SPDSS Memorandum
Final

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From: Ross Bethel and Erin Wilson

Subject: Task 61 – Effective Precipitation Estimates for Determining Crop Irrigation Water Requirements

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INTRODUCTION

SPDSS Task 61 was initially designed to investigate the Kimberly-Penman consumptive use methodology for potential application in SPDSS. Given changes in the acceptance of consumptive use methodologies since the SPDSS scope was prepared, the ASCE Standardized Penman-Monteith method, rather than the Kimberly-Penman method, was recommended for incorporation in CDSS and the originally scoped activities for Task 61 were no longer necessary. Resources that would have been spent on the investigation of Task 61 have been, with approval of the CDSS management team, redirected to an investigation of methodology and associated application for determination of effective precipitation.

The purpose of this memorandum is to convey results of these investigations and provide recommendations for effective precipitation determination in estimating the consumptive use of irrigation water in the SPDSS study area. This memorandum does not address effective precipitation on native vegetation, since that subject is to be addressed in a subsequent SPDSS task. This memorandum describes the approach taken in our investigations, the results of our investigations of effective precipitation methods and applications, and conclusions/recommendations drawn from the investigations.

The Results section of this memorandum is divided into four categories as follows:

1. **Factors Influencing Effective Precipitation.** Discussion of factors that are generally recognized as influencing the amount of precipitation which becomes effective for crop consumptive use.
2. **Methods of Effective Precipitation Estimation/Measurement.** Identification and description of methods of measuring or estimating effective precipitation for consumptive use determinations.
3. **Application Review.** Review of effective precipitation methods applied in Colorado.

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4. **Method Analyses.** Summary of analyses on the validity of methods to determine effective precipitation, with particular emphasis given to the TR21/SCS method.

DEFINITION

The term "effective precipitation" can take on differing definitions in various water resource fields or even within a field. For example, the following definitions of effective precipitation are often used in the respective fields:

- Groundwater Hydrologists – the portion of precipitation that contributes to an aquifer,
- Hydrologists – the portion of precipitation that results in runoff,
- Water Supply Engineers – the portion of precipitation that can be captured in their facilities for subsequent use, and
- Irrigation Engineers – the portion of precipitation usable in serving crop consumptive use, either on a field or project basis.

Effective precipitation in Colorado's Decision Support System (CDSS) has been defined from an irrigation engineering perspective (the portion of the precipitation usable for serving crop consumptive use). Effective precipitation in CDSS is also offered from a planning, rather than an operational (i.e. irrigation scheduling) perspective. The definition for effective precipitation stated in previous CDSS development efforts (see CDSS Rio Grande Basin documentation) is:

> *The amount of precipitation falling during the crop growing season that is available to meet the evapotranspiration requirements of the crop.*

The above definition is very similar to that contained in the Soil Conservation Service (SCS) Technical Release 21 (USDA, 1970) that describes the modified Blaney-Criddle method. This definition is also similar to the following definition of "effective rainfall" taken from Jensen (1990):

> *Effective rainfall is that part of the total rainfall, R_t, that satisfies evapotranspiration requirements. Precipitation lost by runoff from the soil surface and by drainage through the soil is not considered effective in reducing E_t requirements.*

CDSS generally uses the term "effective precipitation" instead of "effective rainfall" since precipitation other than rain can occur in the CDSS study area during the growing season.

Concerns have been raised (Dastane, 1978) whether definitions for effective precipitation such as used by CDSS are overly restrictive with respect to the time period (growing season) by excluding precipitation prior to the growing season, and excluding non-consumptive needs such as leaching or land preparation. The CDSS consumptive use tool, StateCU, has the capability to consider a portion of the non-growing season precipitation available to serve crop consumptive use and has the capability to assign use efficiencies that may include non-consumptive needs. Therefore, it is our opinion that the CDSS effective precipitation definition given above continues to be appropriate for CDSS applications that determine crop consumptive uses.

