How Should Irrigation Water Requirements be Determined?

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CLE – Law of the Rio Grande

One question for the panel today is on quantification of irrigation water rights for the purpose of court decree of rights to beneficial use of water. Other purposes for quantifying irrigation water requirements (IWR) include canal design, water-management operations, basin-water accounting, environmental impact assessment and water-policy planning. Those purposes are distinct from that of decreeing water rights. Most of the work on IWR has been for those purposes rather than for water-right quantification. A "water requirement" is water needed for a particular purpose and "water use" is water actually used for a specific purpose, according to the glossary of the National Handbook for Water-Data Acquisition. Water use includes elements such as water withdrawal, distribution, storage, consumptive use and return flow. The distinction between water "required" and water "used" might be significant for quantifying the water-rights amount. One does not hear that "beneficial requirements" are the basis, limit and measure of water rights.

To refresh ourselves on the past practices, several methods have been relied on for deriving the elements of consumptive use (CU) and the associated adjustments for irrigation system efficiency. The CU, adjusted for water available from other sources (precipitation, water table, stored moisture), and divided by system efficiency, leads to the IWR that is the number sought for indicating the amount of water use in an adjudication decree.

<u>CIR Methods</u>

The methods that have been used include:

a) Empirical, such as Blaney-Criddle[1] (B-C) using temperature, daylight hours, and crop-coefficient factors.
b) Physical Theoretical, such as Penman[2] combining energy balance and atmospheric processes with crop coefficients.
c) Measured, such as by Lysimeters[3] weighing the water lost to the atmosphere; these are used to find crop coefficients.
d) Remote Sensing, such as by LANDSAT[4] using temperature and intensity of reflectance on ¼ acre resolution for relative strength of evapotranspiration (ET) or for calibrated absolute units (mm/day).

B-C was developed in mid-20th century based on experience with the early-20th century Bureau of Reclamation (BOR) projects and professional judgment including "*a personal knowledge of the physical conditions*",[5] but has been found to understate the peak water consumption of above-average farm

[1] Blaney, H.F. and Criddle, W.D., 1950, Determining Water Requirements in Irrigated Areas from Climatological and Irrigation Data: U.S. Department of Agriculture, Soil Conservation Service, SCS-TP-96.
[2] Penman, H.L., 1948, Natural Evaporation from Open Water, Base Soil and Grass: Proceedings of the Royal Society.
[3] Wright, J.L., 1991, Using Weighing Lysimeters to Develop Evapotranspiration Crop Coefficients.
[4] Allen, R. G., Tasumi, M., Morse, A., and Trezza, R., 2005, A Landsat-based Energy Balance and Evapotranspiration Model in Western US Water Rights Regulation and Planning: Irrigation and Drainage Systems, No. 19, ASCE.
[5] Blaney, H.F. and Criddle, W.D., 1962, Determining Consumptive Use and Irrigation Requirements, U.S. Agricultural Research Service, Technical Bulletin 1275.

management operations. The B-C empirical observation hand-book style factors are suited to irrigation project planning and design, which was the original purpose of the method.

Penman is computationally complex requiring data seldom available at farm sites. Penman, at instrumented research sites, has been found to overstate water consumed in average farm management operations.

Lysimeters are accurate to one percent of water loss to the atmosphere, but are limited to research conditions in small areas of ideal moisture, also overstating water consumed in average farm management operations.

Satellite methods are robust for relative intensity of water consumption to ¼-acre detail and are the preferred method to show the range of CU throughout large areas.

