i.e. the time period over which out-of-priority stream depletions are calculated and must be accounted for and replaced, has become shorter over time from 1969 to the present. For example, Denver Southeast Suburban Water and Sanitation District's ("Denver Southeast") augmentation plan, W-6268, [[58]](#footnote-59)58which includes Cherry Creek alluvial wells has annual replacement and accounting of stream depletion. The W-6268 augmentation plan was decreed on November 21, 1977. [[59]](#footnote-60)59In 2011, Denver Southeast filed an augmentation plan for new Cherry Creek alluvial wells in Case No. 11CW198. [[60]](#footnote-61)60This case was entered on August 30, 2016. [[61]](#footnote-62)61The water court decree for this case includes the daily calculation and recording of stream depletions from well pumping and **[\*585]**replacement supplies, and weekly replacement of out-of-priority stream depletion. [[62]](#footnote-63)62

On the main stem of the South Platte ***River***, the daily calculation and replacement of out-of-priority stream depletion from tributary well pumping takes place. Examples of the daily calculation and replacement of South Platte ***River*** depletions from well pumping occur in Case No. 01CW258 for South Adams County Water and Sanitation District, [[63]](#footnote-64)63Case No. 02CW335 for the Ground Water Management Sub District of Central ***Colorado*** Water Conservancy District, [[64]](#footnote-65)64and Case No. 08CW141for the City of Northglenn. [[65]](#footnote-66)65This is in contrast to annual replacement, required for many augmentation plans decreed in the first ten to fifteen post-'69 Act years. There would be little dispute among the water consulting and administrative sectors that current stringent accounting requirements result in a much more efficient use of the available water resource, thereby helping meet the ***Colorado*** Supreme Court's mandate of *optimum utilization*. [[66]](#footnote-67)66By the late 1980's, "conventional wisdom" in ***Colorado*** was that available augmentation supplies and exchange potential largely would be "tapped out" by about the year 2000 in the main stem South Platte ***River*** alluvial aquifers. Obviously, this was wrong - probably for many reasons-but certainly, in part, due to the availability of powerful new ground-water analyses, reporting tools, and more and better data.

B. Analytical Ground Water Modeling

Analytic ground water models are important and powerful hydrogeologic tools that are used by every consulting hydrogeologist in ***Colorado***. Analytical ground water models are computer programs that solve the exact forms of analytical ground water equations. Several of the most important and commonly used ground water equations were developed much earlier than 1969. In addition to Darcy's Law, the Thiem equation was published in 1906 [[67]](#footnote-68)67and the Theis equation was published in 1935 [[68]](#footnote-69)68The Thiem and Theis equations are well hydraulic equations used to calculate drawdown due to well pumping. [[69]](#footnote-70)69The authors of the Glover equation, Glover and Balmer, published ***River*** *Depletion Resulting from a Pumping Well Near a* ***River*** in 1954 [[70]](#footnote-71)70Many other important **[\*586]**papers by Boulton [[71]](#footnote-72)71, Dupuit [[72]](#footnote-73)72, Glover [[73]](#footnote-74)73, Hantush [[74]](#footnote-75)74, Jacob [[75]](#footnote-76)75, Jacob [[76]](#footnote-77)76, Prickett [[77]](#footnote-78)77, Rorabough [[78]](#footnote-79)78, Theis [[79]](#footnote-80)79, and others were published before 1969. Thus, most of the analytic mathematical expressions that explicitly describe well drawdown and stream depletions were developed and in common use by consultants prior to the adoption of the 1969 Act.

Computer programming languages, primarily early versions of FORTRAN and BASIC, were used in the 1970s to develop analytical ground water models. Prior to the development of these simple computer program codes to directly solve drawdown and stream depletion problems, ground water equations were solved, "by hand" which included solutions to differential equations facilitated by curve matching or published tables of functions required by the equations. Analytic ground water models made the application of ground water equations to ground water problems much easier. With a combination of knowledge, judgement, and experience, the hydrogeologist in the 1970's - and still to some extent today - develops the appropriate input data or parameters for the program, runs the program, obtains and error-checks the resulting answer, and interprets and documents the results.

C. Glover Analyses, Stream Depletion Factors, and Unit Response Functions

The Glover equation [[80]](#footnote-81)80was developed prior to 1969. The Glover equation continues to be widely used [[81]](#footnote-82)81- although with care - to quantify stream depletion timing from well pumping. They have also been used to quantify recharge and **[\*587]**lawn irrigation return flow ("LIRF") accretion timing to a stream. Stream depletion factors ("SDF") developed by Jenkins [[82]](#footnote-83)82were used by South Platte ***River*** water users and the ***Colorado*** Division of Water Resources to quantify stream depletion and accretion timing. The South Platte ***River*** stream depletion factors developed by Jenkins were a mapped form of the Glover equation. However, these stream depletion factors are now rarely used, but some augmentation plans decreed in the 1970's and early 1980's continue to rely on the SDF method for stream depletion timing from alluvial well pumping.

Prior to the 1969 Act, there was no explicit legal requirement to quantify the location, timing, and amount of stream depletion. Our research indicates that, in terms of case law, the quantification of stream depletion location, timing, and amount for replacement of depletions first occurred in 1972. Case No. W-2692 by the Fort Morgan Reservoir and Irrigation Company [[83]](#footnote-84)83appears to be the first use of the SDF to time stream depletion. This case was filed on June 12, 1972. The first use of the Glover equation appears in Case No. W-2968 by the Upper Platte and Beaver Canal Company. [[84]](#footnote-85)84This case was filed on May 19, 1972.

Over time there were more and more tributary well augmentation plans that required accounting of well pumping and stream depletion. The quantification of stream depletion timing could be obtained by running the Glover model, a SDF method, or a numerical model each time stream depletion needed to be updated. Running a model every time daily, weekly, monthly, or yearly stream depletions needed to be updated and quantified was cumbersome and expensive. For example, the Glover model can be run each week with updated well pumping to quantify stream depletion from previous weeks and the current week of pumping. As an alternative to running a model for each different time period of pumping, unit response functions ("URFs") were developed. Our research indicates URF's were first developed and used by HRS in the early 1980's, and the method was soon adopted and endorsed by ***Colorado*** Division of Water Resources ("CDWR") [[85]](#footnote-86)85. Now it is common to develop URFs with Glover or a numerical model and a spreadsheet program, and then to incorporate the URFs into augmentation plan accounting. Glover analyses are usually completed with the Alluvial Water Accounting System ("AWAS") model developed at ***Colorado*** State University [[86]](#footnote-87)86The AWAS program simulates the Glover equation and is based on work completed by Dwayne Schroeder [[87]](#footnote-88)87when he was working at the SEO. Today URFs are widely used and their use has **[\*588]**been expanded, where appropriate, to include stream depletion timing for bedrock wells and accretion (recharge plans and LIRF) timing to streams.

D. Spreadsheet Calculations and Models

Spreadsheet programs didn't exist in 1969. The use of spreadsheets in the consulting community began with the advent of the personal computer ("PC") in the early 1980's with spreadsheet programs such as Lotus 123 and Excel. Visicalc [[88]](#footnote-89)88was a primitive Apple compatible spreadsheet that was available for Apple 2 PC's by 1981. HRS used Visicalc for Theis and Glover solutions as well as Blaney-Criddle calculations. Lotus 123 came out in January 1983, and Excel came out in September, 1985. Lotus 123 was used for many years by ***Colorado*** ground water consultants before the Microsoft Office Suite of programs took over. A joke in the HRS office in the mid 80's was that, "Any calculation printed out on computer paper was correct because it came from a computer." Shortly after this time the saying, "GIGO: garbage in - garbage out" was making the rounds in the consulting and legal community. Spreadsheets with their graphing, macro, and database functions have taken the place of many hand calculations and allow for the coding of spreadsheet functions and formulas so that analytical programs and accounting forms can be updated in a straightforward manner. The use of spreadsheets in ground water and water rights work is now ubiquitous. Spreadsheet accounting is further discussed in the accounting section of this paper.

Today, spreadsheets are used in every aspect of ground water hydrology and also as ground water hydrology applies to ***Colorado*** water law. Spreadsheet applications include: stream depletion timing from well pumping, stream accretion timing for recharge plans, lawn irrigation return flows ("LIRFs"), the development and application of URFs, pumping test analyses, determining transmissivity, the specific yield and storage coefficient, the pre-and post-processing of numerical model files, net present value cost analyses, data analysis, accounting, and much more. In the water administrative sector and in many court-decreed augmentation plans, accounting and reporting requirements are exceedingly complex, and simply could not be done nor could administration be accomplished without spreadsheets, given that in any main stem basin there are hundreds of active augmentation plans that must all work together with real-time direct flow and reservoir data. Sophisticated and interactive spreadsheets allow for detailed plan administration. Plan accounting itself has developed into a growing sub-specialty in the water consulting community in ***Colorado***. The accounting section of this paper includes additional discussion of this topic.

E. Numerical Ground Water Modeling

The first numerical groundwater flow models were published around the time of the 1969 Act, including: Pinder and Bredehoeft (1968) [[89]](#footnote-90)89, Pinder **[\*589]**(1969) [[90]](#footnote-91)90, Bredehoeft and Pinder (1970) [[91]](#footnote-92)91, and Prickett and Lonnquist (1971) [[92]](#footnote-93)92A subsequent numerical model was published by Trescott, Pinder, Gray, and Larson (1976) [[93]](#footnote-94)93Prickett and Lonnquist (1971) and Trescott, Pinder, Gray, and Larson (1976) models were used by ***Colorado*** ground water consultants in the 1970s and 1980s until the U.S. Geological Survey's MODFLOW program by MacDonald and Harbaugh became available by 1988 [[94]](#footnote-95)94The MODFLOW program has been updated with several new versions since 1987 and it has become the most commonly used numerical ground-water model code. The current version of the MODFLOW model is MODFLOW 6 Modular Hydrologic Model version 6.0.3 [[95]](#footnote-96)95

Numerical ground water models developed through numerical ground water modeling projects have become more accurate over time. This improved accuracy is demonstrated by the models' ability to more accurately replicate observed time-varying ground-water levels, stream flow rates, and the physical processes that effect ground water level and stream flow rates over time, i.e., ground water budget components of stream gains and losses, agricultural drain flow, well pumping, evapotranspiration, boundary inflow and outflows, and precipitation recharge. This improvement has been the result of several factors that include: improved ground water model codes, i.e., the evolution of the MODFLOW program that includes greater capabilities to more accurately model physical ground water processes, the availability and accumulation of more hydrogeologic data over time which allows for improved match to observations; and thus improved ground water model calibrations, and increased computer processing speed, memory, and storage. Around 1970, Moore's Law was developed. This law said that computer processor speed would double every two years. Additional computing improvements include 64-bit processing, double precision [[96]](#footnote-97)96and multi-gigabyte memory drives. These advances are compared to a 1980s PC with an 8-bit processor and one or two floppy drives. The first relatively simple numerical models developed at HRS ran for hours, often overnight. Currently, multi-layer basin wide model runs are made in a matter of minutes.

There is also an increased understanding by clients, water attorneys, and consultants of the necessity of ground water model accuracy. This last point **[\*590]**has been driven home in water court cases where the use of ground water models has not resulted in a successful outcome. The old adage that, "Whoever has the burden of proof in ground water case loses," [[97]](#footnote-98)97is not as powerful as it once was. It has been shown that accurate ground water models can be developed and used to solve complex ground water modeling projects. An example of this are the recently promulgated Rio Grande Rules. [[98]](#footnote-99)98Those rules relied on a MODFLOW ground water modeling project designed specifically for the development of the Rio Grande rules. [[99]](#footnote-100)99The MODFLOW ground-water model received large investments in time and money for data collection and peer review.

The ways and means of building ground-water model input files, running the ground-water models, and analyzing and presenting ground-water results have changed significantly over time. A major change occurred with the development of the MODFLOW graphical user interface ("GUI") ground-water modeling programs. These GUI programs provide pre-and post-processing programs for efficient and user-friendly data input and output to the core codes of numerical ground-water models. Before the development of GUI-based ground-water modeling programs, ground-water modelers had used Hollerith [[100]](#footnote-101)100punch-and card-reading machines and word-processing programs with files that required specific formatting and coding. A compiled version of the groundwater model sought to read these formatted files, but if the input files were imperfect; for example, a misplaced number in the input file, and there were thousands of numbers, would cause an error message to prevent the ground-water model from running. The development of GUI-based pre-and post-processing ground-water modeling programs - such as Groundwater Vistas, [[101]](#footnote-102)101Visual MODFLOW, [[102]](#footnote-103)102and Ground-Water Management Systems [[103]](#footnote-104)103- however, allowed ground-water modelers to input model commands and input data from a computer keyboard while viewing the inputs and model outputs graphically in two or three dimensions. The pre-processing capabilities of the ground-water model programs could create ground-water model input files. The post-processing functions of the GUI programs allow for the presentation of ground-water model results with increased ease and efficiency as compared to previously **[\*591]**used methods. GUI programs can create graphs, contour maps, cross sections, color-flood maps [[104]](#footnote-105)104, and three-dimensional figures of ground water model results on a computer monitor in a matter of seconds.

The development of geographic information systems ("GIS") has been a major development and improvement to ground-water modeling projects. This has been especially true for data-centered models that base periodic update of ground-water models on newly available data. GIS programs can organize, analyze, and present hydrogeologic data. The presentation of the GIS data can take many graphical forms, but the automated contouring of hydrogeologic data remains a powerful and useful tool for presenting hydrogeologic data. Ground-water modelers develop and check GIS hydrogeologic data files before bringing them into MODFLOW. The development of automated-inverse ground-water modeling techniques and sensitivity analyses also marked major advancements in numerical groundwater modeling. Inverse ground-water modeling programs - such as PEST [[105]](#footnote-106)105and UCODE [[106]](#footnote-107)106- provide alternate methods of calibrating groundwater models. With traditional groundwater-model calibration techniques, the groundwater modeler revised the model through several iterations of input parameters to obtain an acceptable distribution of hydraulic heads and water-balance values. With an inverse groundwater modeling calibration approach, however, the known hydraulic heads and water-balance values serve as input to the inverse ground-water model program. The inverse ground-water model program obtains the most reasonable set of ground-water model input parameters that result in the known hydraulic head and water balance values. The inverse ground water modeling approach relies heavily on hydrogeologic experience, judgement, and data. As part of its model-calibration process, the groundwater modeler establishes reasonable ranges for the model-input values. Additionally, while, in the 1980s, few if any ground-water models included a sensitivity analysis,. [[107]](#footnote-108)107most ground-water modeling projects today include it. The sensitivity analysis demonstrates the validity of the ground-water model, its potential limitations, and the possible need for additional data collection.