APPROACH

The following steps were taken in the investigations of methods for determining effective precipitation:

- Perform online document searches and review using the key words of "effective precipitation" and "effective rainfall" through the following online document search engines.
    - U.S. Geological Survey Publications at http://usgspubs.georef.org/dbtw-wpd/usgsnsa.htm
    - U.S. Bureau of Reclamation Publications at http://ibrlibrary2.usbr.gov/WebOPAC/index.asp
    - Water Resources Papers at Colorado State University at http://www.engr.colostate.edu/ce/grad/publications/water_hydrology.html
    - Colorado research libraries from http://prospector.coalliance.org/search/X
    - General search engines at www.Google.com and www.mamma.com.
- Interview representatives of consulting engineers who are familiar with the application of effective precipitation methods in the South Platte River Basin and other basins in Colorado to learn of the methods commonly applied and documents containing any generalized or regionalized estimates of effective precipitation in the SPDSS study area.
    - Leonard Rice Engineers – Greg Roush
    - W.W. Wheeler & Associates – Gary Thompson
    - Tetratech RMC – Mark McLean
    - Bishop-Brogden Associates – Mike Sayler
    - Helton & Williamsen – Jim Slattery
    - Spronk Water Engineers – Doug Clements
    - Grand River Consulting – Kerry Sundeen
    - Davis Engineering – Allen Davey
    - Agro Engineering – Kirk Thompson
    - University of Idaho – Rick Allen (via e-mail)
    - Northern Colorado Water Conservancy District Augmentation Planning – Jon Altenhofen
    - Ivan's Engineering – Ivan Walter
- Interview representatives of State agencies involved with application of effective precipitation methods in the Platte River Basin:
    - Colorado State Engineer's Office (SEO) – Dick Wolfe, Craig Lis, Ray Bennett
    - Colorado Water Conservation Board/CDSS – Ray Alvarado
- Perform comparisons of the results obtained from the TR21/SCS and Bureau of Reclamation methods to lysimeter results or soil water balance results.
- Prepare this memorandum summarizing findings from research and providing recommendations for consideration of effective precipitation in future SPDSS crop consumptive use activities.

RESULTS

1. Factors Influencing Effective Precipitation

The primary factors influencing the effectiveness of precipitation include precipitation characteristics, crop characteristics, soil water characteristics, and irrigation management factors.

Precipitation Characteristics

The four main characteristics of precipitation are the total amount, frequency, duration and intensity. These characteristics, which vary in time and by location, have a direct relationship to the amount of precipitation that can be stored in the soil moisture 'reservoir' or used by the crops. Generally, precipitation effectiveness increases with lower quantities, frequency, duration, and intensities of precipitation, allowing more precipitation to be absorbed by the soil or consumed. It decreases with greater quantities and intensities of precipitation because the soil moisture reservoir may fill, exceeding intake capacity of the soil, and generating surface runoff.

Crop Characteristics

Precipitation effectiveness increases with higher evapotranspiration rates. When the evapotranspiration rate is high, available moisture in the soil profile is depleted rapidly, thus providing storage capacity at a relatively rapid rate for receiving precipitation and reducing precipitation losses to runoff or deep percolation. Also, direct interception and use of the precipitation by the vegetation is greater. Other aspects of crops that influence the effectiveness of precipitation include the rooting depth of the crop, the stage of growth, and degree of ground cover of the crop.

Though the rate of crop consumptive use may affect the effectiveness of precipitation, the methodology of calculating effective precipitation should be considered independent of the methodology used for calculating crop consumptive use. For example, the method for determining effective precipitation that is proposed along with the modified Blaney-Criddle method in TR21/SCS is often applied to consumptive use results calculated with other consumptive use methodologies.

Soil Water Capacity Characteristics

The amount of precipitation that can be stored in the soil zone, and made available for crop use, varies with soil type and the soil water storage capacity at the time precipitation occurs. The total soil water storage capacity varies with the depth and soil type characteristics (texture, structure, density, salt and organic matter, etc) of the soil within the crop root zone. The amount of unfilled soil storage capacity at a given time is influenced by the frequency and amounts of prior precipitation and prior irrigation, and by the rate of crop evapotranspiration. Soil moisture capacities in three generalized soil types are shown in **Table 1** (IDS, 2004)

Table 1
Soil Moisture Capacities

Soil Type	Inches of Soil Moisture Capacity Per foot of Soil in Root Zone
Sand	1.0
Loam	1.5
Clay	2.0

Generally, precipitation effectiveness increases with increased soil water storage capacities and intake rates.

Irrigation Management Factors

Management practices that influence runoff, permeability, or evapotranspiration also influence effective precipitation. Management factors that influence precipitation effectiveness include the type of tillage, degree of leveling, timing of irrigations vs. soil moisture deficits, and use of soil conditioners.

2. Methods of Estimating Precipitation Effectiveness

Individuals engaged in estimating irrigation water requirements of a crop are confronted with the challenge of determining the portion of the total crop consumptive use that may be served by effective precipitation, and therefore, not required to be served by irrigation. The evaluation of effectiveness of precipitation can be made based on results from direct observation with lysimeters or other field instruments, empirical relationships, and soil water balance models.