<u>What is an "amount" of Water Right?</u>

In quantifying IWR the units to be decreed remain ambiguous. The New Mexico water-right parameters are *"…priority, amount, purpose, periods and place of use…"*[6] The way to express the "amount" of the right has been, variously, the diversion rate as instantaneous cubic feet per second (cfs), peak month in cfs, canal capacity in cfs, diversion volume in acre feet (AF) per season, and "duty of water" as a loading rate (acre feet per acre or feet per annum). The early concept of duty of water was analogous to the duty of a pump sized for flow and head. A heavy-duty canal system served a lot of acres per unit of water, and a low-duty system served fewer acres per unit of water. Irrigation duty originally was expressed as cfs per acre served, then inverted to acres per cfs, and now is expressed as feet (or acre-feet per acre). For interest, Elwood Mead's early discussion is quoted below.[7] New Mexico Regulations[8] since the 1950s provided that "three acre-feet of water per acre applied on the land is ample for irrigation purposes," and allowed a rate of delivery of 70 acres per cfs as the maximum duty of water (10.4 inches/month). That rate is coincidentally close to the 10.2-inch peak monthly rate for alfalfa in Albuquerque published in 1963 as the solar radiation value of potential ET by Jensen and Haise.[9] Diversions are allowed at reasonable rates as necessary to convey the 10 inches/month and three feet for the season to the farm. Jensen and Haise also note that 17 inches is the physical limit on radiant energy to

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[6] New Mexico Statutes, Chapter 72, Water Law 72-4-19 (1978).

[7] Mead, E., 1910, Irrigation Institutions, Chapter III: McMillan. *"The duty of water in irrigation is the area of crop which can be matured with a given volume…An approximate knowledge of the duty of water is as necessary in the distribution of water in irrigation as a unit of value in finance and trade. In the absence of such standard, it has often happened that serious mistakes have been made in fixing the dimensions of canals, usually in the direction of making them too small…The duty of water varies greatly and must of necessity do so. It depends in part on the economy and skill or negligence and waste which governs its distribution…In determining the duty of water, it is manifest that if water is applied sparingly it will cover a larger area, and if applied freely, fewer acres can be served. The limit of profitable economy is to use the least quantity of water necessary to secure the best yield. In the West there are many reasons for endeavoring to reach this limit, if not to go somewhat beyond it. Under the highest duty which can ever be secured not more than 10 per cent of the arid West can ever be reclaimed. A higher duty of water, which will increase the watered area, will, therefore, add to the value of the water-supply and to investments in irrigation works, and render large area of land productive which are now arid and unused. The duty of water is variously stated. When the flow of a stream is not stored, and the water must be used as it comes down from the snows, duty is properly expressed in a unit of flowing water, either the inch or the cubic foot per second…the total area that the stream would serve was determined by dividing its discharge by this assumed duty…it is usual to give the number of acre-feet of water used on an acre of ground. This is in reality the reciprocal of the duty, but is a more convenient form…"*

[8] New Mexico State Engineer, 1953, Manual of Rules and Regulations: New Mexico Office of the State Engineer.

[9] Jensen, M.E. and Haise, H.R., 1963, Estimating Evapotranspiration from Solar Radiation: Journal of Irrigation and Drainage Engineering, Vol. 89, ASCE.

convert water to vapor on a cloudless month in Albuquerque. The 17-inch physical limit on ET is equivalent to 40 acres per cfs, which might serve as a conceptual cap on water use.

Recently the courts have been asked to order project diversion requirements (PDR), farm delivery requirements (FDR), and consumptive irrigation requirements (CIR) separately in terms of loading rates (feet/year) per acre, while neglecting cfs and AF volumes for either a ditch or a project. None of the above CU methods produces a quantification of the amount of water used in terms of any appropriate unit, until the necessary further adjustments are made for system efficiency.

Deficit irrigation produces high efficiency of water applied on farm. "The high irrigation efficiencies …are attributed to the practice of deficit irrigation".[10] The NRCS National Engineering Handbook (Table 6-1) shows the two-fold range (80 percent to 35 percent) in application efficiency for reasonable farm water operations, translating into twice as much IWR for some than for others, at the same CU. The rule-of-thumb nature of the adjustments is part of the problem in converting CIR to IWR for specific farms.