Since enactment of the 1969 Act, hydrologic modeling has become a sub-specialty for water-consulting practitioners in ***Colorado*** and elsewhere. Although many, if not most, practicing hydrogeologists can skillfully develop computer models, they often choose to work interactively with geologists, hydrologists, and engineers to mathematically capture the relevant hydrologic concepts **[\*592]**and dynamics of a situation and to debug, run, calibrate, and verify model results. In the early days after adoption of the 1969 Act, such a division of labor among consultants was unnecessary and largely inconceivable. Today, in many water court cases, however, it is not unusual for applicants and objectors each to retain testifying experts to address some of the following key questions before the court: (1) Does this model or accounting accurately reflect the physical / hydrogeologic situation? (2) Will operation of this water right (or augmentation plan, exchange, etc.) by use of the model or accounting result in non-injury to all other water rights in the system? (3) Is this water right, augmentation plan, or exchange as described by this model or accounting administrable and enforceable? As technical sophistication has increased, it has become increasingly rare that a single expert, no matter how experienced, qualifies to answer all of these complex and highly specialized questions.

F. Senate Bill 213

Senate Bill 213 ("S.B. 213") became effective in 1973, four years after the 1969 Act. [[108]](#footnote-109)108S.B. 213 came about after the State Engineer, Clarence J. Kuiper, asked the ***Colorado*** Legislature for a law his office could apply in the issuance of permits for non-tributary groundwater wells, particularly in the Denver Basin. "The 1973 49th General Assembly agreed there was nothing in the statutes to cover the non-tributary, non-designated water." [[109]](#footnote-110)109In 1973, the State Engineer had issued non-tributary well permits based on the "well-cylinder method" [[110]](#footnote-111)110and a nominal 100-year aquifer life, but the legislature had not supported these methods as a means for determining a well's permitted pumping amount. Uncomfortable with these circumstances, Mr. Kuiper had asked the legislature to remedy the situation by giving his office statutory direction for well permitting. [[111]](#footnote-112)111

As a result, S.B. 213 applied to non-tributary groundwater outside of designated basins. [[112]](#footnote-113)112After much debate, the law introduced three significant non-tributary groundwater appropriation provisions: (1) that a land owner may obtain a permit to develop the non-tributary ground water beneath his property; (2) that permits for ground-water withdrawal should issue on the basis of a nominal 100-year aquifer life; and (3) that the annual withdrawal volume is one percent of the total appropriation beneath the property. [[113]](#footnote-114)113

The provisions of S.B. 213 to adjudicate and administer Denver Basin ground water in ***Colorado*** as development took off in the 1970s and 1980s. [[114]](#footnote-115)114 **[\*593]**From 1970 to 1990, Douglas County's population grew among the fastest in the country - from 8,407 in 1970 to 60,391 in 1990. [[115]](#footnote-116)115

Determining ground-water appropriations proved a contentious process between applicant and objectors in Denver Basin ground-water appropriation cases under S.B. 213. Characteristics such as land area, specific yield, and saturated sandstone/siltstone thickness within the top and base of the aquifer, along with the nominal 100-year aquifer life, determined whether land owners would receive a permit to pump water. [[116]](#footnote-117)116Findings of fact about the tops and bases of aquifers required detailed argument and scrutiny of borehole-geophysical logs. [[117]](#footnote-118)117Consultants spent a lot of time focusing on their ground-water appropriation analyses. A determination of the land area for the entitlement was fairly straightforward if the owner could show title to the overlying land or permission from the owner landowner for use of underlying groundwater. The parties determined land area by using land-area surveys or planimetering map areas. [[118]](#footnote-119)118S.B. 213 established pre-S.B. 213 well cylinders. [[119]](#footnote-120)119But at times, discussions about appropriate land-area subtraction for pre-S.B. 213 overlapping well-cylinder areas took place, questioning whether or not the size and area of the pre-213 well cylinder had been developed correctly. The selection of appropriate values of specific yield, saturated sandstone/siltstone thickness, and the depth to an aquifer's top and base provided additional points of discussion. I recall applicant-objector meetings where the hydrogeologists discussed whether their geophysical-borehole logs showed the correct amounts of sandstone/siltstone versus claystone and shale. Pointing to a specific depth on the log, an objector would say, "I think this is shale, not sandstone." But with Senate Bill 5 and its Denver Basin rules, the water-court system finally obtained a more straightforward and standardized way to determine specific yield, saturated thickness, and the depth from aquifers' tops to base.

In the years prior to Senate Bill 5, water courts had used contour maps were extensively used in water court cases to support analyses of Denver Basin aquifer appropriations analyses. They had plotted by hand the values of aquifer top elevations, base elevations, and saturated sandstone/siltstone thicknesses within the aquifer were plotted on topographic base maps and contoured by hand. Draft persons, (remember them?), prepared contour maps as report figures and trial exhibits. Borehole geophysical logs taken from the subject property determined the data for these reports. These contour maps were based on analyses of borehole geophysical logs taken from and around the subject property. The development of these contour maps became less important in water court cases post after the passage of S.B. 5 , however, which provided rules based on contour **[\*594]**maps of the aquifers' top elevations, base elevations, and sandstone/siltstone thicknesses. [[120]](#footnote-121)120

Parties at water court had determined values for aquifers' specific yields by providing site-specific evidence, negotiating with objectors, and obtaining decrees. In some cases, parties had even drilled aquifer-test holes to geophysically log an aquifer's saturated sandstone/siltstone thickness and take physical samples from it. They used these test holes to determine saturated sandstone/siltstone thickness and specific yields because relatively little other data existed at the time. For example, under S.B. 213, a water court decreed the rights to the Laramie-Fox Hills Aquifer. [[121]](#footnote-122)121In that decree, the court determined saturated sandstone/siltstone value and the specific yield values from borehole geophysical logs taken at each well. [[122]](#footnote-123)122Each well had a specific annual appropriation value. [[123]](#footnote-124)123

G. Senate Bill 5-1985

The bedrock aquifer ground water law, Senate Bill 5 ("S.B. 5"), became effective on July 1, 1985. [[124]](#footnote-125)124This law resulted in significant changes to hydrogeologic consulting inside and outside of the Denver Basin. For the Denver Basin aquifers and the Dakota Aquifer, which primarily lies beneath eastern ***Colorado***, [[125]](#footnote-126)125S.B. 5 and its accompanying rules made obtaining an entitlement to bedrock ground water a more straightforward process. [[126]](#footnote-127)126Outside of the Denver Basin, for bedrock aquifers other than the Dakota and Cheyenne Aquifers, the primary S.B. 5 benefit to potential ground water users was clarity on the definition of non-tributary groundwater. The Getches Committee - a working group of water attorneys, engineers, and administrators - had recommended the administrative rules that would accompany S.B. 5. [[127]](#footnote-128)127Based on their recommendations, State Engineer Jeris Danielson had then overseen hearings to hammer out the details of the S.B. 5 rules, including rules that define non-tributary ground water. Many witnesses before the hearings had supported these recommendations providing numerical modeling of the Denver Basin for support.

Perhaps unsurprisingly, S.B. 5 increased numerical ground-water modeling in the Denver Basin and analytical and numerical groundwater modeling outside of the Denver Basin. S.B. 5 had also streamlined the Denver Basin groundwater appropriation process. Denver Basin numerical-modeling activities increased as the State Engineer began using MODFLOW groundwater models to determine the location of non-tributary and tributary groundwater in **[\*595]**each of the Denver Basin aquifers. [[128]](#footnote-129)128Therefore, water providers and private land owners applying to water court for not non-tributary ground water also used MODFLOW to quantify the location and timing of pumping and post-pumping stream depletion over 100-year pumping periods.

S.B. 5 authorized the development of statewide non-tributary groundwater rules [[129]](#footnote-130)129and rules specific to the Denver Basin. [[130]](#footnote-131)130Six primary elements of S.B. 5 caused significant changes to hydrogeologic consulting work: (1) application of a statewide definition of non-tributary ground water outside of designated ground water basins; (2) implementation of an augmentation plan requirement for actual replacement and four percent replacement "not nontributary" ground water. (3) The augmentation of post-pumping stream depletions.

(4) For the Denver Basin bedrock aquifers, the Denver Basin Rules determined the location of nontributary, four percent not-nontributary, and actual replacement not nontributary ground water.

The Denver Basin Rules established to give presumptive values to the Denver Basin aquifers' top and base elevations, specific yield, and sandstone/siltstone thickness.

(5) establishment of rules requiring a two-percent relinquishment of non-tributary ground water, causing it to return to the surface water system; and (6) establishment of statewide rules controlling annual appropriation-banking provisions and wellfields. Implementation of rules for the Denver Basin streamlined processes of adjudication and appropriation there. These rules included CDWR-developed contour maps that depicted the elevation of the top of the aquifer, the elevation of the base of the aquifer, and the sandstone/siltstone thickness. [[131]](#footnote-132)131The Denver Basin rules also mapped the locations of tributary and non-tributary ground water.. [[132]](#footnote-133)132The state published these maps in four hydrogeologic atlases, one for each aquifer in the Denver Basin. [[133]](#footnote-134)133This information ended most hydrogeologists' debates over the appropriate aquifer top and base elevations, and over the appropriate sandstone siltstone value at a well location. However, the permitted aquifer top or base was frequently revised based on site-specific evidence, usually the borehole geophysical logs run after the borehole was drilled, and before the well was cased and completed. For this revision **[\*596]**to occur, the consultant brought the borehole geophysical log to the State Engineer's Office for their review and approval. [[134]](#footnote-135)134

Denver Basin groundwater appropriation analyses under S.B. 5 use an average sandstone/siltstone value for the property based on the appropriate Denver Basin sandstone/siltstone map. [[135]](#footnote-136)135For many years, consulting work determined the sandstone/siltstone value at a well location or an average sandstone/siltstone value for a property. For many of these analyses, consultants developed and analyzed contour maps by hand. Currently, the appropriate sandstone/siltstone value (average or location specific) can be obtained through SEO's online Aquifer Determination Tool. [[136]](#footnote-137)136Following S.B. 5, the final sandstone/siltstone value and annual appropriation is included as a retained jurisdiction decree provision. [[137]](#footnote-138)137The final annual appropriation value is based on an average saturated sandstone/siltstone value, which is determined from an analysis of wells' borehole geophysical logs obtained after the well is drilled. [[138]](#footnote-139)138A landowner's final entitlement (decreed annual appropriation value) for a particular bedrock aquifer can be obtained through an analysis, a report, and a petition to the water court for a determination of a final annual appropriation.

Rule 6 of the Denver Basin S.B. 5 Rules includes presumptive specific yield values for the Denver Basin aquifers. [[139]](#footnote-140)139These specific yield values range from 20% for the Upper Dawson and Lower Dawson aquifers to 15% for the Laramie-Fox Hills Aquifer. [[140]](#footnote-141)140The determination by rule of these presumptive specific yield values ended much of the debate and consulting effort related to the determination of specific yields that took place under S.B. 213. Under the Rules, it is possible to petition for a change to the specific yield of a particular property based on presentation of site-specific evidence, such as evidence obtained from advanced geophysical logging tools, laboratory analysis of sediment cores, or certain types of aquifer testing. [[141]](#footnote-142)141

Under S.B. 5, all groundwater outside of the Denver Basin and designated groundwater basins is presumed to be tributary groundwater. [[142]](#footnote-143)142The Rules determined the location of tributary and non-tributary groundwater inside the Denver Basin. [[143]](#footnote-144)143Groundwater modeling analyses convincing to objectors and CDWR must overcome the presumption of tributary or not non-tributary groundwater inside and outside the Denver Basin. Tributary and not non-tributary groundwater require augmentation plans before the groundwater can be **[\*597]**put to beneficial use. [[144]](#footnote-145)144These augmentation plans require groundwater modeling to determine the location, timing, and amount of stream depletion from well pumping. [[145]](#footnote-146)145

Outside of designated groundwater basins, a determination of non-tributary groundwater under S.B. 5 is made based on whether or not the calculated rate of stream depletion after 100 years of continuous pumping is greater than or less than 0.1%. This stream depletion ratio is defined as the rate of stream depletion ("q") divided by the well's pumping rate ("Q"), i.e. q/Q. As part of the development of the S.B. 5 Denver Basin Rules, the SEO developed and ran a MODFLOW model for each of the Denver Basin aquifers to determine the location of the non-tributary groundwater and the "non-tributary ground water line" which was drawn along section lines. These groundwater models followed the S.B. 5 provision "that the hydrostatic pressure level in each such aquifer has been lowered at least to the top of that aquifer through that aquifer." [[146]](#footnote-147)146This means the aquifer specific yield is determined as if the aquifer is under water table conditions (whether or not it is), not the confined storage coefficient, was used for the calculation of stream depletion rate (q/Q). As a practical matter, the S.B. 5 criterion to achieve non-tributary status presents a very high bar, and evidence to overcome the tributary presumption must be clear and convincing.

For actual replacement and four percent not nontributary ground water, water suppliers adjudicated the ground water and developed the required augmentation plans These augmentation plans required the numerical modeling of stream depletion for 100 years of continuous pumping and very long (1,000 year) post-pumping depletion periods. In 1987, HRS quantified stream depletion from pumping not non-tributary Denver and Arapahoe aquifer groundwater for ***Colorado*** Spring Utilities using a numerical groundwater model, one of the first models specifically developed for this use. The results were included in ***Colorado*** Springs Utilities Augmentation Plan, Case No. 89CW36, Division 2. [[147]](#footnote-148)147

Following Rule 13 of the Denver Basin Rules and Rule 17 of the Statewide nontributary Ground Water Rules, site-specific data could be presented to challenge a rule for a specific area. Hydrogeologic consultants commonly evaluated the accuracy of the nontributary line for their clients. The information used for the rules was compared to hydrogeologic consultant's site-specific information. One instance where the Denver Basin Rules were revised was Case No. 89CW36, as referenced above. In this case, hydrogeologic mapping completed by Gronning Engineering Company resulted in a change to the Laramie-Fox Hills outcrop area. [[148]](#footnote-149)148This revised outcrop area was provided to HRS for our ground water modeling work and was used to quantify actual replacement not nontributary stream depletions for the ***Colorado*** Springs augmentation plan. [[149]](#footnote-150)149

**[\*598]**S.B. 5 also resulted in more analytical and numerical groundwater modeling outside of the Denver Basin. Under S.B. 5 and the Statewide Ground Water Rules, all groundwater outside the Denver Basin and designated groundwater basins is presumed to be tributary, consultants for ground water providers performed analytical or numerical ground water modeling analyses to evaluate whether or not their ground water was indeed tributary, and if it was, to quantify the location of stream depletions and stream depletion timing with time. An example of a numerical ground water modeling project is Case No. 88CW420 in the Piceance Basin. [[150]](#footnote-151)150As part of this case, a multi-layer MODFLOW model was developed to quantify stream depletion. [[151]](#footnote-152)151Analytical stream depletion models were and are currently used in more straightforward hydrogeologic conditions. In an unusual example, HRS succeeded in obtaining a non-tributary finding for a non-bedrock (alluvial or Aeolian) aquifer located in eastern ***Colorado*** based on analytical (Glover/AWAS) modeling and very conservative aquifer parameter values. [[152]](#footnote-153)152

In summary, Senate Bill 5 and its attendant administrative rules, marked a key point in the evolution of how consultants, attorneys, and administrators view complex aquifers and approach the problem of quantifying injury. Key elements in this evolution of the thinking process of consultants and attorneys include the following:

Consultants now feasibly run one or more peer-reviewed and generally accepted numerical models to determine depletive effects of pumping one or more bedrock aquifers. At the time of the S.B. 5 hearings, in many quarters there was still doubt that this process could be effectuated in a practical and economic manner. Increasing data availability and the proliferation of computer codes and pre-and post-processing software accounts for much of this development.