Field Instruments/Studies

Lysimeters, soil probes, and other field instruments can be used to perform measured investigations of the effectiveness of precipitation in a given crop/soil/climate environment. While these measured investigations generally provide more accurate results than empirical methods, they can be cumbersome, labor intensive and site specific. The only example of field study of effective precipitation in Colorado found during our investigation is the Kruse/Haise investigation described below.

In 1969 and 1970, investigations (Kruse, 1974) were performed of the effectiveness of precipitation using lysimeters in the vicinity of Gunnison Colorado. In these investigations, two of the lysimeter tanks (containing pasture grass) were left uncovered through the irrigation seasons. Two other tanks were provided with roofs on tracks so that the tanks could be covered at the start of each storm and uncovered as soon as the storm ended. The effectiveness of the precipitation was calculated as the measured difference in irrigation water demand divided by the measured total precipitation at the lysimeter site. Figure 1 presents some of the graphical results presented by Kruse (Figure 19 in Kruse, 1974).

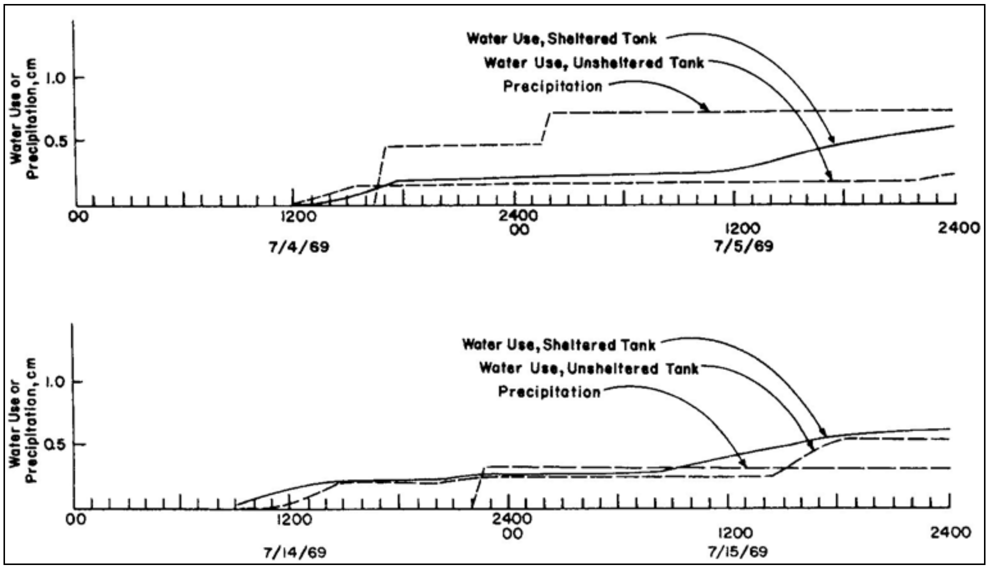

Figure 1 - Precipitation and Withdrawal Rates from Sheltered and Unsheltered Lysimeters

Kruse summarizes the precipitation effectiveness as 74 percent on a seasonal basis for 1969 and 80 percent for June-September of 1970 (April and May of 1970 were excluded due to data problems). He indicates in his summary section that the effectiveness of all rainfall received during the growing season was 75 percent.

Empirical Relationships

The descriptions below are of monthly and daily empirical methods implemented in models that calculate effective precipitation. This list is not exhaustive but based primarily on review of empirical methods used for effective precipitation calculations in Colorado.

Technical Release 21 (TR21/SCS)

A popular relationship used to estimate monthly effective precipitation is contained in the Technical Release 21 (USDA, 1970). In Technical Release 21, the effective precipitation is estimated according to the mean monthly rainfall, the monthly estimated evapotranspiration for the crop, and the net irrigation application. The following relationship was developed to estimate the effective precipitation.

$$\text{Effective Precipitation} = f \times (1.25 \times \text{Monthly Total Precipitation}^{0.824} - 2.93) \times (10^{(0.000955 \times \text{Crop ET})})$$

where f is the following function related to the net irrigation depth (D):

$$f = .53 + 0.0116 \times D - 8.94 \times 10^{-5} \times D^2 + 2.32 \times 10^{-7} \times D^3$$

It is noted that increasing the depth of application increases the estimated precipitation effectiveness. For example, moving from the commonly used 3 inch application depth to 4 inches increases the result of the effective precipitation calculation by 2 percent.