System efficiency, accordingly, remains uncertain and variable on many scales. Figure 1, adapted from the second National Water Assessment,[11] illustrates the problem in converting estimates of CIR to IWR for a decree of water-right amount. Highly-refined measures of on-farm CU contribute little to the overall question. The average water use for 17 western states shows that there are many components of necessary water losses to the atmosphere. For example, losses may occur above the diversion point, in conveyance to the farm operation, on the farm and below the farm including increased riparian zone

Figure 1

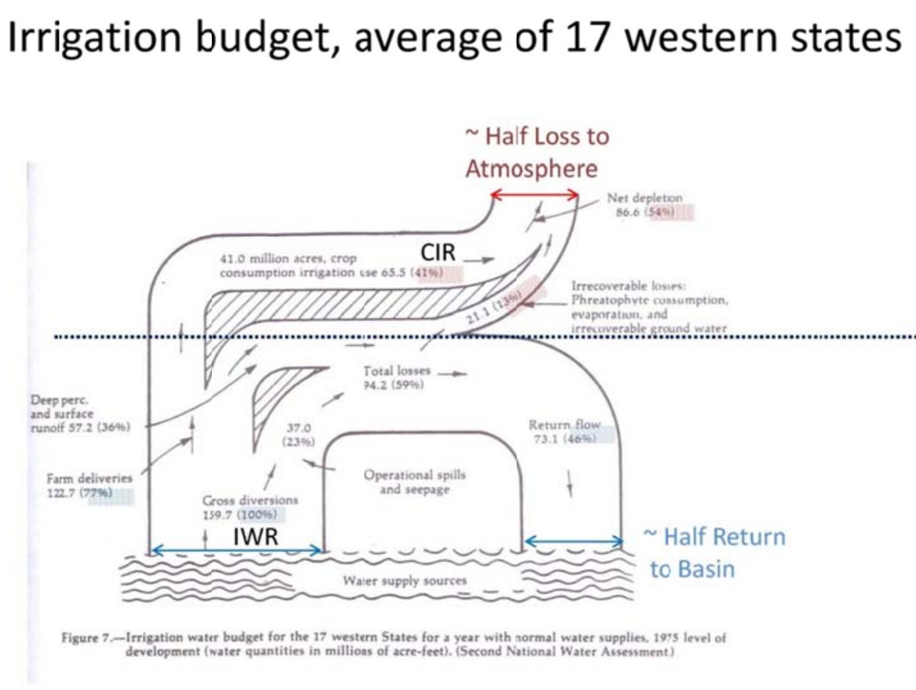


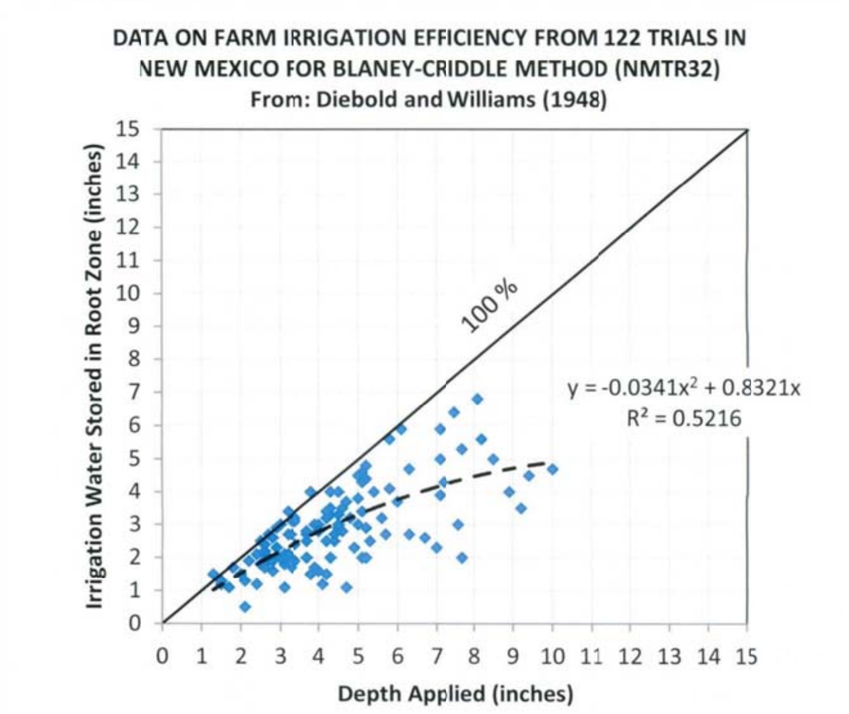
Figure 7.—Irrigation water budget for the 17 western States for a year with normal water supplies, 1975 level of development (water quantities in millions of acre-feet). (Second National Water Assessment)