In the 30-plus years since enactment of S.B. 5 and its attendant administrative rules, revisions to aquifer mapping, introduction of new parameter values, and similar data-intensive items, have become commonplace though still time-intensive. Updates and revisions of this type have largely become feasible and economical through the development of more efficient, easy to use, and sophisticated data processing and mapping software, as well as the proliferation of internet technology, including online databases of public-record data. In ***Colorado***, much credit is due to the foreseeing consultants, attorneys, and particularly water administrators, who saw the need for nimble and sophisticated Decision Support Systems.

Use of the available online tools and hydrologic data, coupled with the fast computer processing speeds and the resulting ability to run multiple "what-if" scenarios in a practical timeframe, has increased the ability of consultants to provide clients and attorneys with the means to make better decisions.

**[\*599]**All of these evolutionary developments have had an ancillary but very important result: consultants, attorneys, water judges and hearing officers, administrators, and clients have developed a much clearer and more robust understanding of the complex and oftentimes interactive nature of bedrock and alluvial aquifers. Clients (and some attorneys!) still seek to push the envelope of what can be done in terms of groundwater development, augmentation, exchange, re-use, and other aspects of conjunctive use. But now, as compared to 30-plus years ago, the knowledge of where the envelope is, and what may be feasible as compared to nonsensical, is much more sharply defined. The nonsensical, in most instances, can be readily debunked. The limits of the possible, and thereby  *optimum utilization*  of the resource, can be defined as never before.

H. House Bill 09-1303

House Bill 1303 passed in 2009 to allow determination of the availability of non-tributary groundwater statewide for groundwater developed as an incidental consequence of the "mining of minerals" which included oil and gas production wells. [[153]](#footnote-154)153The bill also permitted the SEO to adopt rules regarding the withdrawal of nontributary groundwater to facilitate "mining of minerals." [[154]](#footnote-155)154Mineral, oil, and gas providers participated in the Division of Water Resources rulemaking hearing for the determinations of nontributary groundwater at their properties and in the basins where they operated. Hydrogeologic consultants evaluated the nontributary character of formations, statewide, from which the mining of minerals occurred. As a part of this work, hydrogeologic consultants developed analytical and numerical ground water models to determine whether or not the ground water produced incidentally to the mining of minerals at specific locations was nontributary or tributary groundwater. This work resulted in a determination of the location of nontributary groundwater in ***Colorado*** and in the development of the "Produced Nontributary Ground Water Rules." [[155]](#footnote-156)155These rules resulted in a series of maps showing the location of nontributary groundwater for specific areas and formations.

I. Aquifer Storage and Recovery

1. Alluvial Recharge Augmentation Projects

With the creation of augmentation plans through the 1969 Act, alluvial aquifer recharge augmentation plans were developed to provide an alternative means to provide water to augment out-of-priority stream depletions from tributary well pumping. [[156]](#footnote-157)156Many recharge augmentation plan projects were developed by South Platte ***River*** municipalities, as well as by ditch and irrigation companies and individual water users. A basic recharge augmentation plan included diverting in-priority or free-***river*** water into storage and timing the ground water accretions from storage back to the ***river***, to offset stream depletions from well **[\*600]**pumping. A few examples of these recharge project augmentation plans include the Fort Morgan Reservoir and Irrigation Company Plan for Augmentation, City of Brush Plan for Augmentation Case No. W-9383-78, and the Lower Platte and Beaver Canal Company Plan for Augmentation Engineering Report. [[157]](#footnote-158)157These projects and resultant augmentation plan decrees which provide out-of-priority alluvial well water supplies without water right injury are a critical and indispensable water supply element of optimum use of the available water resource. [[158]](#footnote-159)158

Although recharge-based augmentation or replacement plans have been proposed, and some decreed and operated, since the mid-to late 1970's, their efficiency in terms of the timing of recharge water at the point needed to offset depletions, was not particularly high due to the relatively coarse analytic modeling and slow numerical modeling used. [[159]](#footnote-160)159With the advent of improved databases leading to more accurate aquifer mapping, coupled with much faster computer processing, it is now possible to more easily optimize operation of recharge facilities to get the "most bang for the buck." Recharge-based augmentation plans have been so successful on the South Platte ***River***, that certain areas are experiencing an unintended consequence: a damaging rise in water levels in the alluvial aquifer in some areas. This is not to say that recharge causes all water level rises in the South Platte ***River***; there are myriad reasons. [[160]](#footnote-161)160 Solution of this problem, it is safe to say, will involve many of the tools - including large databases and computer models - that have revolutionized water consulting over the past decades.

2. Nontributary Ground Water Storage and Recovery Projects

The Denver Basin Artificial Recharge Extraction Rules became effective on July 1, 1995 (1995 Rules). [[161]](#footnote-162)161The 1995 Rules, which only applied to the Dawson, Denver, Arapahoe, and Laramie-Fox Hills aquifers, were revised in 2018 to include nontributary groundwater aquifers outside of the Denver Basin. [[162]](#footnote-163)162The 1995 Rules allowed the development of a new hydrogeologic area of practice for hydrogeologists working in ***Colorado***, through the development of aquifer storage and recovery ("ASR") projects. Under the provisions of the 1995 Rules, water providers have developed ASR projects inject and store totally reusable water in a Denver Basin aquifer for later withdrawal. In many cases, these ASR projects are viable technical and economical alternatives to surface water storage projects. A constraint on the development of ASR projects for many **[\*601]**water providers is the availability of totally consumable water rights that can be stored. As is the case of any water storage project, the water supplier has to have available water at the appropriate time of year for storage. Currently, several members of the Water Infrastructure and Supply Efficiency ("WISE") project in the South Platte ***River*** basin implement ASR projects to store their WISE water through wells located on their properties in Arapahoe and Douglas counties. Now groundwater providers commonly obtain an ASR decree to adjudicate their ASR rights.

Under ASR, water is most commonly stored at, and through, existing wells. The wells, along with the ancillary surface pumping equipment, are retrofitted with the equipment required for ASR operations. When new wells are drilled, these wells are constructed considering ASR injection and pumping requirements. Hydrogeochemistry and water quality analyses are very important to a successful ASR project. The purpose of water quality analyses for the injected, stored, and the native ground water are to ensure water quality compatibility such that adverse water quality and aquifer production effects do not occur.

3. Lawn Irrigation Return Flow Projects

Lawn irrigation return flow ("LIRF") credits are a relatively small, though important, economical source of water for municipal water providers. LIRF credits comprise the water that passes the lawn root zone, accretes to the water table, and subsequently to a surface water drainage. A LIRF credit can be taken for this deep percolation water that is derived from totally reusable water. LIRF return flow percentages are small compared to indoor use return flow percentages which are commonly accepted to be 90-95%. LIRF return flow percentages can range from less 10% to more than 20%.

The first modern [[163]](#footnote-164)163LIRF decree was obtained by Cottonwood Water and Sanitation District in March, 1986, through Case No. 81CW142. [[164]](#footnote-165)164For this decree, the ***Colorado*** Division of Water Resources in conjunction with W.W. Wheeler and Associates developed the "Cottonwood methodology" and the Cottonwood curve through lysimeter studies. [[165]](#footnote-166)165The Cottonwood methodology and curve continue to be used to determine the LIRF deep percolation percentage for Front Range LIRF projects and water court cases. Since 1986, many water providers have undertaken LIRF quantification projects and obtained LIRF Water Court decrees. Additional examples of LIRF cases include Case No. 85CW415 by Centennial Water and Sanitation District [[166]](#footnote-167)166, Case No. **[\*602]**04CW121 [[167]](#footnote-168)167by Denver Water, and more recently Denver Southeast Suburban Water and Sanitation District Case No. 11CW198. [[168]](#footnote-169)168Water suppliers obtain these decrees in order to take full advantage of their fully reusable water. This is specifically true in light of the high costs and high level of competition related to the development of new water supplies. The development of LIRF water is economic as LIRF projects and their water court decrees are the means of taking credit for water that water suppliers already own. Without new tools of data collection and analysis, including easily available satellite imagery, improved water level databases, and fast computer processing, taking advantage of LIRF credit--yet one more aspect of *optimum utilization* - may not be economical.

J. Computing

In 1969, a practical, personal office computer didn't exist. The ***Colorado*** consult's office used telephones, typewriters, and the U. S. Mail to communicate and slide rules for calculations. Rudimentary calculators were available in the early 1970s and fax machines were available in the mid-1980s. The first fax machines used rolls of thermal printing paper and later on plain paper fax machines were developed. Fax machines were a major development in reducing the delivery time of written communications. A project letter or a draft decree could be faxed in a matter of minutes instead of being mailed and delivered over a period of days. I recall a phone call from a client shortly after he had sent a fax. On the call he asked why I hadn't yet replied as he had, "faxed the letter to me". The speed of business had increased dramatically.

In the late 1970s, Zorich-Erker Engineering, Inc. [[169]](#footnote-170)169paid for the timeshare use of a Boeing Company mainframe which utilized an over the phone dial-up connection. The mainframe was used for Blaney-Criddle consumptive use analyses and ground water modeling. HRS bought its first computer around April or May 1981, just a month or two after the company was established. The computer was an Apple 2+, with 64k memory and dual 5 [fr1/4] inch floppy drives. A dot matrix printer, which used green and white computer paper, was also purchased. The cost of the Apple 2+ was about $ 8,000. Personal computer ("PC") technology and computer chip speed advanced at a rapid pace in the 1980s and 2000s (see Moore's Law). HRS and other consulting companies in ***Colorado*** kept pace with improvements in personal computing as faster and more powerful PCs improved project and modeling efficiency. The personal computer progression was from 5 [fr1/4] inch floppy drives, to 5 [fr1/4] inch floppy drives with one or more hard drives, to 3 [fr1/2] inch disk drives and hard drives, to a combination of 3 [fr1/2] inch disk drives, compact disk ("CD") drives and hard drives, to the current PC with a CD drive, USB ports, and multiple gigabyte hard drives. Additionally, for many consultants the storage of back up computer files is no longer on site but rather files are upload to main frame computers, **[\*603]**"in the cloud". Beyond the use of desktop PCs, the development and use of laptop computers established the use of computers in hydrogeologic field work. Additionally, color printers which became affordable into the 1990s greatly improved the presentation of data, figures, and maps for hydrogeologic reports.

K. Data Collection

1. Ground-Water Level Measurement

Since 1969, ground-water level measurement methods have improved through the development and use of water level measurement pressure transducers and data loggers. Circa 1969, a tape measure or electrical well sounder ("m-scope") [[170]](#footnote-171)170was used to measure the ground water level in production and monitoring wells. While these devices are still used to measure ground water levels, ground water pressure transducers and data loggers are used more often. Ground-water level pressure transducers measure the pressure of water above the transducer and data loggers record and store the pressure measurement. Data loggers can be programmed to take readings in seconds, minutes, hourly, or at time-logarithmic or daily time intervals. Wireless telemetry systems and cellular-based data transmission systems are also now available to transmit this data to remote computers located in an office or a laptop computer.

2. Hollow-Stem Drilling Augers

Continuous flight auger drilling is the primary method used to drill test holes and install monitoring wells in unconsolidated alluvial and eolian sediments. This drilling method is not amenable to drilling into consolidated bedrock materials which are too hard for augers to penetrate effectively. Continuous flight hollow-stem drilling augers were first used in ***Colorado*** in the 1980s. Prior to hollow-stem drilling augers, solid-stem drilling augers were used. Each hollow-stem drilling auger includes a cylindrical void space area over the entire five-foot length of the auger. Tools are inserted into the cylindrical void space area while the augers are in the ground to obtain lithologic samples of undisturbed sediments as drilling progresses. Previous to the development and use of hollow-stem augers, solid-stem augers were used. Solid-stem augers had to be removed from the hole to obtain lithologic samples for some sampling methods. The use of hollow-stem augers provided a significant improvement in obtaining representative lithologic samples over the total depth of the augered hole.

Hollow-stem augers also allow for improved monitoring well installations. Monitoring wells are installed inside of the auger's cylindrical void space area. Once the well is installed at the desired depth, the hollow-stem augers are pulled back out of the hole and the monitoring well remains in place. Monitoring well installations with solid-stem augers required the removal of all the augers and the installation of the monitoring well down the open borehole. In an alluvial aquifer, the borehole will not remain open below the water table so various well **[\*604]**materials and well installation methods were used to install the monitoring well to the desired depth. Other drilling technologies that have improved hydrogeologic sampling and lithologic interpretation are pneumatic downhole hammers and dual and triple wall drilling systems.

3. ***Colorado*** Division of Water Resources Ground-Water and Hydrogeologic Data

The ***Colorado*** Division of Water Resources ("CDWR") Records Section ("Records Section") has moved from paper files and microfiche circa 1969 to the online records and data portals of today. In the 1970s and 1980s hydrogeologic consulting firms had their technicians at the SEO almost constantly, because a technician had to list the records they wanted on a form in order for a records person look for and hopefully find the document. It was also common to send a person to the Records Section office to review files and printout documents from a microfiche reader or to copy paper files. With the development of fax machines, Records Section personnel would perform document searches and fax the results for a fee. The internet has resulted in the greatest change to Records Section operations. The internet and the CDWR internet portals now allow individuals to obtain ground water and hydrogeologic data online.

The development of ***Colorado*** Decision Support System ("CDSS") by the ***Colorado*** Division of Water Resources and the ***Colorado*** Water Conservation Board has resulted in major advancements in hydrogeologic and hydrologic knowledge. The CDSS projects develop a data centered water budget for the ***river*** basin under investigation. To date, CDSS projects have been completed for the ***Colorado***, Rio Grande, and South Platte ***River*** Basins. The initial phase of the CDSS study is underway for the Arkansas ***River*** Basin. With each CDSS study, the "body of knowledge" on the hydrogeology and hydrology of the ***river*** basin is greatly expanded.

Ground water and hydrologic data is available from the ***Colorado*** Decision Support System ("CDSS") website in the form of data sets and tools. Hydrogeologic data and information available online includes: [[171]](#footnote-172)171

Complete well files including the well's permit(s), all other Division of Water Resources forms that were submitted, and all well correspondence

Listings of wells by area

Borehole geophysical logs

Ground-water levels

An aquifer determination tool which allows for the determination of the annual appropriation beneath a property for the Denver basin, Dakota, and Cheyenne aquifers

A map viewer online tool which locates well on a map.