Effective precipitation, as determined by the TR21 method and as applied in SPDSS, is limited to the monthly consumptive use. The TR21/SCS method was developed based on "comprehensive analysis of 50 years of precipitation records at each of 22 Weather Bureau stations so selected that all climatic conditions throughout the 48 continental states were represented. These studies were made by using the daily soil moisture balance procedure…" (U.S.D.A. 1970). Through the development with a daily soil moisture balance procedure, the TR21 method implicitly accounts for both direct crop use of precipitation and storage and subsequent use from the soil zone. The TR21/SCS method does not explicitly account for geographical location, soil type or precipitation intensity or frequency since it is based on a composite of soil water balance calculations at 22 climate stations. However, we understand from consulting engineer Ivan Walter that his further research indicates that 8 of the 22 climates stations were in areas with arid climate. The TR21/SCS effective precipitation method is the only method detailed in Jensen (1990), commonly referred to as ASCE Manual 70.

In Technical Release 21, the following examples of effective precipitation are given to illustrate the concept that in arid areas of little growing season precipitation, the effectiveness of precipitation is relatively high and in humid areas with greater precipitation, the effectiveness of precipitation is lower:

> Effective Precipitation at Albuquerque, New Mexico (where growing season precipitation is about 8 inches) is about 92 percent.
>
> Effective Precipitation at Baton Rouge, Louisiana, (where growing season precipitation is about 39.4 inches) is about 64 percent.

Bureau of Reclamation Method

A monthly method to determine effective precipitation was suggested in the U. S. Department of Agriculture Technical Bulletin No. 1275 (Blaney,Criddle, 1962) and later suggested in the Bureau of Reclamation Manual. This method divides mean monthly precipitation into one inch increments and then calculates effective precipitation from the following percentages as indicated in **Table 2**.

Table 2
Bureau of Reclamation Effective Precipitation

Total Monthly Precipitation (inches)	Monthly Precipitation Considered Effective	
	Part of Each Inch Increment (percent)	Accumulated Total (inches)
1	95	0.95
2	90	1.85
3	82	2.67
4	65	3.32
5	45	3.77
6	25	4.02
Over 6	5	Varies

For example, if monthly precipitation is 2.5 inches, the effective precipitation for the month would be 2.26 inches (1.85 + (.82 x .5)) or 90 % of the monthly precipitation.

Dastane (1978) describes a variation (Stamm 1967) of the Bureau of Reclamation method that uses percent ranges for each precipitation increment and is based on monthly precipitation averages from the past five years. Dastane notes that the Bureau of Reclamation method does not take into account the type of soil, degree of aridity, nature of the crop, or frequency and distribution of rain. Dastane, in his review of effective precipitation methods, indicates the Bureau of Reclamation Method is not considered satisfactory.

We understand the Bureau of Reclamation method is used in the HI modeling for the Arkansas River Compact (historical analysis and compliance investigations). The Bureau of Reclamation previously used their method to estimate crop consumptive use in their five-year Colorado River Consumptive Uses and Losses reporting obligation. However, since the 1986 through 1990 report, they have adopted the TR21/SCS approach.

Maximum Effective Precipitation

Similar to the concept in the USBR method that larger amounts of precipitation lose effectiveness, a simplified daily approach considers all precipitation available for serving crop needs effective, if equal to or less than a user-specified precipitation (in inches per day). If the precipitation is greater than a user-specified maximum, then the effective precipitation is assumed equal to the user-specified maximum.

The Maximum Effective Precipitation method has been applied in the determination of return flows from irrigation of lawn grass with the “Cottonwood Curve” nomograph. Effective precipitation in this determination of lawn grass return flows is often limited to the first inch of precipitation that occurs during a precipitation event.

Percentage Effective Precipitation (Winter or Irrigation Season)

A second simplified daily or monthly method for determining effective precipitation is to multiply the precipitation by a user-specified percentage. A similar strategy on a seasonal basis is sometimes used to determine how much of the winter precipitation may be available at the start of the irrigation season. In StateCU, the winter precipitation available at the initiation of the irrigation season can be calculated as the minimum of the winter precipitation times a user-specified percentage or the available root zone soil moisture storage at the start of the irrigation season. For CDSS applications that determine crop consumptive use of irrigation water only (i.e. consumptive use due to man's influence), winter precipitation has not been considered.