[10] Samani, Z. and others, 2005, Measuring On-Farm Irrigation Efficiency with Chloride Tracing under Deficit Irrigation: Journal of Irrigation and Drainage Engineering, Vol. 131, Issue 6, ASCE.
[11] U.S. Water Resources Council, 1978, The Nation's Water Resources 1975-2000: Second National Water Assessment, Washing DC, U.S. Government Printing Office.

losses due to a rising water table associated with seepage and deep percolation or leaching through soil from the irrigation system. The on-farm CIR may average in the range of 40 percent of the total water use, and two-thirds of the overall loss to the atmosphere, while another quarter of water use (operational spills) is used in the farm operation then returned to the source stream. Beneficial use is comprised of all these components. Return flows and operational losses do not constitute waste because 100 percent efficiency in any water operation is unattainable. Averages for the western region, however, do not characterize individual rights. The attribution of losses and returns among these components is highly variable case-by-case, also depending on the scale of the account whether the right is attached to farms, ditches, irrigation projects, districts or basins. Accordingly, the appropriate answer for the amount for water use to be decreed for adjudicated rights must depend on the specific features and on the scale of operation that the right represents. The amount of use for a BOR project in the lower Rio Grande that recycles return flow over hundreds of miles of river reach will have a different set of water accounts and efficiencies than that of a private ditch in the mountains above 7000 feet.

Figure 2, from the B-C method[5 above] appendix, shows the variation in operations among farms can be as much as an order of magnitude.

Figure 2



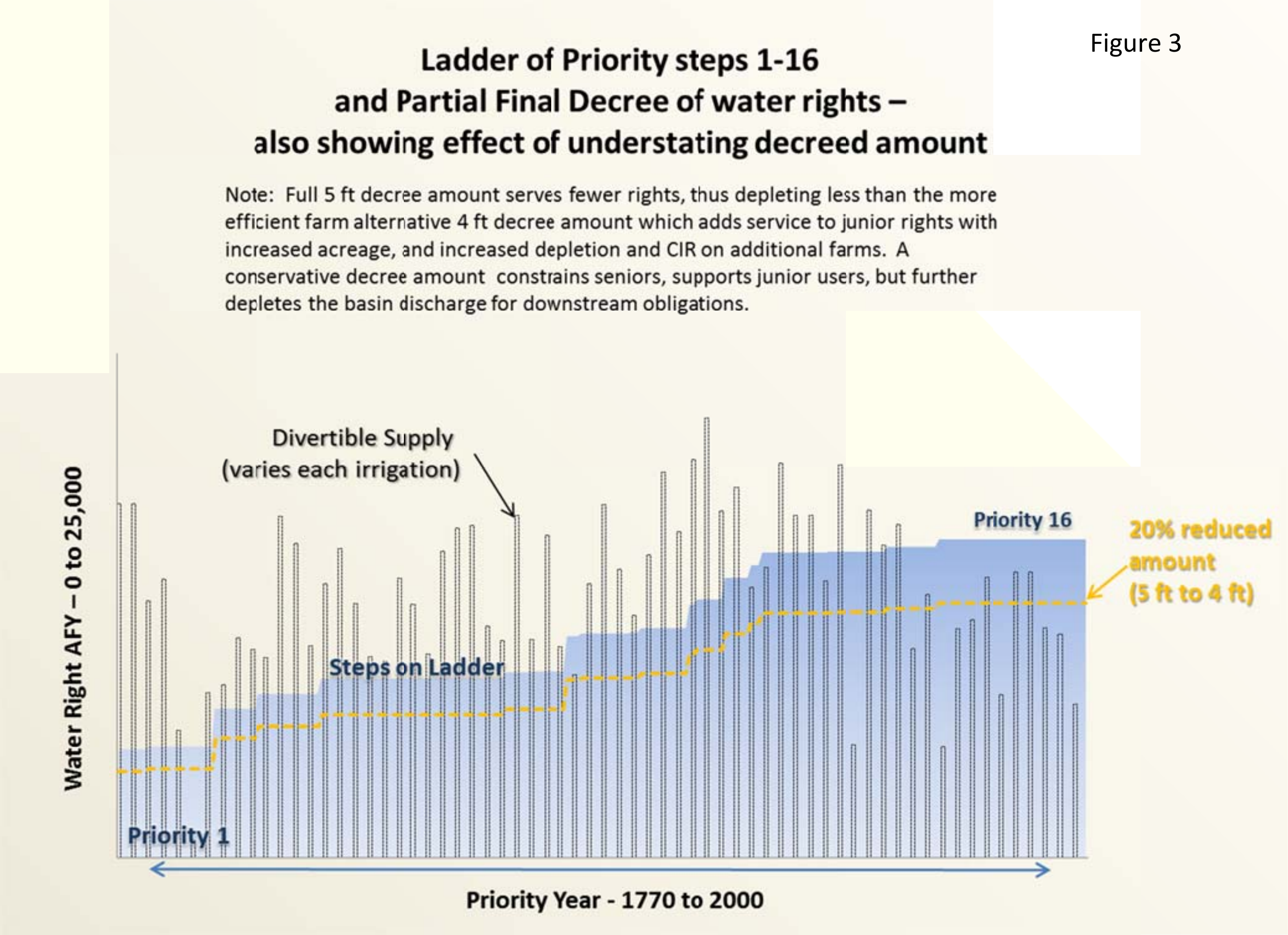
The amount of water use appropriate for decree in basin adjudication is the net diversion in the head of the canal, rather than any number derived from CIR or CU. A reasonable duty of water applied to the farm is more amenable to characterization (such as three feet per acre, or 70 acres per cfs) than is the conveyance efficiency to the farm which varies by distance and type. The uncertain rule of thumb adjustments are incapable of describing the specific IWR in the variety of specific cases of farm operations entitled to a decree.