Aerial Photography and Google Earth

Aerial photography and satellite imagery is used in hydrogeology as an investigation tool to locate hydrogeologic features and to develop a hydrogeologic understanding of an area, including aquifer boundaries, recharge / discharge areas, and identification of quasi-linear features such as faults and fractures. **[\*605]**Aerial photos are often used in initial hydrogeologic work and are used again in subsequent field work and analyses. Historical use analyses have relied on aerial coverage of agricultural areas for decades. Aerial photos for an area could be obtained from a private or public supplier. Pre-1969 black and white stereoscopic coverages were available, and relatively inexpensive for most Front Range metro areas going back to Army Map Service flights circa 1937-1938. For mountain areas, United States Forest Service had color and black and white flights in some areas (not all) for the 1960's, if not before. To obtain these aerial photos, a technician was sent to one of several aerial photo supply houses to obtain photos or place an order which could take four to six weeks to fill. For a project area where aerial photos were not available or the aerial photo was not available for the desired years, aerial photography flights were arranged and performed - usually at great expense - in order to obtain the desired aerial photo coverage. In almost all cases, obtaining aerial photography for a project was time consuming, and in many cases, an expensive process.

The Google Earth program began in 2001. It has revolutionized the use of aerial imagery, primarily from an orbiting satellite platform, in hydrogeology by providing desktop access to multiple years of photographic coverage for any location in ***Colorado***. It has expanded the use of aerial photography in our project work as the photography is now readily available where previously it was either not available, was of poor resolution, had too much cloud cover to be useful, or was difficult to obtain. It is common in hydrogeologic project work to obtain Google Earth images to understand the location of wells; the location, course, and size of ***rivers***, creeks, and drainages; seeps, springs, and wetlands; the location and size of properties; distances between objects; and much more.

Aerial photographs are still be used in hydrogeologic projects where detailed hydrogeologic analyses are required. The aerial photographic analysis would be performed with matched pairs of aerial photos and a stereoscope to further analyze topography, seep areas, bedrock areas, and other hydrogeologic features.

L. Well Installation

1. Well Screens

Current day shallow and deep municipal well construction includes the use of stainless steel wedge-wire-wrapped continuous slot opening well screens ("stainless steel well screens"). Although these wells screens were developed prior to 1969, they were not commonly used in ***Colorado*** until the late 1970s. Before the use of stainless steel well screens, wells were installed with mild steel well screens or more commonly steel well casing which was slotted with a welding torch, hand grinding tool, hack saw, or a mechanical slotting tool. These casing slots were cut horizontally or vertically. Stainless steel well screens are much more efficient in transmitting water to a well as they have much more open area per foot of length. Additional advantages of stainless steel well screens are that the slot opening of a stainless steel well screen can be designed and built to accommodate the aquifer's or gravel pack's grain size distribution. Finally, stainless steel well screens result in better well longevity. They are therefore more economic to use even though their initial cost is much higher.

**[\*606]**

IV. Accounting

Water accounting is used to create a record of water use, diversions, storage, pumping, replacements, and other obligations or operations. In ***Colorado***, water accounting is typically prepared by the water user and submitted to the Division of Water Resources, in accordance with a decree or an administrative request from the Division of Water Resources. Today, various types of decrees require regular accounting to report information on water use, decreed limits, storage account volumes, and other information to both provide a record that injury to senior water users is being prevented and that water is being used lawfully, in accordance with the priority system which is important for both intrastate administration and interstate compact administration.

The accounting requirements vary between the water divisions in ***Colorado*** for each major ***river*** basin. The accounting requirements in Divisions 1 and 2 (the South Platte ***River*** Basin and Arkansas ***River*** Basin, respectively) are the most detailed. While other divisions' accounting requirements are also increasing, the pace of change in Divisions 1 and 2 seems to be faster. The accounting requirements and changes are mainly led by both the Division of Water Resources and water rights holders which generally provide input through the water court process.

This paper focuses on accounting in Division 1 over the last 50 years since the passing of the 1969 Act. Division 1 was chosen because of the high number of water court decrees and the significant changes over time to the accounting in that division.

A. Accounting in the Early Years Following the 1969 Act

The concept of water accounting appears to have begun taking form in the 1970s. In order to evaluate the accounting for the decrees following the 1969 Act, a search was conducted for the words "account" and "report" in early Water Division 1 decrees. These early decrees are often referred to as "W" decrees, because the case numbers started with a capital W, such as Case No. W2024. The W decrees began with applications to the water court in the year 1969 and continued through 1978. A review of over 200 W decrees entered from 1972 through 1979 in which the search words, or derivatives thereof, were found indicates that only 18 of those decrees actually related to water accounting and reporting in the context of reporting data and information to the Division Engineer or another State water official.

To try to put this number of 18 W decrees into context, the Division 1 Water Court entered more than 9,000 W decrees. Therefore, the 18 Division 1 W decrees having the word "account" or/and "report" constitutes approximately two tenths of one percent (0.20%) of the W decrees. Perhaps a broader search of the Division 1 W decrees for additional key words, such as "provide" or "records" would have increased the number of W decrees with accounting requirements. Regardless, it is clear that the concept of water accounting was not widely required in decrees in the 1970s immediately following the 1969 Act.

The decreed accounting requirements from the 18 Division 1 W decrees **[\*607]**are summarized in Table 1 [[172]](#footnote-173)172below and range from the W2024 decree's simple requirement "to the claimant to account for the water pumped under the surface decree" to the more complex requirements of the W8743-77 decree. Most of the accounting from these cases in the 1970s had to do with fairly mundane counts of the number of constructed dwellings and reports of known violations of the conditions of the decree. Further, many of these early decrees allowed for annual balancing of depletions and replacements under the augmentation plans, such the W6268 decree which approved the plan to augment certain wells used by the Denver Southeast Suburban Water and Sanitation District and required an annual balance of depletions and returns to the alluvium. [[173]](#footnote-174)173

Another decree entered in the early 1970s, but technically not a decree of the water courts, rather a decree under a district court, with no stated requirements for accounting is Denver Water's Douglas County Civil Action 3635 Exchange Decree entered on May 18, 1972. [[174]](#footnote-175)174The Denver Water accounting for the CA3635 exchange began in the middle of the 1970s and continues to be created today. This accounting is limited to exchanges of fully consumable treated wastewater from wastewater treatment plants. (Denver Water uses different accounting forms to track its reservoir-to-reservoir exchanges.) Figure 2 below represents Denver Water's accounting of its exchanges of fully consumable wastewater for the month of July 1977, a date early in the operation of this exchange, and somewhat early in the span of experience under the 1969 Act. The accounting was hand-written and was contained within one page of information. In contrast, Denver Water's exchange accounting in July 2007 is six pages long, includes additional structures to keep up with Denver Water's changing water system, was created using computers, and includes a record of call changes (which were not recorded on the 1977 form). The calculations in the two files remain similar, and the modernization of the form is evident when comparing the 1977 form (Figure 2) to page 1 of the 2007 form in Figure 3.

**[\*608]**

Table 1

**Summary of Division 1 W Decrees with Water Acounting Requirements**

**[\*609]** Figure 2. Denver Water Exchange Accounting from 1977

**[\*610]** Figure 3. Denver Water Exchange Accounting from 2007 (page 1 only

**[\*611]**Given that less than 1 percent of Division 1's W decrees contained clearly identified accounting provisions strongly suggests that the subject of water accounting was of low importance to the water community in the early years of the 1969 Act.

B. Accounting in Later Years Following the 1969 Act

Water accounting developed over time to include additional information in the reports and more frequent reporting as water operations became more complex and recording technology became more sophisticated. The original decrees for early irrigation water rights did not require specific accounting or reporting, and water commissioners or Division Engineer staff recorded diversions under these water rights in their field books and in commissioner reports. [[175]](#footnote-176)175

As changes of water rights and plans for augmentation continued to be filed with the water courts, cases from the 1980s often required an annual report of monthly water diversions or use and an annual balancing of the augmentation plan depletions and the replacement supplies or credits. During the 1980s and early 1990s, there was a transition of accounting from paper forms to the use of computer spreadsheets (using Lotus 1-2-3, QuatroPro, and then MS Excel). Many accounting submittals were still hard-copy reports mailed to the Division of Water Resources and then later became electronic pdf files, first created through scanning hard copies, which could be emailed.

In the 2000s and 2010s, it is common for Division 1 decrees to require daily accounting with monthly submittals, in electronic spreadsheet format, provided to the Division of Water Resources. The accounting files are submitted through email or web-link downloads. The submitted accounting files for water users are available to the public through the Division of Water Resources website.

Current diversion or use data are typically based on: 1.) flow meters which continuously record the water flowing through the pipe (such as totalizing flow meters for well pumping); 2.) diversion data recorded based on flow through a parshall flume or other standard measuring device (first recorded on hand-written logs of flume depths, then recorded continuously on paper charts created by Stevens recorders, and then recorded continuously with digitally logged electronic flow data); and 3.) water level data in reservoirs (through manual checks of a staff gage or "ruler" in the reservoir, and then with a pressure transducer to measure the depth of water). These advancements in data collection with data reporting to operators and engineers through telemetry (from radio transmission to satellites) have supported the change to more detailed and more frequent reporting.

Today, the information required to be included in the accounting is defined in one or more places: detailed in the decree, included by a reference within the decree to proposed accounting forms, or requested by the Division of Water Resources. In the 1980s through even 2010, initial accounting forms were **[\*612]**submitted to the Division of Water Resources for review and acceptance and then approved for use after the decree was entered. There were no reviews from other parties under this system. Now decrees often require initial accounting forms to be provided to all parties in the case prior to entry of the decree. The Division of Water Resources can participate via comments and requested modifications during the decree process or after the decree is entered, usually within two to three months following entry of the decree. Decrees in the last ten years or so often require that any future changes to the accounting forms require submittal to the Division of Water Resources for consideration and notice to objectors, who get a review and comment period, prior to approval from the Division of Water Resources before the modified accounting forms can be used. This process provides for long-term involvement of other water users in each other's accounting and shows how much more important accounting has become to water users over the last fifty years.

C. Storage Accounting

Some changes between the early years of the 1969 Act accounting, which are very limited, and the more detailed current accounting can be illustrated by the accounting associated with recently decreed water storage rights.

In Case No. 14CW3164, East Cherry Creek Valley Water and Sanitation District received a decree for water storage rights in three reservoirs (Barr Lake, United Reservoir No. 3, and Gilcrest Reservoir) north of Denver. [[176]](#footnote-177)176The reservoirs hold water for multiple water users, so the accounting must be sufficiently detailed to track the contents of each water user's individual accounts (the reservoirs are holding water for at least two different water users) and record the daily changes (reductions or increases) to the storage accounts. The description of the minimum information to be included in the accounting takes up nearly one page of text in the decree. [[177]](#footnote-178)177The draft accounting forms, attached to the decree as Exhibit 4, are seven pages long even though the forms only include six days of example data.

The accounting required under the Case No. 14CW3164 decree includes the following specifics: 1.) calculations of daily evaporation based on published daily data from an identified nearby weather station and the assessment of evaporation to the various accounts of water stored in the reservoirs; 2.) tracking of in-and out-of-priority precipitation falling on the reservoirs; 3.) changes in storage based on staff gage readings; 4.) water balance calculations to determine unmeasured losses or gains on a daily basis; 5.) assessment of losses and gains to the various storage accounts and water rights; 6.) a series of calculations related to the storage water rights including provisions for tracking the volumetric limits of the water rights; 7.) calculations regarding how to handle water remaining in the reservoirs at the end of the year and its impact to the exercise of the water right in the following year (carryover); 8.) and provisions regarding how to account for water which the Applicant could have diverted in priority but did not to divert (paper fill). [[178]](#footnote-179)178

**[\*613]**Older storage accounting for this area did not generally include varying evaporation rates or assessments based on varying daily data or even specifics on evaporation calculations. The older evaporation assessment, or assessment in areas without detailed daily data, was often based on annual average evaporative losses from mapped evaporation contours created by the National Oceanic and Atmospheric Administration. [[179]](#footnote-180)179Then, the annual data was distributed to all months based on guidelines from the Division of Water Resources. [[180]](#footnote-181)180The water balance, carryover, and paper fill accounting requirements have become standard in recent Division 1 storage decrees and are consistent with reservoir accounting guidelines developed by the Division of Water Resources. [[181]](#footnote-182)181

D. Division of Water Resources Involvement

In last two decades, the Division of Water Resources has developed a number of guidelines and protocols detailing requested calculations, accounting information, and measurements for accounting and water administration including the following documents:

Division 1 Administrative Protocol regarding Augmentation Plan Accounting [[182]](#footnote-183)182

Division Protocols regarding Data Loggers and Measurement Rules for the Arkansas ***River*** Basin, Republican ***River*** Basin, Rio Grande ***River*** Basin, and South Platte ***River*** Basins [[183]](#footnote-184)183

Division 1 Protocol regarding Recharge [[184]](#footnote-185)184

Reservoir Administration Guidelines, statewide [[185]](#footnote-186)185

Some of the above-listed documents were developed due to requirements **[\*614]**of interstate ***river*** compacts, and they also aid in administration of surface water and groundwater rights.

Additionally, the Division 1 office conducts water accounting reviews or audits of water users' accounting. This process has resulted in updates to water accounting forms that had not been modified in decades, in order to meet the Division of Water Resources protocols and guidelines. Sometimes the trigger for the accounting review is a new water court application or decree, such as for an enlargement of a storage facility, or a lease of water to another water user and the need to track numbers between the two sets of records. The audits can also occur based on the request of the Water Commissioner or essentially without an identified reason, within the context of standard accounting reviews which the Division 1 office is now conducting with specialized accounting staff.

E. Additional Details on Accounting for Specific Types of Water Rights

Particular types of water rights which developed following the 1969 Act require detailed accounting. This section includes some of these water rights types and provides information regarding typical accounting requirements.

1. Augmentation Plan Accounting

Augmentation plans allow out-of-priority diversions as long as the depletion to the ***river*** can be replaced in an appropriate time, location, and amount in order to prevent injury to senior water rights holders. This concept, developed and allowed in the 1969 Act, is now widely used. For example, a municipality that diverts water at the upstream end of the city may return a significant portion of that diversion back to the ***river*** at a wastewater treatment discharge downstream of the city. If there are no intervening water users, only the out-of-priority water which was consumed, and therefore not returned to the ***river***, must be replaced in order to offset, or augment, the impact to the ***river*** and other water users. Augmentation plan accounting must report and calculate these quantities of water and provide information on the location and timing.

Augmentation plan accounting in the current era typically includes daily data that is provided on accounting forms submitted to the Division Engineer on at least a monthly basis and sometimes more frequently. Augmentation plan accounting generally includes the following components: 1.) call information (necessary to determine when the water right was in priority and where out-of-priority depletions are due above); 2.) daily diversions or pumping data (these data must be measured and recorded, not simply estimated as would have been done historically); 3.) calculation of out-of-priority depletions; 4.) accounting regarding the use of any changed water rights including diversions, deliveries, return flow obligations, and related volumetric limits; 5.) replacement of out-of-priority depletions with data detailed enough to indicate the time, place, and amount of replacements; 6.) transit loss assessment as determined necessary by the Division Engineer or by decree; and 7.) an augmentation balance (of the difference between replacements and depletions). The augmentation balance should show a zero balance or excess water to the ***river***. A negative augmentation balance must be replaced as soon as possible and could lead to curtailment of the junior water right by State water officials.