SCS Curve Number Approach

The SCS Curve Number Approach was developed in the 1950s and 1960s by a USDA-SCS scientist for determining the amount of precipitation that becomes runoff in ungaged watersheds. While the result of this method is sometimes labeled as effective precipitation, this effective precipitation label is from the perspective of a drainage engineer and does not equate to the effective precipitation perspective used in irrigation applications. The equation was developed to predict how land use changes affect watershed runoff, usually in the context of problems caused by large precipitation events, but its use has been broadened to include general watershed modeling. While this approach should be used to directly calculate effective precipitation, as defined by irrigation engineers, it has been used to define the surface runoff component of ineffective precipitation from an irrigation engineering perspective. This method could be combined with soil water balance modeling to determine the effective precipitation from an irrigation engineering perspective.

The SCS Curve Number method is based on the potential of the soil to absorb moisture. Based on field observations, runoff from a field or farm was related to watershed storage capacity (S) which was in turn related to a soil curve number. The following primary equations are used in this method.

$$\text{Runoff} = (\text{Precipitation} - (0.2 * S))^2/(\text{Precipitation} + (0.8 * S))$$
$$(\text{If (Precipitation - 0.2 S) is negative Runoff} = 0)$$

where: S = watershed storage capacity=(1000/Curve Number) – 10 (inch basis)

Curve numbers are a function of soil type, land use, and antecedent moisture. Curve numbers are typically extracted from the National Engineering Handbook (USDA 1985) or other sources.

Daily Soil Water Balance Model

The implementation of a daily soil water balance model may provide an accurate estimate of effective precipitation. The model's accuracy depends on the availability of reliable daily climate data (temperature, solar radiation, wind movement, precipitation, and relative humidity) used to calculate evapotranspiration, accurate data on the soil moisture capacity, and the ability to accurately simulate irrigation practices. The soil water balance in equation form, similar to Patwardhan (1990), is shown below.

$$\Delta V = P + IR - (I + Q + ET + DP)$$

where:
- ΔV = change in soil water storage
- P = precipitation
- IR = irrigation amount
- I = interception loss
- Q = surface runoff
- ET = evapotranspiration
- DP = deep percolation

An equation form of the irrigation definition of effective precipitation (EP) in a daily soil water balance model would be the portion of total precipitation that does not contribute to surface runoff or deep percolation or

$$EP = P - (Q + DP)$$

The model typically includes a soil moisture reservoir from which evapotranspiration takes place. Water sources available to the reservoir include precipitation, after reduction for a portion becoming surface runoff, and irrigation applications. A determination of the portion of the precipitation that results in surface runoff is sometimes calculated through the SCS curve number method described above. Irrigation is typically implemented in a soil water balance model by the addition of irrigation water to the soil profile, whenever a user-specified level of soil deficit is reached.

3. Application Review

In a companion memorandum for Task 58, interviews were conducted with Colorado Division of Water Resources (DWR) representatives, consulting engineers, and other individuals about their use of methods to determine crop consumptive use. A number of these individuals, who routinely perform consumptive use determinations, have been contacted about methods they apply for effective precipitation determinations and other information they may have on methods for determining effective precipitation.

Colorado Division of Water Resources

As indicated in the Task 58 memorandum, consumptive use analysis performed at the DWR typically is performed on a monthly or annual time step using the modified Blaney-Criddle method. DWR representatives indicate that the only method they are aware that has been applied at the DWR for determining effective precipitation is the TR21/SCS method. The TR21/SCS method is the only method contained in the commonly used TR21 spreadsheet prepared by Keith Vander Horst of the Colorado State Engineers Office. In reviews of consultant determinations of consumptive use calculations and results, DWR representatives indicated the predominant method used for determinations of effective precipitation is the TR21/SCS method, with infrequent submittals to their office based on a soil water balance model (see discussion on Consultants below).

The TR21/SCS method has been the only method for the determination of effective precipitation employed in the development of historic consumptive use estimates and associated development of CDSS Basin models (Upper Colorado, White, Yampa, Gunnison, San Juan, and Rio Grande).

Consultants

The predominant effective precipitation method that is currently employed for use in crop consumptive use analyses in Colorado is the TR21/SCS method. The primary reason given by many of the consultants for the use of the TR21/SCS method relates to the general acceptance in the engineering community and by State water administrators. However, two consultants (Ivan Walter and Jim Slattery) expressed reservations in using the TR21/SCS effective precipitation method since that method may understate effective precipitation and, therefore, overstate irrigation water requirements. The issue of TR21/SCS overstating effective precipitation in calculations of crop consumptive use is explored in the following "Method Analyses" section.