What if the Wrong Amount is Decreed?

The priority system of administering water has many virtues, one of which is in mitigating the impact of any errors in decreeing IWR. For example, how would a policy of minimizing (or maximizing) decreed rights play out in basin depletion? Is there any merit in minimizing the amount of right for conserving the resource? Elwood Mead[7 above] says *"…if water is applied sparingly it will cover a larger area…a higher duty of water …will, therefore, add to the value of the water supply*" (he uses 'duty' in the inverse of today's sense). But covering a larger area implies increased depletions in the basin. An aspect of water-short basins under a priority system of rights leads to the, perhaps counter-intuitive, result that constraining individual rights does not save water. Due to the prevailing water shortage, any water left unused by senior rights is taken and used by juniors to the limit of supply-whether decreed rights are minimal or expansive.

Figure 3 illustrates the pattern. A listing of priority dates and amounts (PDR and CIR) from a partial final decree on a tributary of the Rio Grande is charted to display the ladder of priority service of the water supply. Overlain is the divertible supply history for gaged flow to serve the water rights. In water-short streams, rarely is supply sufficient for decreed rights. The administrative goal in New Mexico is to minimize the amount of decreed rights in the spirit of conserving water from exercise thus aiding the Rio Grande Compact. Figure 3 shows that reducing the total rights by 20 percent (by, for example, decreeing a 4 foot PDR instead of the full 5 feet historical use) saves no water, but instead redistributes the supply in shortage years to junior users from the seniors. The increased depletion from junior users on top of the continued depletion by seniors acts to reduce basin outflow.

Figure 3



Somewhat contrary to first glance, decreeing a cap on water rights should not be expected to save water in a western basin managed under priority. Attempts to minimize IWR and reduce rights to save water may prove to be counterproductive by increasing depletion from an expanded number of users. The better procedure for determining a decreed amount would be based on a best-estimate of historical rates of exercise, such as is indicated by verified claims for canal capacity or well metering (for many years the simple wetted acreage was accepted as a valid measure of water use). A decree of CIR slanted to minimize decreed amounts of water use and the associated depletion might worsen deliveries for downstream and environmental obligations.