**[\*615]**Augmentation plan accounting is closely tracked in Division 1, and the Division staff have regular meetings with larger water users about their accounting and operations, particularly those water users with more recent water court decrees.

2. Exchange Accounting

Generally, recent exchange decrees require the following components for accounting in order to record the exchange operation: 1.) call information including the date, water right name, priority date, and administration number; 2.) daily deliveries of each substitute supply to be exchanged (based on measured releases from storage, through measured returns to the ***river***, or calculated recharge accretions) recorded by exchange-from location and potentially including the associated water right and end use of the water; 3.) recording of water diverted or received at the exchange-to location; 4.) recording of whether there is a live, flowing stream between the exchange-from and exchange-to location; 5.) transit loss assessments for substitute supplies moving in the downstream direction; and 6.) tracking of any volumetric limits associated with the exchanges (such as an annual maximum volume).

Accounting for exchanges becomes more complicated based on the number of structures included in the decree and the number of substitute supplies, as each must now be separated in the accounting in order to provide clear records and transparency for other water users. Historically exchanges were allowed based on Water Commissioner or Division Engineer approval, and often now while that is still required, the water user must also show that adequate water is present at both the exchange-from and exchange-to locations. This may require water users to install additional streamflow measurement devices or other recording equipment in order to meet the decree requirements. It may also lead to additional record keeping or a log of such approvals in the accounting.

3. Recharge Accounting

Accounting is required for recharge projects and typically includes tracking of the amounts of water measured going into a recharge facility and then a calculation of the lagged credit or accretion as that water returns to the stream or ***river***. These accretion calculations are often done in the Alluvial Water Accounting System (AWAS) developed by the Integrated Decision Support Group at ***Colorado*** State University using the Glover equation. In some instances, the accretion calculations are done with a spreadsheet file, often using a calculation matrix or a macro. The Division of Water Resources has, in the last ten years, begun to allow more of these accretion calculations to be performed within the spreadsheet accounting file instead of requiring that the AWAS software be used in all cases.

Additionally, in the recharge accounting, the amount of water recharged into the alluvium is reduced by evaporation from the recharge facility for the days that water remains in the recharge facility prior to infiltration. This evaporation reduction was not always required but is now standard.

Recharge facilities can sometimes foster the growth of plants, which then consume the water which would have been recharged to the stream. For this **[\*616]**reason, current accounting also includes recording and calculations regarding any areas of recharge sites that contain vegetation and an associated reduction in the recharge accretions to account for the estimated consumption of the water.

F. Accounting Changes Summary

Since the 1969 Act was passed, water users and State water officials have focused significantly more on water accounting. Water court decrees entered now almost universally require detailed measurements and accounting whereas decrees in the 1970s rarely required measurement and accounting of actual water use or frequent reporting of the data. The Division 1 accounting that is required now is based on real data, not estimated values of water use or needs, and is often reported for a daily time-step using actual recorded data instead of using averaged values based on less frequent data collection. Augmentation plans require the balancing of depletions to replacement supplies often daily, instead of the coarser seasonal or annual replacements that were historically considered reasonable and acceptable in order to prevent injury. The Division of Water Resources also reviews accounting submittals for accuracy of data and calculations as the accounting is submitted electronically in spreadsheet format, whereas into the early 2000s, calculations were not provided with the accounting as they were first performed manually, then accounting was provided in paper format or pdf format, and water data was harder to confirm. The movement to real-time measurements and public data reporting of diversions, stream flow, reservoir levels, and augmentation station returns accompanied by the near real-time dissemination of this information on websites has aided with this transition and increased transparency between water users and between water users and the Division of Water Resources.

V. Are We Better Off Now Than We Were?

A. Administration

by Steve Witte

Are we better off now than we were? Yes! Absolutely! Without belaboring the point, recognition of the interaction between ground water and surface water has been critical to the preservation of our system of allocation based on seniority of appropriation. Similarly, the concept of augmentation has allowed use of resources to be maximized while preserving the rights of others. Protection of rights granted by the state and providing opportunities for more people to enjoy the benefits of commonly held resources must be counted as good things.

Within the framework established by the 1969 Act, a more consistent statewide definition of non-injury has been allowed to mature and the necessary means of preserving the rights of other water users have been progressively applied. Additionally, specialized courts and the consultation process promote better informed decision makers and participants. Also, specialized courts provide a clear venue for regulatory enforcement issues to be determined. Equity and expedience under the law deserve to be applauded.

Although only an indirect result of the legislation enacted 50 years ago, the **[\*617]**amount, variety and timeliness of water data that is now available to water users and regulators for analysis and decision making is an indicator of the value of the resource and its relative importance to society today as compared to that which existed in the mid-twentieth century. Having access to the facts is something to be applauded in a free and open society, especially as those facts relate to our public resources. More factual information equals better.

B. Surface Water a Case Study - Water Availability Analysis for Houston Lighting and Power Company

By Joe Tom Wood

In 1972 I was a then-young, 26-year-old engineer practicing engineering at a then well-known, but no longer existing, consulting firm of Forrest and Cotton, in Dallas, Texas. While I realize that the locus of this work lay outside the State of ***Colorado***, this case study will serve us well in its detail of water resources engineering at the time that the ***Colorado*** 1969 Water Act became effective.

Forrest and Cotton consisted of an office of some 125 to 150 employees in its main office in Dallas, Texas, and another 25 or so in its branch office in Austin. This firm specialized in water treatment plants, wastewater treatment plants, pump stations and pipelines, reservoir sizing and design, water rights, flood hydrology, airport design, road and bridge design, and surveying. In 1972 Forrest and Cotton's Dallas office had one computer, an IBM 1130 in its own room of perhaps 15 feet by 30 feet, with a couple of card keypunch machines, a couple of card keypunch verifiers, a small single office for the key operator of the system, and a card keypuncher/card verifier person. I don't remember if the Austin office had a computer, but I doubt that it did. FORTRAN was the computer programing language of the day. One computer for as many as 150 people. And, per my conversation October 31, 2018, with J. Crozier Brown, who was the professional engineer in charge of Forrest and Cotton's computer department, this one computer had a whopping 16 kilobytes of random-access memory.

Output from the computer went to an IBM printer. It printed on the green-and-white banded paper in a landscape-oriented paper of 11 inches high by 14 7/8 inches wide, as best as I can remember. The printer "tractored" the movement of the paper by means of a sprocket on each side of the paper and holes in each side of the paper.

In 1972 along come the Houston Lighting and Power Company (HLPC) and its plans to construct twin nuclear power plants near the mouth of the Brazos ***River***, near the Gulf of Mexico, a little south of the City of Houston itself. (See the attached Figure 4 of the Brazos ***River***'s drainage area within the State of Texas, obtained on November 5, 2018, from the home page of the Brazos ***River*** Authority of Texas.) These two plants were to produce some 750 Megawatts each, if I remember correctly - big pups. At the same time, the Brazos ***River*** Authority of Texas (BRA) had interests in six existing water supply reservoirs within the Brazos ***River*** basin in Texas and plans for four additional reservoirs. HLPC's questions for Forrest and Cotton were (1) "Does the BRA have a sufficient supply of water for **[\*618]**HLPC's two power plants from its six existing reservoirs," and (2) "Does the BRA have a sufficient supply of water for HLPC's two power plants from its six existing reservoirs, together with the four additional planned reservoirs?"

HLPC contracted with Forrest and Cotton to conduct the water availability studies to answer the two primary questions, along with another overlay or two of alternatives concerning the type(s) of water rights administrations that could possibly follow. At the time, the State of Texas was proceeding through a basin-by-basin adjudication, and it was not known whether the result would be an appropriative system, a riparian system, or a state permit system, or some combination of two or all three of the systems. So, from an engineering viewpoint, Forrest and Cotton employed several approaches.

By the time that I entered into employment with Forrest and Cotton, the firm had, and employed the use of, two principal water availability computer programs for (surface) reservoirs, both in the FORTRAN programming language. One could be called the YIELD program, and it worked backward in time from the end of a given study period to the beginning of the study period. The YIELD program used a simple water balance (or mass balance) approach on a monthly time step, where

Inflow = Outflow + Change in Storage

Inflow typically consisted of streamflow, calculated as the product of the streamflow from the closest streamflow gaging station and the ratio of the reservoir's drainage area to the drainage area of the gaging station.

Outflow consisted of the sum of (1) any spills when the reservoir's water level exceeded the reservoir's full water supply capacity; (2) evaporation (usually net evaporation); and (3) the sum of all releases of water for beneficial use, such as municipal and/or industrial and/or irrigation. Because the YIELD program utilized net evaporation, the inflow attributable to precipitation on the reservoir's surface was captured or incorporated by net evaporation.

Change in storage was taken from a set of area-capacity data, based on the areas below given contour elevations on a map by use of a planimeter.

Also, if the reservoir had a defined minimum content greater than zero acre-feet, the YIELD program recognized this limitation and defined the net usable water supply pool as the amount of water for a full reservoir, less the reservoir's minimum content. The minimum content could also be described as the reservoir's "dead pool." For example, a reservoir designed to provide a supply of cooling water for a lignite-fired steam power plant would have a minimum water surface area, and hence a minimum content, to provide the amount of cooling by evaporation that the power plant needed. A side note is that we calculated this annual evaporative cooling demand on the basis of one acre-foot per one million kilowatt-hours of energy produced per year.

The end products of the YIELD program consisted of (1) the annual amount of release for beneficial use that could be realized without shortage over the entire study period, which is the so-called "firm yield;" (2) the amount of water supply storage needed for the firm yield; and (3) the "critical drought period," being the month and year of the beginning of the drought, *i.e.*, when the reservoir was last full, and the month and year of the end of the drought, *i.e.*, when the reservoir's content was at its lowest.

Forrest and Cotton utilized a second program that could be called the ROUTING program, or what some ***Colorado*** water engineers would call an **[\*619]** *operational* study. The ROUTING program started at the beginning of the study period and terminated at the end of the study period. It utilized all of the same data as does the YIELD program, but its *monthly* output includes month and year; inflow in acre-feet; water surface area in acres; net evaporation both in terms of the unit rate in feet and the volumetric amount in acre-feet; the demand(s) for beneficial use in acre-feet; the end-of month amount of water in storage in acre-feet; and any shortage, or inability of the reservoir to provide the full amount of demand, in acre-feet. End-of month water surface elevation or depth, in feet, could also be outputted. The ROUTING program's beauty lay in its production of monthly results that would allow the engineer to describe the operation of the reservoir on a monthly basis throughout the study period, such as how often the reservoir's depth or water surface elevation fell below a certain level or amount, a characteristic useful for certain recreational uses, among other things.

By the time in 1972 when Forrest and Cotton had begun work for HLPC's power plants, a younger engineer, named John Phillip (Phil) Deaton had joined the company. Phil was a very bright and skilled engineer, and very good with the FORTRAN language. Phil took the Forrest and Cotton ROUTING program, which modeled a single-reservoir system, and expanded it so that it could model both (1) the BRA's then-existing 6-reservoir system and (2), separately, the contemplated future BRA 10-reservoir system. Whatever operational rules that Phil imposed escape my memory, such as which of the 6 reservoirs would first supply the power plants' demands, and to what extent, and then which of the remaining 5 reservoirs would supply the power plants' remaining demand, and to what extent, and so on and so on (and ditto for the future BRA 10-reservoir system).

While Phil's job required FORTRAN programming and probably included a role in creating the operational rules for the 6-and 10-reservoir systems, my job included calculating the monthly runoff, or the pieces of the streamflow, that historically arose from a multitude of sub-basins upstream from the BRA reservoirs, all of which turned into the monthly inflows to each of the BRA reservoirs. Phil would then adopt my inflows into his multi-reservoir systems.

Wake up now! This is where the fun part of this story begins!

The ROUTING program that Phil created for the 6-reservoir required 2 1/2 hours for one run!

The ROUTING program that Phil created for the 10-reservoir required 3 1/2 hours for one run!

And, for whatever reason, the IBM printer produced 5 paper copies for each run, an original copy and then 4 additional *carbon copy* copies!

As Forrest and Cotton's sole computer had to satisfy the needs of all of the other engineers in its 125-130 employee office, sometimes these needs of other engineers, who had their own deadlines, precluded Phil from making his runs during normal working hours. So, what did our first-in-his-civil-engineering class at Texas A&M University do? Phil brought into the computer room, after hours, *i.e.*, at night, his bedroll and an alarm clock. When it was time for Phil to go to sleep, he would set his alarm clock for either 2 [fr1/2] or 3 [fr1/2] hours ahead, lie down on the floor in/on his bedroll, and be awakened 2 1/2 or 3 1/3 hours **[\*620]**later. Then he would pull the paper output from the printer, make sure that the printer had enough paper for the next run, and set his alarm clock, and go back to sleep for another 2 1/2 or 3 1/2 hours.

The next morning, I and others would help out by stripping the four sets of the carbon paper from between each of the five copies of the printout to create the five copies. One of Forrest and Cotton's vice presidents named Bill Sims occasionally helped out with this dirty daytime task, stating that "I must be the highest paid stripper in Dallas!"

The HLPC/BRA project had its deadlines, and one of them crowded the Christmas season of 1972. Phil and the other engineers and I bore huge loyalties to Forrest and Cotton and to our client, HLPC, so much so that we offered to work Christmas afternoon after having spent the morning with our families. Fortunately, our bosses declined that offer and told us to stay with our families all of Christmas day.

Are we better off now, or were we better off in the early 1970s? You be the judge.

C. Ground Water

By Mark R. Palumbo

The amount of scientific and technological change that has influenced and improved the science of ground water hydrology from 1969 to the present is simply amazing. With respect to ***Colorado*** water law and water court cases the scientific and technological changes are represented by:

Water rights administration that includes the administration of ground water rights and hundreds of augmentation plans involving tributary and not nontributary wells,

The proliferation of ground water and hydrogeologic data that is used to develop and support ever more sophisticated ground water models.

Ground water model programs that are able represent in more detail and accuracy each component of a ground water budget and thereby more accurately represent the physical and hydrologic situation.

The operation of augmentation plans that use ground water models and their results to demonstrate non-injury to all other water rights in the system.

The demonstration that the water right or augmentation plan, as described by a ground model or accounting is administrable and enforceable.

The use of the available online tools and hydrologic data, coupled with fast computer processing speeds and the resulting ability to run multiple "what-if" scenarios in a practical timeframe, have increased the ability of consultants to provide clients and attorneys with the means to make better decisions.