One exception to the use of TR21/SCS Method, as briefly discussed in the Methods section, is the use of the Bureau of Reclamation method in water resource modeling (HI – Hydrologic Investigations Model) accepted by the Special Master of the Colorado/Kansas Compact litigation. This acceptance by the Special Master has caused Colorado also to adopt the Bureau of Reclamation method in their investigations of historic and future uses in the Arkansas River Basin. Since the Division Engineer's Office in the Arkansas River Basin relies heavily on this modeling in the evaluation of changes of water rights and augmentation plans submitted to their office, one engineer (Jim Slattery) has indicated that the Bureau of Reclamation method for determining effective precipitation may be used more by consultants performing studies in the Arkansas River Basin. However, we were unable to find consultants who currently apply the Bureau of Reclamation method in their crop consumptive use determinations for the Arkansas River Basin.

Other identified exceptions to the use of TR21/SCS method by consultants involve the application of a soil water balance model to determine effective precipitation. This method is typically applied as a companion to a daily crop consumptive use method (i.e. Penman-Monteith, Kimberly Penman, etc.). The use by Colorado based consultants stems from the development of a model, called SMB, by W.W. Wheeler and Associates. The SMB model is used by W.W. Wheeler and Associates and Ivan Walter, formerly with W.W. Wheeler and Associates. This model typically operates on a daily time step and subtracts surface runoff (calculated by the SCS Curve Number method) from total precipitation in obtaining an amount of precipitation available to the soil reservoir and subsequent crop use. Evaporation from the surface of the soil is often considered separately from the crop transpiration.

Rick Allen, from the University of Idaho Research and Extension Center, is a recognized expert on consumptive use methods and indicates that a daily soil water balance model, with soil evaporation estimated separately from the crop transpiration, is a better method of determining effective precipitation than the TR21/SCS method. Mr. Allen has applied this soil water balance method with multiple runs with varying impact from irrigation (irrigation the day of precipitation, the day after precipitation, two days after precipitation, etc.) to obtain estimates of crop consumptive use on a project basis.

Several consultants also indicated that they do not use the TR21/SCS method for effective precipitation when calculating lawn irrigation return flows or consumptive use of lawn grass using the "Cottonwood Curve" method. For this determination, only the first 1 inch of precipitation occurring during a storm is considered effective.

4. Method Analyses

Dastane (1978) has evaluated various means of estimating effective precipitation. Portions of his Table 9 that present factors taken into account for methods, whether special equipment is needed, the accuracy, relative costs and remarks have been extracted into **Table 3**.

Table 3
Relative Merits of Different Methods for Determining Effective Precipitation*

Methods	Factors Taken into Account				Special Equip	Accuracy	Relative Costs	Remarks
	Runoff	Soil	Aridity	Crop				
Field Studies of Soil Moisture	+	+	+	+	+	Very high	Medium	Good for Verifying other methods; cumbersome, practicability low
Daily Soil water balance	-	+	+	+	+	Very high	Medium	Practicability medium
Lysimeter	-	+	+	+	+	Very High	Very High	Practicability medium, good as a check on other methods
US Bureau of Reclamation	+	-	-	-	-	Low	Negligible	Not suitable for wide use
TR21/SCS Method	-	B	+	B	-	Medium	Low	Good for areas with low intensity of rainfall and high soil infiltration rate

* Extracted from Dastane (1978), Table 9. Some methods more applicable to non-Colorado areas have not been included in this table.
+=Positive, -=Negative, B=first approximation

Dastane concludes that the use of large lysimeters is the best and most reliable method to determine effective precipitation; however, it is expensive for field use. Dastane also indicates other field measurement techniques can also be accurate if a sufficient number of observations are made, but those techniques tend to be cumbersome and expensive. Due to the extensive cost and site-specific nature of the field methods, Dastane indicates these methods are inappropriate to implement for general and basin-wide applications, such as required by the SPDSS. However, results from field methods, such as the Kruse lysimeter studies, are useful for checking the accuracy of other methods.

Dastane ranks the daily soil water balance as having very high accuracy. As indicated earlier, this method's accuracy is dependant on the accuracy of the input data including climate data, irrigation operations, and soil data. Based on the reviews performed for this memorandum, the soil water balance method is often used to validate other methods, such as the TR21/SCS method.