Role of CIR in Transfers

Transfers of decreed rights are one justification of putting CIR into a decree, "*subsequent changes in the purpose of use from irrigation to non-irrigation uses may result in increased depletions. In order to avoid impairment…the depletion or beneficial consumptive use rights must be adjudicated…CIR is the measure of the depletion or beneficial consumptive use right*".[12] However, transferred CIR derived as above must be further corrected for the water loss from regrowth of non-farm vegetation (annual, shrub, and trees) on the move-from acreage, but for the farm CIR. Panel member Richard Allen (and others[13]) found in 2002 that evaporation from abandoned agricultural fields in the Middle Rio Grande lost another 15 inches from bare soil above the shallow water table in the valley and that Bosque trees ranged up to five feet of passive water loss. Obviously, transferring a water right to a new use at agricultural rates can be completely canceled by regrowth of unmanaged vegetation on the abandoned field. A court decreed CIR for transfer might be highly unrealistic in terms of the impairment standard where balance is required for pre-transfer conditions. Thus a court-ordered fixed amount for transfer from all acres in a district could result in new hydrological depletion. The goal of a steady baseline of depletion after the transfer is not satisfied unless subsequent depletion due to regrowth (alongside return flow adjustments) is made on a case-by-case basis. It is not as easy as defaulting to transfer a court ordered CIR to maintain hydrologic balance. Evaluating such net effects of an application is the core administrative function. The court cannot provide a number that substitutes for it.

Conclusions on How IWR Should be Determined

The recent intense focus on PDR, FDR and CIR values in adjudication supports the view of late friend and water colleague Tim DeYoung, Esq. who posed the question "*Why do we need to adjudicate, at all?*" The early-stated purpose of rights adjudication was to learn what excess water was available for BOR-funded federal projects. The century-long delay in New Mexico adjudication suggests that the modern purposes do not rank high among the felt needs of current society.

1) A decree of water rights is understood to be a means of removing controversy and adding certainty to the distribution of available water supply.[14] It is based on *ex-post* data, but serves *ex-ante* purposes. A decree might aid allocation among senior and junior users, interstate obligations, and environmental waters, although there is no example of a decree being used that way in New Mexico.

2) Precise computation of CIR does not aid those objectives, but has other good effects on water accounting for planning purposes. CIR is a small part of the "amount" of IWR for use. There is

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[12] Sanders, D.L., 1996, New Mexico Motion for Order Adjudicating IWR. No. CIV 83-104 ISC.

[13] Allen, R.G. and others, 2007, Satellite-based Energy Balance for Mapping Evapotranspiration with Internalized Calibration (METRIC) – Applications: Journal of Irrigation and Drainage Engineering, ASCE.

[14] Scott, A. and Constalin, G., 1995, The Evolution of Water Rights: Natural Resource Journal Vol. 35 No. 4 pp. 821-979. Scott and Constalin give the purpose as "*social recognition, enforcement and protection*".

no solid hydrologic foundation for converting CIR to the amount of water used by individual farms. The product of a precise number and a rough one remains rough.

3) Diversion capacity is a sound indicator of IWR for the adjudication purpose.

4) Decreed amounts of water right need not be minimized to save water. A full right exercised by seniors consumes and depletes less water than shifting some diversion to otherwise unserved junior water operations.

5) CIR from farm operations is not appropriate for blind transfer to other places and purposes of use without administrative evaluation of the net effect of each case.

6) The prevailing methodology of quantifying CIR and converting to IWR is inadequate to the task, due to the order of magnitude variability of hydrologic conditions attached to each farm water operation. A default 70 acres per cfs at the farm, further adjusted for observed conveyance fractions might serve as well.

Perhaps we are making adjudication too hard. With a view to protecting rights in order of priority and to meeting downstream obligations, the amount of the right should not be a stumbling block. Certainly, the issue of amount of right to be decreed could be resolved more simply by reverting to a number more meaningful than CIR, that is, the historic use as verified in the capacity of the diversion facility whether canal or well.