With the advent of improved databases leading to more accurate aquifer mapping, coupled with much faster computer processing, it is now possible to more easily optimize operation of recharge facilities to get the "most bang for the buck".

Consultants, attorneys, water judges and hearing officers, administrators, and clients, all have developed a much clearer and more robust understanding of the complex and often times interactive nature of alluvial and bedrock aquifers.

**[\*621]**

D. Accounting

By Cristyn R. Radabaugh

The 1969 Act's recognition of the connection between groundwater and surface water is instrumental in better administration and protection of water rights. In addition, the allowance of augmentation plans has provided greater flexibility for water use that would not be permitted within a strict interpretation of the Prior Appropriation Doctrine. I think we are better off because of these changes.

From an engineering perspective, I think the increase in measurement devices and the ability to obtain and track detailed water data have given water users the additional ability to make operational decisions on a daily basis (sometimes without being near the water structures) and to more efficiently use their water resources. Regarding accounting, which was my topic within this paper, the water data reporting is more common now than ever before and significantly more detailed than fifty years ago. The ***river*** systems have more users and support more needs. Providing additional data and better reporting is an improvement. There have also been major advances in technology and communications for measurement, recording, reporting, and accounting itself allowing for the changes.

Going forward, we must find ways to balance data needs and non-injury standards with some of the challenges including varying ditch losses under irrigation systems particularly as less ditch water is being used for irrigation, increasing demands on water supplies for growing populations, diurnal streamflow fluctuation, and accommodating to changes in climate and runoff patterns.

Generally, I believe the additional reporting and accounting are beneficial to the ***river***, but they come with a monetary and manpower cost to the water rights holders. I believe the future collection of data and inputs to the accounting will become more automatic as forms can be maintained online, instead of on individual computers and servers located in offices and municipal buildings, potentially reducing the on-going expense. Additionally, data reporting can be configured to load directly and be uploaded to forms through programmed systems or input online and then managed in a more hands-off fashion. There are already water users implementing these changes.

I also believe that the future of data collection is changing and perhaps we will see a time when streamflow or diversions are measured via drones (drones are already measuring dry areas, such as performing imaging surveys to develop elevation-area-capacity data for dry storage sites) or even automated adjustments of diversions based on the streamflow, call, volumetric limits, or other factors and constraints. But who could make or program this decision? And who should make it? And so much more...

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**End of Document**

1. 1

   Principal Hydrologist, HRS Water Consultants, Inc., Lakewood, ***CO***.

   [↑](#footnote-ref-2)
2. 2

   Water Resources Engineer, Martin and Wood Water Consultants, Inc., Golden, ***Colorado***, Retired.

   [↑](#footnote-ref-3)
3. 3

   ***Colorado*** Division of Water Resources, Office of the State Engineer (1978-2018), Retired.

   [↑](#footnote-ref-4)
4. 4

   Vice President, Martin and Wood Water Consultants, Inc., Golden, ***Colorado***.

   [↑](#footnote-ref-5)
5. 5

   *See* [***Colo.*** *Rev. Stat. 37-92-102 (2)*](https://advance.lexis.com/api/document?collection=statutes-legislation&id=urn:contentItem:61P5-WY01-DYDC-J3FN-00000-00&context=1516831) (2019).

   [↑](#footnote-ref-6)
6. 6

   [*Larimer County Canal No. 2 Irrigating* ***Co****. v. Poudre Valley Reservoir* ***Co****., 23* ***Colo.*** *App. 249, 129 P. 248 (1913)*](https://advance.lexis.com/api/document?collection=cases&id=urn:contentItem:3VWN-2DX0-0039-454V-00000-00&context=1516831).

   [↑](#footnote-ref-7)
7. 7

   Change of water right, [***Colo.*** *Rev. Stat. § 37-92-103(5)*](https://advance.lexis.com/api/document?collection=statutes-legislation&id=urn:contentItem:689F-SY73-CGX8-03R2-00000-00&context=1516831).

   [↑](#footnote-ref-8)
8. 8

   Unless otherwise noted, all factual assertions in this section are from *Crystal Lakes Development Company's Change Decree*, Case No. W275, (Division 1 Water Court).

   [↑](#footnote-ref-9)
9. 9

   Unless otherwise noted, all factual assertions in this section are from *Melvin C. Rich's Change Decree*, Case No. W445, (Division 1 Water Court) *.*

   [↑](#footnote-ref-10)
10. 10

    Unless otherwise noted, all factual assertions in this section are from *Genesee Associates' Change Decree,* Case No. W1564, (Division 1 Water Court).

    [↑](#footnote-ref-11)
11. 11

    *Parenthetical in the original.*

    [↑](#footnote-ref-12)
12. 12

    Unless otherwise noted, all factual assertions in this section are from *City of Lafayette's Change Decree*, Case No. W8346-A-76, (Division 1 Water Court).

    [↑](#footnote-ref-13)
13. 13

    Whether the report's statements regarding Lafayette's future needs for the changed Howard ditch water rights could be looked upon as checking off a legal box, it is interesting to contrast the old-time simple statement in the engineering report, as to need, with the much more rigorous engineering requirements of later changes and other water rights applications, such as: the dismissed applications of High Plains A & M, LLC, to change water rights appurtenant to shares in the Fort Lyon Canal Company ( *see* Case Nos. 04SA266 and 04SA267); Pagosa Area Water and Sanitation District's and San Juan ***River*** Water Conservancy District's application for conditional water rights ( *see* Case No. 06SA338); and the City and County of Broomfield's application for appropriative rights of exchange ( *see* Case No. 09SA213).

    [↑](#footnote-ref-14)
14. 14

    Unless otherwise noted, all assertions are from *United Water District-Arapahoe County Water and Wastewater Authority-East Cherry Creek Valley Water and Sanitation District Change Decree, Case* No. 12CW73.

    [↑](#footnote-ref-15)
15. 15

    *Id.*

    [↑](#footnote-ref-16)
16. 16

    I do not specifically describe ECCV's changes herein, because of their parallelism with ACWWA's change.

    [↑](#footnote-ref-17)
17. 17

    I realize that the efficiency values in the 12CW73 decree do not quite match up with the values in the preliminary B&C report, and that is due to B&C's preparation of subsequent engineering reports for this change case.

    [↑](#footnote-ref-18)
18. 18

    I intend the term "crop mix" of "crop distribution" to reflect both the types of irrigated crops and the relative areas irrigated by each crop. For example, if I were to perform an historical use analysis for the irrigation of 120 acres within a 160-acre farm where throughout the study period 80 of the 120 irrigated areas grew alfalfa, and the other 40 irrigated acres grew corn, I could say that I had a crop mix of 67% alfalfa and 33% corn. I could as well say that our crop mix was 80 acres of alfalfa and 40 acres of corn. Because certain irrigated crops desire more water for optimum growth and yield, quantification of crop mix can often be very important in an historical use analysis.

    [↑](#footnote-ref-19)
19. 19

    An augmentation station is a structure to deliver water from a ditch to a stream. In a typical change case, like 12CW73, an augmentation station delivers both the fully consumable portion of the historical use of the changed shares, as well as the return flow portion of historical use. Generally speaking, the fully consumable portion may be used to augment out-of-priority depletions from well pumping, or to provide a substitute supply of water to effectuate an exchange to an upstream location, or to deliver to a downstream storage structure.

    [↑](#footnote-ref-20)
20. 20

    Steve Witte thinks that this is a consideration that engineering practitioners should be aware of in order to serve their clients and the court well. This requires an engineer to be cognizant of the changing status of the law. The location of use is not just a matter of historical fact. Until recently the law forbade consideration of historical use that was outside of the intent of the original appropriator or the area prescribed by the decree, whichever was less. Since the Legacy Ditch Bill, the legislature has allowed a certain amount of expanded use beyond that which existed at the time of the original decree, in instances where the decree lacked specificity. An applicant may elect to proceed with a change of an expanded water right if the engineer is aware of what is allowable.

    [↑](#footnote-ref-21)
21. 21

    It seems that in my experience early change decrees adopted study periods that tended to contain larger than average diversions, while later change decrees adopted study periods that were focused more on average diversions, not that any of our three early change decrees supports this observation. Also, today's change decrees frequently adopt a study period ending in or near the date of filing for a change. Also, Steve Witte adds that from his perspective, the position once advocated by the State Engineer to the effect that study periods should include all available records of diversion so as to reflect the entire period of historical use is the most accurate and complete representation of a water right's effect on other water users and served as a check on applicants claiming study periods advantageous to themselves. Of course, recent legislation made the ambiguous "representative" period the new standard.

    [↑](#footnote-ref-22)
22. 22

    *See*Case No. 12CW73, PP 15.7, 15.7.2, 15.7.3.

    [↑](#footnote-ref-23)
23. 23

    *See*Case No. 04CW174; *see also*13CW3025; 14CW3006.

    [↑](#footnote-ref-24)
24. 24

    While I have not been able to find such a decree, it is my understanding that some engineer(s) in the State Engineers Office favor this approach. Also, the resume of water court applications in Division 1 reveals a few recent applications that seek an appropriation of historical return flows, complete with a claimed date of appropriation; see resume notices for Case Nos. 18CW3195, 19CW3016, and 19CW3084.

    [↑](#footnote-ref-25)
25. 25

    *See*Case No 12CW73.

    [↑](#footnote-ref-26)
26. 26

    C. T. Jenkins published the SDF method in 1968, a method widely used in the South Platte basin in the 1980s and 1990s.

    [↑](#footnote-ref-27)
27. 27

    I distinguish a true volumetric limit, for example, for a direct flow right of 1.0 cfs, of any number of acre-feet in a given 365-day year less than 723.97 acre-feet, rounded to two decimal places. I recognize that a direct flow water right for 1.0 cfs, if diverted on a 24-7 basis for all 365 days of a 365-day year, has an implied, but almost meaningless, volumetric limit of 723.97 acre-feet, where 723.97 acre-feet = 1.0 cubic feet/second x 365 days/year x 86,400 seconds/year/43,560 cubic feet/acre-foot.

    [↑](#footnote-ref-28)
28. 28

    I self-published a paper on the 919 pre-1969 Act transfer decrees on October 16, 1995, entitled Happy Birthday, Orr (on file with author).

    [↑](#footnote-ref-29)
29. 29

    Case No. 95CW205, Division 1.

    [↑](#footnote-ref-30)
30. 30

    So, I self-published another paper, dated November 25, 1996, entitled In Defense of Old Transfers (on file with author).

    [↑](#footnote-ref-31)
31. 31

    The Term Consumptive Use, Its Origin, And The Early Development of Its Methodologies.

    [↑](#footnote-ref-32)
32. 32

    Thoughts on "Changes In Change Decrees" Or "You Cannot Step Twice Into The Same Water, For Other Waters Are Continually Flowing In (on file with author).

    [↑](#footnote-ref-33)
33. 33

    [***Colo.*** *Rev. Stat. § 37-83-104*](https://advance.lexis.com/api/document?collection=statutes-legislation&id=urn:contentItem:61P5-WY01-DYDC-J377-00000-00&context=1516831).

    [↑](#footnote-ref-34)
34. 34

    [***Colo.*** *Rev. Stat. § 37-83-104(4)*](https://advance.lexis.com/api/document?collection=statutes-legislation&id=urn:contentItem:61P5-WY01-DYDC-J377-00000-00&context=1516831).

    [↑](#footnote-ref-35)
35. 35

    [*Empire Lodge Homeowners' Ass'n v. Moyer, 39 P.3d 1139 (****Colo.*** *2001)*](https://advance.lexis.com/api/document?collection=cases&id=urn:contentItem:44PW-3160-0039-4363-00000-00&context=1516831), as modified on denial of reh'g (Feb. 11, 2002).

    [↑](#footnote-ref-36)
36. 36

    [*Id.at 1155*](https://advance.lexis.com/api/document?collection=cases&id=urn:contentItem:44PW-3160-0039-4363-00000-00&context=1516831).

    [↑](#footnote-ref-37)
37. 37

    Unless otherwise noted, assertions are from *City and County of Denver Exchange Decree* Douglas Cnty. C.A.3635, (1972).

    [↑](#footnote-ref-38)
38. 38

    Later, the Division 1 Water Court decree in Case No. W-8783-77 added Chatfield Reservoir as an eighth point of diversion by exchange.

    [↑](#footnote-ref-39)
39. 39

    Unless otherwise noted, assertions are from *Pinewood Springs Municipal Water System's Exchange Decree,* Case No. W8001-75, (Division 1).

    [↑](#footnote-ref-40)
40. 40

    Unless otherwise noted, assertions are from *Arapahoe County Water and Wastewater Authority's (ACWWA) and United Water and Sanitation District's (United) Exchanges*, Case No. 09CW283, (Division 1).

    [↑](#footnote-ref-41)
41. 41

    [*Matter of Bd. of Cty. Comm'rs of Cty. of Arapahoe, 891 P.2d 952 (****Colo.*** *1995)*](https://advance.lexis.com/api/document?collection=cases&id=urn:contentItem:3RX4-02X0-003D-92Y7-00000-00&context=1516831).

    [↑](#footnote-ref-42)
42. 42

    [***Colo.*** *Rev. Stat. § 37-92-103(9)*](https://advance.lexis.com/api/document?collection=statutes-legislation&id=urn:contentItem:689F-SY73-CGX8-03R2-00000-00&context=1516831).

    [↑](#footnote-ref-43)
43. 43

    Unless otherwise noted, assertions are from *Gordon Sonnenberg Farms, Inc. Plan for Augmentation*, Case No. W8186-76, (Division 1).

    [↑](#footnote-ref-44)
44. 44

    Unless otherwise noted, assertions are from *Columbine Country Club's Plan for Augmentation,* Case No. W8521-77, (Division 1).

    [↑](#footnote-ref-45)
45. 45

    The application also sought changes of water rights for the Club's interests in the Brown Ditch and the Last Chance Ditch, but this paper will only address the plan for augmentation.

    [↑](#footnote-ref-46)
46. 46

    Unless otherwise noted, assertions are from *Indian Hills Water District's Plan for Augmentation*, Case No. W8549-77, (Division 1).

    [↑](#footnote-ref-47)
47. 47

    Unless otherwise noted, assertions are from *Groundwater Management District's Plan for Augmentation*, Case No. 02CW335, (Division 1).

    [↑](#footnote-ref-48)
48. 48

    Another example of such engineering innovation is the engineering performed by Doug Clements in the City of Thornton's change of water rights represented by shares in the Burlington and Wellington systems in Division 1 Case No. 87CW107. Here the cause was not lack of records, but rather the Court's finding that not all of the historical use under the subject shares was lawful. The Court had found that some of the historical use of the April 1, 1864, Duggan Ditch right was unlawful. So, Mr. Clements backed out of the historical use the unlawful use of the 1864 Duggan Ditch right, but he was able to "fill back in," or recoup, some of that lost Duggan Ditch use with use of the more junior November 20, 1885, Burlington Ditch right, which was also a part of the Burlington and Wellington systems.

    [↑](#footnote-ref-49)
49. 49

    Case No. 02CW335, P17.2.7.