Dastane also indicates the empirical method from TR21/SCS has been based on data representing a wide range of conditions and is satisfactory after verification in a given situation. He indicates that it provides good estimates in situations of low intensity of rainfall and high soil infiltration rates. He does not believe that the US Bureau of Reclamation Method is appropriate for use in calculating effective precipitation.

As indicated previously, interviews with several individuals involved in the determination of effective precipitation in the South Platte River Basin have questioned whether the TR21/SCS Methodology understates effective precipitation, thus resulting in an overstatement of the consumptive use of irrigation water. To investigate these claims, we have compared results obtained from the TR21/SCS method to other results and measurements.

Kruse Lysimeter Results vs. TR21/SCS and Bureau of Reclamation Methods

Temperature, precipitation, and growth stage coefficients for an original Blaney-Criddle formula (K_t=1) are available for 1969 and 1970 in the Kruse report (Kruse, 1974) for the Gunnison station used in the lysimeter investigations. Effective precipitation results were generated using the precipitation, temperature and measured evapotranspiration values contained in the Kruse report with a TR21/SCS method for comparison to the Kruse measurements. The results of this comparison are shown in **Table 4**.

Table 4
Comparison of Kruse, TR21/SCS, and Bureau of Reclamation Effectiveness of Precipitation

Period	Kruse Measured	TR21/SCS Calculated	Bureau of Rec. Calculated
May-August 1969	75%	74%	92%
May-September 1970	80%	73%	92%
Average Both Periods	77%	74%	92%

Comparison of the TR21/SCS calculated method to measured values from the Kruse report indicate that, during the period of measurements in 1969 and 1970, the TR21/SCS method appears to understate the effectiveness of precipitation by less than 5% on average. Kruse does note, however, that measured consumptive use in the sheltered tanks in 1969 is lower than expected (compared to unsheltered tanks), and if corrections are made for this condition, the precipitation effectiveness would increase in 1969. Our conclusion from this comparison is that the TR21/SCS method produces a reasonable determination of effective precipitation at this site for these two periods but, as shown in Table 3, may underestimate effective precipitation.

We have also calculated the effective precipitation at the Gunnison site with the Bureau of Reclamation method and this calculation resulted in 92 percent effective precipitation for 1969 and 92 percent effective precipitation for 1970. Comparison to the Kruse measured values (even if 1969 adjustments are made) indicates that the Bureau of Reclamation method overstates effective precipitation at this site.

Soil Water Balance vs. TR21/SCS and Bureau of Reclamation Methods

A review of several effective precipitation estimation methods was performed by Patwardhan (1990). In his investigation he compared the TR21/SCS method for estimating effective precipitation (and another nomograph method based on the same data as TR21/SCS method) to calculated results based on a soil water balance model applied to 50 years of data synthesized for each of the 22 locations used in the TR21/SCS development.

Water balance calculations were performed for two distinct soil conditions – one for highly permeable, well-drained soil with a SCS curve number of 42 (antecedent moisture condition I) and the other for low permeability, poorly drained soils with a SCS curve number of 90 (antecedent moisture condition I).

Patwardhan's results from the soil water balance model were found to be sensitive to the soil drainage conditions. Patwardhan presented results from the original calculation as well as the calculations that limit the effective precipitation to the monthly evapotranspiration, consistent with the TR21/SCS calculation. Data extracted from the Patwardhan summary table is shown in **Table 5**.

Table 5
Effective Precipitation for Different Soil Types

Soil Type	Seasonal Effective Precipitation (mm)		
	Soil Water Balance Model (Eff. Precip<ET)	TR21/SCS Method	Percent TR21/Soil Water Balance
Well drained soil (CN=42)	330	309	94%
Poorly drained soil (CN=90)	163	308	190%

The conclusions offered from the Patwardhan analyses were that the prediction of seasonal effective precipitation by the TR21/SCS method and the soil water balance model are in fairly good agreement for well drained soil conditions. However, the TR21/SCS method significantly over predicts effective precipitation for the case of poorly drained soils when compared to the soil water balance model. Patwardhan indicates this conclusion is in agreement with comments made by Dastane (1974). Patwardhan concludes the TR21/SCS method has limited usefulness for irrigation planning for specific locations because of the averaging of soil type, climatic condition, and soil water storage to estimate effective precipitation. We note that, based on the average comparison given in the above table for well drained soils, the TR21/SCS method understates the effective precipitation calculated by the soil water balance method by about 6 percent.

Along the lines of the Patwardhan analysis, we have calculated values for a more local SPDSS study area comparison of precipitation effectiveness calculated with TR21/SCS method and a soil water balance model. This analysis was based on climate data (from Northern Colorado Water Conservancy District) for the Sterling climate station and the seven year period of 1996 through 2002. The effectiveness of precipitation determined by the soil water balance was found to be dependant on the frequency and amounts of the irrigation applications. Generally, more frequent applications (that may occur, for example, if the irrigation is being conducted by a center pivot sprinkler system) maintain the soil moisture reservoir closer to capacity, therefore resulting in precipitation being less effective. The analysis was performed for four scenarios; 1) flood irrigation of an alfalfa field with a full irrigation supply, 2) flood irrigation of a corn field with a full irrigation supply, 3) center pivot sprinkler of a corn field with a full irrigation supply, and 4) center pivot sprinkler of a corn field with limited irrigation supply. The basic input assumptions are shown in **Table 6**.

Table 6
Soil Water Balance Assumptions

Scenario	Root Depth (feet)	Available Soil Capacity (inches/foot)	Available Soil Capacity (inches)	Maximum Allowable Deficit	Approx. Application Depth (inches)
1 – Flood Irrigation of Alfalfa, full supply	4	1.5	6.0	55%	3
2 – Flood Irrigation of Corn, full supply	3	1.5	4.5	60%	3
3 – Sprinkler Irrigation of Corn, full supply	3	1.5	4.5	25%	1
4 – Sprinkler Irrigation of Corn, limited irrigation	3	1.5	4.5	25% (partial refill)	1

For the first three scenarios, the soil water balance analysis was performed by filling the soil moisture reservoir with applied irrigation water when the soil water is depleted to the level of the maximum allowable deficit. For the fourth scenario, the irrigation applications were limited, leaving the soil moisture reservoir about two-thirds full after an irrigation. The TR21/SCS analysis was performed with the same precipitation data and crop evapotranspiration data used in the soil water balance analysis. The TR21/SCS analysis was conducted with and without limiting the effective precipitation to the monthly potential consumptive use. A comparison of the effective precipitation results from this analysis is shown in **Table 7**.

Table 7
TR21/SCS and Soil Water Balance Results

Scenario Using Sterling Climate Data	Effective Precipitation Percentages (average annual 1996-2002)		
	TR21/SCS		Soil Water Balance
	Limited to PCU	Not Limited to PCU	
Alfalfa - Flood Irrig.	81%	81%	85%
Corn – Flood Irrig.	69%	73%	79%
Corn - Sprinkler Irrig.	69%	73%	69%
Corn – limited supply	69%	73%	92%

As can be seen from the soil water balance entries for corn in the above table, the calculated effectiveness of precipitation, as determined by the soil water balance, can vary significantly with irrigation practice and crop type. By changing the average number of irrigations during a season from about five under flood irrigation to about 12 under sprinkler operation, the calculated effectiveness of precipitation using a soil water balance was reduced from about 79% to 69%. In the fourth scenario, representing water-short conditions, the TR21/SCS method appears to significantly understate the estimated effective precipitation from the soil water balance.

The effective precipitation was also calculated by the Bureau of Reclamation method for the Sterling Climate stations. Since only dependant on precipitation intensity, this method results in an 85 percent effective precipitation for the Sterling climate station. This is within the range of effective precipitation estimated by the soil water balance and presented in Table 7.

CONCLUSIONS/RECOMMENDATIONS

The CDSS efforts are designed for basin-wide or regional planning-based assessments of water use on a basin scale. A survey of irrigation management in Colorado (Frasier, 1999) indicates that in the South Platte region, most interviewed irrigators use crop appearance to determine when to apply irrigation water, not soil moisture deficit. Other irrigators interviewed indicated the use of a fixed number of days between irrigation applications rather than a soil moisture threshold when scheduling irrigation applications. Based on this information, it would be difficult and potentially inaccurate, to apply the typical soil moisture deficit trigger used in soil water balance models throughout the SPDSS study area. Further, the detailed information necessary for proper application of a soil water balance model is not generally known for farm or project-specific irrigation practices throughout the entire SPDSS study area.

From the investigations performed for this memorandum and based on our general knowledge of irrigation practices and supplies in the SPDSS study area, we believe that application of the TR21 method for the SPDSS regional analyses would produce reasonable estimates of effective precipitation. Given the general acceptance of the TR21 effective precipitation method in the water community, the application of the TR21 method in previous CDSS basin investigations, and the reasonableness of the TR21 effective precipitation estimates, it is our recommendation that the TR21/SCS method be applied in the SPDSS analyses.

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