    [↑](#footnote-ref-50)
50. 50

    Bruce Kroeker, P. E., likely resurrected the idea and the name - projection - in the engineering he did for the Lower Logan Well Users, Inc. in Division 1 Case No. 03CW208. From my research, the decree entered in 1981 on behalf of Emmett Seaman &Sons, Inc., in Case No. 79CW184, was the first Division 1 decree to incorporate a true projection provision as we know them today. The Seaman decree required applicant to "furnish to the Division Engineer and to the Water Commissioner for former Water District No. 1 on or before May 31 of each calendar year ... an annual accounting of the augmentation credits developed under this plan and applied to the out-of-priority depletion of the proposed well adjudicated herein for the immediately preceding augmentation year and a  *projection* for the immediately ensuing augmentation year. (emphasis added)

    [↑](#footnote-ref-51)
51. 51

    John Phillip "Phil" Deaton, Dallas, Texas, circa 1973.

    [↑](#footnote-ref-52)
52. 52

    Henry Darcy, Les Fountains Publiques De La Ville Dijon [The Public Fountains of the City of Dijon] 647 (Victor Dalmont ed., 1856); *see also,* G.O.Brown, Henry Darcy and the making of law, Water Resources Research, 1106 (American Geophysical Union, Vol. 38, No. 7, 2002).

    [↑](#footnote-ref-53)
53. 53

    *See,* David Keith Todd and Larry W. mays, Groundwater Hydrology 1, 86-91 (John Wiley & Sons eds., 3d ed. 2005).

    [↑](#footnote-ref-54)
54. 54

    ***Colorado*** Water Law Benchbook, 3-7 (Carrie Ciliberto & Timothy Flanagan eds., Continuing Legal Educ. In ***Colo.*** 1st ed. 2006).

    [↑](#footnote-ref-55)
55. 55

    Todd, *supra* note53, at 13 (noting that transmissivity is the rate at which water is transmitted through a unit width of aquifer under a unit hydraulic gradient, and that transmissivity equals hydraulic conductivity times saturated aquifer thickness).

    [↑](#footnote-ref-56)
56. 56

    Herman Bouwer, Groundwater Hydrology 29 (McGraw-Hill 1978) (providing that the specific yield "is the volume of water released from a unit volume of saturated aquifer material drained by a falling water table").

    [↑](#footnote-ref-57)
57. 57

    *Id.* at 205-206 (explaining that the unit response function method is a mathematical approach used to calculate stream depletion or accretion. URFs give the stream response from one acre-foot of pumping applied at the location in the aquifer. The effect of five acre-feet of pumping will be five times as large as the effect of one acre foot, but the response of depletion as a percentage of pumping to the aquifer with time will be identical to the unit acre foot. The URF calculation adheres to the principle of superposition).

    [↑](#footnote-ref-58)
58. 58

    *In re* the Application for Water Rights of the Denver Se. Suburban Water and Sanitation Dist. and Terracor, Inc., out of Cherry Creek and its Tributaries, in Douglas County, ***Colo.***, Case No. W-6268 at 9-16 (Division 1 Water Court, Nov. 21, 1977).

    [↑](#footnote-ref-59)
59. 59

    *Id.* at 1.

    [↑](#footnote-ref-60)
60. 60

    Concerning the Application of Denver Se. Suburban Water & Sanitation Dist. D/B/A The Pinery Water and Wastewater Dist., Case No. 11CW198 at 2-6, 21 (Division 1 Water Court, Aug. 30, 2016).

    [↑](#footnote-ref-61)
61. 61

    *Id.* at 70.

    [↑](#footnote-ref-62)
62. 62

    *Id.*at 21-24, 27, 56, 65-66.

    [↑](#footnote-ref-63)
63. 63

    *In re* the Application for Water Rights of S. Adams Cnty. Water and Sanitation Dist., Case No. 2001CW258 at 43-46 (Division 1 Water Court, Sept. 15, 2010).

    [↑](#footnote-ref-64)
64. 64

    Concerning the Application of Water Rights of: The Ground Water Mgmt. Subdistrict of the Cent. ***Colo.*** Water and Conservancy Dist., Case No. 02CW335 at 33-56 (Division 1 Water Court, June 3, 2005).

    [↑](#footnote-ref-65)
65. 65

    *See,* Concerning the Application of Water Rights of: The City of Northglenn in Jefferson, Weld, Boulder and Adams Counties, Case No. 08CW141 (Division 1 Water Court, Apr. 6, 2017).

    [↑](#footnote-ref-66)
66. 66

    Justice Gregory Hobbs Jr., ***Colorado*** *Water Law: An Historical Overview*, 1 U. Denv. Water L. Rev. 1, 23 (1997).

    [↑](#footnote-ref-67)
67. 67

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84. 84

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    [↑](#footnote-ref-97)
97. 97

    Charles Corker, University of Washington Seattle.

    [↑](#footnote-ref-98)
98. 98

    The San Luis Valley Rules were promulgated in September 2015, and tried in January and February 2018, the Div 3 Water Court approved the rules in March 2019.

    [↑](#footnote-ref-99)
99. 99

    *See* MODFLOW-GUI Version 4, [*https://water.usgs.gov/nrp/gwsoftware/mfgui4/modflow-gui.html*](https://water.usgs.gov/nrp/gwsoftware/mfgui4/modflow-gui.html) (last visited Mar. 6, 2019). H.B. 98-1011 may have incentivized the development of MODFLOW by requiring the State Engineer to do "specific studies" for development of confined aquifer rules;*See* [***Colo.*** *Rev. Stat. § 37-90-102(3)(a)*](https://advance.lexis.com/api/document?collection=statutes-legislation&id=urn:contentItem:61P5-WY01-DYDC-J3C2-00000-00&context=1516831) (2003) (repealed 2004).

    [↑](#footnote-ref-100)
100. 100

     Herman Hollerith was an American computer pioneer. In 1890, he invented the Hollerith Code, which early computers later employed using twelve bits per alphanumeric character. *See* Herman Hollerith, [*http://www.columbia.edu/cu/computinghistory/hollerith.html*](http://www.columbia.edu/cu/computinghistory/hollerith.html) (last visited Mar. 6, 2019).

     [↑](#footnote-ref-101)
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     *See* Tutorial Manual for Groundwater Vistas, [*http://www.groundwatersoftware.com/ftp/gv6\_tutorial\_manual.pdf*](http://www.groundwatersoftware.com/ftp/gv6_tutorial_manual.pdf) (last visited Mar. 6, 2019).

     [↑](#footnote-ref-102)
102. 102

     *See* Visual MODFLOW Flex, [*https://www.waterloohydrogeologic.com/visual-modflow-flex/*](https://www.waterloohydrogeologic.com/visual-modflow-flex/) (last visited Mar. 6, 2019).

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103. 103

     *See* Groundwater Modeling Systems, [*https://www.aquaveo.com/software/gms-groundwater-modeling-system-introduction*](https://www.aquaveo.com/software/gms-groundwater-modeling-system-introduction) (last visited Mar. 6, 2019).

     [↑](#footnote-ref-104)
104. 104

     Color-flood maps are maps that use different colors and shadings to represent a range in a parameter value: for example, transmissivity or saturated-aquifer thickness.

     [↑](#footnote-ref-105)
105. 105

     *See* John Doherty, PEST: Model-Independent Parameter Estimation User Manual 1 - 3 (Watermark Numerical Computing 5th ed. 2005), [*https://www.nrc.gov/docs/ML0923/ML092360221.pdf*](https://www.nrc.gov/docs/ML0923/ML092360221.pdf).

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106. 106

     UCODE\_2005 and Six Other Computer Codes for Universal Sensitivity Analysis, Calibration, and Uncertainty Evaluation, [*https://pubs.usgs.gov/tm/2006/tm6a11/pdf/TM6-A11.pdf*](https://pubs.usgs.gov/tm/2006/tm6a11/pdf/TM6-A11.pdf) (last visited Mar. 6, 2019).

     [↑](#footnote-ref-107)
107. 107

     Engineers perform a sensitivity analysis to establish the effect of uncertainty on a calibrated ground-water model. *See* Paul K.M. van der Heijde, *Ground-Water Modeling Issues in Ground-Water Development: Model Calibration and Verification*, *in* Uncovering the Hidden Resource: Groundwater Law, Hydrology, and Policy in the 1990s (Summer Conference June 15-17, 1992), [*https://scholar.law.****colorado****.edu/groundwater-law-hydrology-policy/12*](https://scholar.law.colorado.edu/groundwater-law-hydrology-policy/12).

     [↑](#footnote-ref-108)
108. 108

     The legislature codified S.B. 213 at [***Colo.*** *Rev. Stat. § 37-90-137(4)*](https://advance.lexis.com/api/document?collection=statutes-legislation&id=urn:contentItem:689F-SN93-GXF6-81VM-00000-00&context=1516831) (1973).

     [↑](#footnote-ref-109)
109. 109

     Cook, Mary and Charles N. Woodruff, 1979, Legislative History and Analysis of Senate Bill 213.

     [↑](#footnote-ref-110)
110. 110

     A well-cylinder appropriation can be determined through the following formula: Annual Appropriation = (Area x Specific Yield x Saturated Sandstone/Siltstone thickness)/100 years. With this formula, an engineer can also determine the area of a well cylinder by incorporating the equation for a circle.

     [↑](#footnote-ref-111)
111. 111

     Cook, *supra*note 109.

     [↑](#footnote-ref-112)
112. 112

     [***Colo.*** *Rev. Stat. § 37-90-137(4)*](https://advance.lexis.com/api/document?collection=statutes-legislation&id=urn:contentItem:689F-SN93-GXF6-81VM-00000-00&context=1516831) (2018).

     [↑](#footnote-ref-113)
113. 113

     Cook, *supra*note 109.

     [↑](#footnote-ref-114)
114. 114

     For example, Centennial Water and Sanitation District, the water provider for Highlands Ranch, adjudicated the Arapahoe Aquifer after two companies had filed applications for conditional underground-water rights. *See* [*Mission Viejo* ***Co****. v. Willows Water Dist., 818 P.2d 254 (****Colo.*** *1991)*](https://advance.lexis.com/api/document?collection=cases&id=urn:contentItem:3RX4-0K40-003D-91V6-00000-00&context=1516831) (citing In re Application for Water Rights of Highland Venturers and Mission Viejo ***Co***. in the Arapahoe Formation and the Laramie-Fox Hills Aquifer, Case No. W-9192-78 (Water Court Div. 1 1989).

     [↑](#footnote-ref-115)
115. 115

     ***Colorado*** Population of Counties by Decennial Census: 1900 to 1990, [*https://www.census.gov/population/cencounts/co190090.txt*](https://www.census.gov/population/cencounts/co190090.txt) (last visited Mar. 6, 2019).

     [↑](#footnote-ref-116)
116. 116

     [***Colo.*** *Rev. Stat. § 37-90-137(4)*](https://advance.lexis.com/api/document?collection=statutes-legislation&id=urn:contentItem:689F-SN93-GXF6-81VM-00000-00&context=1516831).

     [↑](#footnote-ref-117)
117. 117

     "Borehole geophysics is the science of recording and analyzing measurements of physical properties made in wells or test holes" into the Earth's surface. Borehole Geophysics, U.S. Geological Survey, [*https://www.usgs.gov/centers/ny-water/science/borehole-geophysics?qt-science\_center\_objects=0#qt-science\_center\_objects*](https://www.usgs.gov/centers/ny-water/science/borehole-geophysics?qt-science_center_objects=0#qt-science_center_objects).

     [↑](#footnote-ref-118)
118. 118

     *Id.*

     [↑](#footnote-ref-119)
119. 119

     [***Colo.*** *Rev. Stat. § 37-90-137(5)*](https://advance.lexis.com/api/document?collection=statutes-legislation&id=urn:contentItem:689F-SN93-GXF6-81VM-00000-00&context=1516831).

     [↑](#footnote-ref-120)
120. 120

     [***Colo.*** *Rev. Stat. § 37-90-137(8)*](https://advance.lexis.com/api/document?collection=statutes-legislation&id=urn:contentItem:689F-SN93-GXF6-81VM-00000-00&context=1516831).

     [↑](#footnote-ref-121)
121. 121

     *See* *In re Application for Water Rights of Highland Venturers and Mission Viejo* ***Co***., Case No. W-9192-78.

     [↑](#footnote-ref-122)
122. 122

     *Id.* at 3-5.

     [↑](#footnote-ref-123)
123. 123

     *Id.* at 3-6.

     [↑](#footnote-ref-124)
124. 124

     The ***Colorado*** Legislature codified S.B. 5 at [***Colo.*** *Rev. Stat. § 37-90-137*](https://advance.lexis.com/api/document?collection=statutes-legislation&id=urn:contentItem:689F-SN93-GXF6-81VM-00000-00&context=1516831).

     [↑](#footnote-ref-125)
125. 125

     Dakota Aquifer, [*https://catalog.data.gov/dataset/dakota-aquifer*](https://catalog.data.gov/dataset/dakota-aquifer) (last visited Mar. 6, 2019).

     [↑](#footnote-ref-126)
126. 126

     *See* § 37-90-137.

     [↑](#footnote-ref-127)
127. 127

     *See* [*Water Rights of Park Cty. Sportsmen's Ranch LLP v. Bargas, 986 P.2d 262, 270 (****Colo.*** *1999)*](https://advance.lexis.com/api/document?collection=cases&id=urn:contentItem:3XDB-1PH0-0039-404C-00000-00&context=1516831); *see also* Teresa Rice, *Nontributary, Nondesignated Ground Water: The Huston Decision*, 56 U. ***Colo.*** L. Rev. 135, 148 n.85(1984).

     [↑](#footnote-ref-128)
128. 128

     Four aquifers comprise the Denver Basin: the Dawson, Denver, Arapahoe, and Laramie-Fox Hills Aquifers. *See* [*Water Rights of Park Cty. Sportsmen's Ranch, 986 P.2d at 271*](https://advance.lexis.com/api/document?collection=cases&id=urn:contentItem:3XDB-1PH0-0039-404C-00000-00&context=1516831).

     [↑](#footnote-ref-129)
129. 129

     *See* [*2* ***Colo.*** *Code Regs. § 402-7*](https://advance.lexis.com/api/document?collection=administrative-codes&id=urn:contentItem:5XSH-9F01-DXHD-G2S6-00009-00&context=1516831):1 (1986).

     [↑](#footnote-ref-130)
130. 130

     *See* *id.* at § 402-6:1

     [↑](#footnote-ref-131)
131. 131

     *See id.* at § 402-6 *et seq*

     [↑](#footnote-ref-132)
132. 132

     *Id.*

     [↑](#footnote-ref-133)
133. 133

     VanSlyke, George and others (1988), Geologic Structure, Sandstone/Siltstone Isolith, and Location of Non-Tributary Ground Water for the Dawson Aquifer, Denver Basin, ***Colorado***, Office of the State Engineer, ***Colorado*** Division of Water Resources, Denver Basin Atlas No. 1; VanSlyke, George and others (1988), Geologic Structure, Sandstone/Siltstone Isolith, and Location of Non-Tributary Ground Water for the Denver Aquifer, Denver Basin, ***Colorado***, Office of the State Engineer, ***Colorado*** Division of Water Resources, Denver Basin Atlas No. 2.; VanSlyke, George and others (1988), Geologic Structure, Sandstone/Siltstone Isolith, and Location of Non-Tributary Ground Water for the Arapahoe Aquifer, Denver Basin, ***Colorado***, Office of the State Engineer, ***Colorado*** Division of Water Resources, Denver Basin Atlas No. 3; VanSlyke, George and others (1988), Geologic Structure, Sandstone/Siltstone Isolith, and Location of Non-Tributary Ground Water for the Laramie-Fox Hills Aquifer, Denver Basin, ***Colorado***, Office of the State Engineer, ***Colorado*** Division of Water Resources, Denver Basin Atlas No. 4.

     [↑](#footnote-ref-134)
134. 134

     ***Colo.*** Code Regs. § 402-6:9 (1986).

     [↑](#footnote-ref-135)
135. 135

     *Id.* at § 402-6:7.

     [↑](#footnote-ref-136)
136. 136

     *See* "Denver Basin Aquifer Evaluation Tools: Tract of Land Determination Tool," ***Colorado***.Gov, [*https://www.****colorado****.gov/cdss/denver-basin-aquifer-evaluation-tools*](https://www.colorado.gov/cdss/denver-basin-aquifer-evaluation-tools) (last visited Mar. 6, 2019); "Denver Basin Aquifer Evaluation Tools: Specific Location Determination Tool," ***Colorado***.Gov, [*https://www.****colorado****.gov/cdss/denver-basin-aquifer-evaluation-tools*](https://www.colorado.gov/cdss/denver-basin-aquifer-evaluation-tools) (last visited Mar. 6, 2019).

     [↑](#footnote-ref-137)
137. 137

     ***Colo.*** Code Regs. § 410-1 Rule 5.

     [↑](#footnote-ref-138)
138. 138

     *Id.*

     [↑](#footnote-ref-139)
139. 139

     ***Colo.*** Code Regs. § 402-6:6 (1986).

     [↑](#footnote-ref-140)
140. 140

     *Id.*

     [↑](#footnote-ref-141)
141. 141

     *Id.*

     [↑](#footnote-ref-142)
142. 142

     S.B. 5, Gen. Assemb., Reg. Sess (***Colo.*** 1985) codified at § 37-90-137.

     [↑](#footnote-ref-143)
143. 143

     *See id.*at § 402-6:5.

     [↑](#footnote-ref-144)
144. 144

     [***Colo.*** *Rev. Stat. § 37-92-305(3)(a)*](https://advance.lexis.com/api/document?collection=statutes-legislation&id=urn:contentItem:61P5-WY01-DYDC-J3G3-00000-00&context=1516831).

     [↑](#footnote-ref-145)
145. 145

     [***Colo.*** *Rev. Stat. § 37-92-103(9)*](https://advance.lexis.com/api/document?collection=statutes-legislation&id=urn:contentItem:689F-SY73-CGX8-03R2-00000-00&context=1516831).

     [↑](#footnote-ref-146)
146. 146

     [***Colo.*** *Rev. Stat. § 37-90-103*](https://advance.lexis.com/api/document?collection=statutes-legislation&id=urn:contentItem:68BY-DJC3-GXF6-82XJ-00000-00&context=1516831) (2016).

     [↑](#footnote-ref-147)
147. 147

     HRS Water Consultants, Inc., 1987, City of ***Colorado*** Springs Summary Report Denver and Arapahoe Aquifer Modeling, prepared for the City of ***Colorado*** Springs.

     [↑](#footnote-ref-148)
148. 148

     Gronning Engineering Company, 1988, work completed as part of Case No. 89CW36, Division 2.

     [↑](#footnote-ref-149)
149. 149

     HRS Water Consultants, Inc. 1988, City of ***Colorado*** Springs, Revised Laramie-Fox Hills SEO-Type Model, Prepared for the City of ***Colorado*** Springs.

     [↑](#footnote-ref-150)
150. 150

     *See* *In re the Application for Water Rights of NaTec Minerals*, ***Colo.*** Water Div. No. 5 (1991) (No. 88CW420).

     [↑](#footnote-ref-151)
151. 151

     HRS Water Consultants, Inc. 1990, NATEC Lease Depletion Modeling Analysis, prepared for NATEC Mineral, Inc.

     [↑](#footnote-ref-152)
152. 152

     HRS Water Consultants, Inc., 2016, Application for Nontributary Groundwater, Bighorn Land, LLC, Pueblo County, ***CO***.

     [↑](#footnote-ref-153)
153. 153

     House Bill 09-1303, 67th Gen. Assemb., 1st Reg. Sess. (***Colo.*** 2009).

     [↑](#footnote-ref-154)
154. 154

     *Id.*

     [↑](#footnote-ref-155)
155. 155

     *See****Colo.*** Code Regs. § 402-7:17 (1986).

     [↑](#footnote-ref-156)
156. 156

     Mary Lou Smith, "Working the Water: A Brief Human History of the South Platte and its Alluvial Aquifer," ***Colorado*** *Water (*CSU Water Center) Jan.-Feb. 2014 at 2,4.

     [↑](#footnote-ref-157)
157. 157

     HRS Water Consultants, Inc., 1985, Fort Morgan Reservoir and Irrigation Company Plan for Augmentation, prepared for Fort Morgan Reservoir and Irrigation Company; HRS Water Consultants, Inc., 1992, City of Brush Plan for Augmentation Case No. W-9383-78, prepared for the City of Brush; HRS Water Consultants, Inc., 1983, Lower Platte and Beaver Canal Company Plan for Augmentation Engineering Report, prepared for Lower Platte and Beaver Company.

     [↑](#footnote-ref-158)
158. 158

     *See*Gregory J. Hobbs, *History of the Referee, Division Engineer, State Engineer, and Water Court Consultation Process Under the Water Rights Determination and Administration Act of 1969*, [*21 U. Denver. Water L. Rev. 1 (2017)*](https://advance.lexis.com/api/document?collection=analytical-materials&id=urn:contentItem:5RYT-7GY0-00SW-50SV-00000-00&context=1516831).

     [↑](#footnote-ref-159)
159. 159

     *See*Reagan M. Waskom, HB12-1278 Study of the South Platte Alluvial Aquifer, 68th Gen. Assemb.  *(****Colo.*** 2013).

     [↑](#footnote-ref-160)
160. 160

     *See id.*

     [↑](#footnote-ref-161)
161. 161

     ***Colo.*** Code Regs. § 402-11, Rule 6.10 (2018).

     [↑](#footnote-ref-162)
162. 162

     ***Colo.*** Code Regs. § 402-11.

     [↑](#footnote-ref-163)
163. 163

     In the 1950s, Pete Wheeler did some cases for Golden where the municipal depletions considered lawn irrigation return flows with water balance analysis versus the historical depletions for the irrigation water rights that were being changed. The City of Fountain, Security Water District, and Widefield Water & Sanitation District also got lawn irrigation return flow credit included in their augmentation plans around this same time period. Personal communication with Mr. Gary Thompson (Nov. 28, 2018).

     [↑](#footnote-ref-164)
164. 164

     *See In Re the Application for Water Rights of James L. Orr,****Colo.*** Water Div. No. 1 (1985) (No. 81CW142).

     [↑](#footnote-ref-165)
165. 165

     W.W. Wheeler and Associates, 1985, Cottonwood Water and Sanitation District Engineering Report, Case No 81CW142.

     [↑](#footnote-ref-166)
166. 166

     Decree, In the Matter of the Application for Water Rights of Mission Viejo ***Co***. in Water Dist. No. 1, Centennial Water and Sanitation Dist., No. 85CW415, December 12, 1988.

     [↑](#footnote-ref-167)
167. 167

     Decree, Concerning the Application of Water Rights of the City and County of Denver, Water Div. No. 1, No. 2004CW121, May 15, 2012.

     [↑](#footnote-ref-168)
168. 168

     Decree, Concerning the Application of Denver Se. Suburban Water and Sanitation Dist. D/B/A The Pinery Water and Wastewater Dist., Water Div. No. 1, Case No. 11CW198, August 30, 2016.

     [↑](#footnote-ref-169)
169. 169

     Zorich-Erker Engineering, Inc. was the predecessor company to HRS Water Consultants Inc. and several other ***Colorado*** water consulting firms.

     [↑](#footnote-ref-170)
170. 170

     An m-scope is an electronic ground water level measurement device. An electric probe is connected to a wire or tape measure. The m-scope makes a buzzing noise when the electric probe intersects ground water.

     [↑](#footnote-ref-171)
171. 171

     ***Colorado***'s Decision Support System, [*https://www.****colorado****.gov/cdss*](https://www.colorado.gov/cdss), (last visited March 6, 2019).

     [↑](#footnote-ref-172)
172. 172

     The Division 1 Water Court entered some decrees in the mid-1980s for applications filed in the early years of the 1969 Act, including a decree for the Riverside Irrigation District in Case No. W2919, entered on April 1, 1986, with its application having been filed on June 16, 1972. ( *See* Decree, In the Matter of Riverside Irrigation Dist., Div. 1 Water Court, No. W2919, June 16, 1972). We obtained a copy of the decree's Exhibit B, the accounting, from the District's Superintendent, Don Chapman. This accounting for well pumping, well depletions, SDF factors, and even a 24-month projection, resembles today's detailed accounting. But, because the W2919 decree was entered in the mid-1980s, its accounting, which is more detailed and similar to current accounting, had to have been influenced by the more modern accounting of the middle 1980s. Therefore, Riverside's W2919 decree is not considered to be a decree of the early period of the 1969 Act and is instead representative of the trend toward accounting and data that appears to have begun after the first decade following the 1969 Act. The same could be said for the early 1970s applications and mid-1980s decrees of the Fort Morgan, Bijou, Lower Platte and Beaver, and Upper Platte and Beaver ditch systems. None of these cases are included in Table 1.

     [↑](#footnote-ref-173)
173. 173

     In the Matter of the Application for Water Rights of the Denver Se. Suburban Water and Sanitation Dist. and Terracor, Inc., *supra* note 58.

     [↑](#footnote-ref-174)
174. 174

     Decree, In the Matter of the Adjudication of Priorities to the Right to the Use of Water for all Beneficial Purposes in Water Dist. No. 8, Irrigation Div. No. 1, Civ. Action No. 3635, May 18, 1972.

     [↑](#footnote-ref-175)
175. 175

     ***Colorado*** Division of Water Resources provides scanned historical field books beginning in 1911 and commissioner reports beginning in 1889. ***Colo.*** Dept. of Nat. Res., [*https://dnrweblink.state.****co****.us/dwr/search.aspx*](https://dnrweblink.state.co.us/dwr/search.aspx) (select search type; then enter general search terms).

     [↑](#footnote-ref-176)
176. 176

     Decree, Concerning the Application for Water Rights of East Cherry Creek Valley Water and Sanitation Dist., Water Division No. 1, Case No. 14CW3164, December 26, 2016.

     [↑](#footnote-ref-177)
177. 177

     *Id.* at 25.

     [↑](#footnote-ref-178)
178. 178

     Water Rights of East Cherry Creek Valley Water and Sanitation Dist., *supra*note 176.

     [↑](#footnote-ref-179)
179. 179

     Richard K. Farnsworth, Edwin S. Thompson, and Eugene L. Peck, *Evaporation Atlas for the Contiguous 48 United States*, NOAA Technical Release NWS 33. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service 23 (1982), [*www.nws.noaa.gov/oh/hdsc/PMP\_related\_studies/TR33.pdf*](http://www.nws.noaa.gov/oh/hdsc/PMP_related_studies/TR33.pdf).

     [↑](#footnote-ref-180)
180. 180

     ***Colorado*** Division of Water Resources, *General Guidelines For Substitute Water Supply Plans For Sand And Gravel Pits*, 3 (2011), [*http://water.state.****co****.us/DWRIPub/Documents/gravelpits.pdf*](http://water.state.co.us/DWRIPub/Documents/gravelpits.pdf); ***Colorado*** Division of Water Resources,*General Administration Guidelines for Reservoirs* 21 (2016), [*http://water.state.****co****.us/DWRIPub/Documents/Reservoir%20Administration%20Guidelines.pdf*](http://water.state.co.us/DWRIPub/Documents/Reservoir%20Administration%20Guidelines.pdf).

     [↑](#footnote-ref-181)
181. 181

     *Id.* at 11-13.

     [↑](#footnote-ref-182)
182. 182

     ***Colorado*** Division of Water Resources, *Administrative Protocol - Augmentation Plan Ac count ing, Divi sion One - South Platte* ***River*** *(*2009), [*https://drive.google.com/file/d/1JpOH2ylr1MlkIx8\_rgKExkSaf1gviigC/view*](https://drive.google.com/file/d/1JpOH2ylr1MlkIx8_rgKExkSaf1gviigC/view).

     [↑](#footnote-ref-183)
183. 183

     *See generally*, ***Colorado*** Division of Water Resources, *Amended Rules Governing the Measurement of Tributary Ground Water Diversions Located in the Arkansas* ***River*** *Basin*, (2005), [*http://water.state.****co****.us/DWRIPub/Documents/arkmeasrule.pdf*](http://water.state.co.us/DWRIPub/Documents/arkmeasrule.pdf); ***Colorado*** Division of Water Resources,*Final Approved Amended Rules (as adopted by the State Engineer on Septem ber 16, 2015)*, [*http://water.state.****co***](http://water.state.co) .us/DWRIPub/Documents/FINAL\_Approved\_Amended\_Rules\_October\_19th\_2015.pdf; ***Colorado*** Division of Water Resources,*South Platte Ground Wa ter Measur ement Rules*, file:///S:/Personal%20Folders/Personal/DU/Law%20Review/New%20folder/Div1WellMeasRules-12\_2011\_VERSION.pdf (last visited March 4, 2019); ***Colorado*** Division of Water Resources, *Rules Governing the Measurement of Ground Water Diversions located in Water Division 3, The Rio Grande Basin* [*http://water.state.****co****.us/DWRIPub/Documents/div3measurementrules.pdf*](http://water.state.co.us/DWRIPub/Documents/div3measurementrules.pdf) (last visited March 4, 2019).

     [↑](#footnote-ref-184)
184. 184

     ***Colorado*** Division of Water Resources, *Administrative Protocol - Recharge. Division One - South Platte* ***River***, 2 (2008), [*https://drive.google.com/file/d/1G1G7GaffQkloQIcvp5KUS\_3yV\_tX7a0p/view*](https://drive.google.com/file/d/1G1G7GaffQkloQIcvp5KUS_3yV_tX7a0p/view) .

     [↑](#footnote-ref-185)
185. 185

     *General Administration Guidelines for Reservoirs*, *supra*note 180.

     [↑](#footnote-ref-186)