Appendix I

Effective Precipitation Comparison Memo

Memorandum

To: Jim Prairie
From: Brenna Mefford and Erin Wilson
Date: Updated 11/19/2021
Re: Effective Precipitation Methods

During the June 22, 2020 Kickoff meeting, Wilson Water Group (WWG) agreed to develop a comparison of different effective precipitation methods. There are six main effective precipitation methods that were discussed as possibilities for the Upper Colorado River Basin (UCRB) Consumptive Use Comparison Project.

1. Monthly NRCS method outlined in Technical Release 21 (SCS Method)
2. Monthly Reclamation method in which effective precipitation is linearly related to the monthly precipitation
3. Daily method that sets a user-specified maximum effective precipitation in inches per day (can be a different maximum by region)
4. Daily method that sets a user-specified percentage of total daily precipitation (for example, 80 percent of all precipitation is effective)
5. Daily SCS NEH4 method that estimated direct runoff from daily rainfall, and applies the remaining rainfall as effective to meet crop demands
6. On-farm soil balance to determine how much of the precipitation can be stored in the crop root zone

To date, the monthly SCS Method (No. 1) has been used for the project to determine effective precipitation. The Consumptive Use (CU) Working Group has discussed the six options in past meetings, but a final decision has not been made on the appropriate method to use in the future. This memo describes the six methods, discusses pros and cons, and the provides results of calculating effective precipitation using five of the six methods for a farm growing grass hay near Delta, Colorado.

Descriptions of Each Method

The following provides a short description of each of the six effective precipitation methods.

1. **Monthly NRCS method outlined in Technical Release 21 (SCS Method)**
   Monthly Effective Precipitation (R_e) is dependent on the net depth of application (D), total monthly precipitation (R_t) and average monthly consumptive use (cu)

$$R_e = (0.7091*R_t^{\,0.82416} - 0.11556) * (10^{(0.02426*cu)}) * F$$
$$F = 0.531747 + 0.295164D - 0.057697D^2 + 0.003804D^3$$

2. **Monthly Reclamation method in which effective precipitation is linearly related to the monthly precipitation**
   Monthly Effective Precipitation (R_e) is linearly related to the monthly precipitation (R_t). Different linear relationships are used for different ranges of precipitation.

$R_e = 0.95 * R_t$	$R_t < 1.0$ inch
$R_e = 0.90 * (R_t – 1.0) + 0.95$	$1.0 < R_t < 2.0$ inches
$R_e = 0.82 * (R_t – 2.0) + 1.85$	$2.0 < R_t < 3.0$ inches
$R_e = 0.65 * (R_t – 3.0) + 2.67$	$3.0 < R_t < 4.0$ inches
$R_e = 0.45 * (R_t – 4.0) + 3.32$	$4.0 < R_t < 5.0$ inches
$R_e = 0.25 * (R_t – 5.0) + 3.88$	$5.0 < R_t < 6.0$ inches
$R_e = 0.05 * (R_t – 6.0) + 4.02$	$R_t > 6.0$ inches

3. **Daily method that sets a user-specified maximum effective precipitation in inches per day (can be a different maximum by region)**
   Effective Precipitation (R_e) is equal to the total daily precipitation (R_t) if R_t is less than or equal to the set maximum effective rainfall (R_M).

$Re = R_t$	$R_t <= R_m$
$Re = R_m$	$R_t > R_m$

4. **Daily method that sets a user-specified percentage of total daily precipitation**
   Effective Precipitation (R_e) is a fixed percentage (F) of total rainfall (R_t). Typically, F is assumed to be 0.8.

   $R_e = R_t * F$

5. **Daily NEH4 method that estimates direct runoff from daily rainfall, and applies the remaining rainfall to meet crop demands**
   Effective Precipitation (R_e) is calculated using the total precipitation (P), runoff (R_o), curve number (CN), and the potential maximum retention (S). The curve number is based on soil type and land use.

$$R_o = \frac{(P - (0.2S))^2}{(P + (0.8S)}$$

$$S = \frac{1000}{CN} - 10$$

$$R_e = P - R_o$$

6. **On-farm soil balance considering diversions and soil moisture to determine effective precipitation**

   Methodology performs a daily mass-balance of storage in the soil "reservoir".

   Change in Soil Storage = Inflows – Outflows

   Inflows = Irrigation supply, precipitation supply

   Outflows = Crop ET, deep percolation, surface runoff

   Precipitation is effective if there is "room" to store in the soil zone

Advantages and Disadvantages of each Method

The pros and cons of each method are compared in Table 1.

Table 1. Pros and Cons of each of the effective Precipitation Methods

Method	Pros	Cons
Monthly NRCS method outlined in Technical Release 21 (Monthly SCS Method)	• Applicable in every state • Used by some states and by Reclamation for the Upper Colorado Consumptive Uses and Losses Report	• Developed on a monthly time step • Assumes "well-watered" fields, therefore may over-estimate irrigation events that do not fill the soil root zone • Does not account for soil type, irrigation method, or rainfall intensity or frequency, or water stored in the soil root zone
Monthly Reclamation method	• Applicable in every state • Used for specific reporting in every state (for example, used for Arkansas River Basin Compact reporting in Colorado and for Rio Grande Project analyses in New Mexico	• Does not account for soil type, irrigation method, crop type, or rainfall intensity or frequency • Not recommended by FAO-25 • Does not account for irrigation events that could fill the soil root zone or water stored in the soil root zone.
User-specified Maximum Daily	• Applicable in every state	• Does not account for soil type, irrigation method, crop type, or rainfall intensity or frequency • Would need to develop maximum effective rainfall values for basin-wide or for specific regions • Does not account for irrigation events that could fill the soil root zone or water stored in the soil root zone

Method	Pros	Cons
User-specified Percent of Daily	• Applicable in every state	• Does not account for soil type, irrigation method, crop type, or rainfall intensity or frequency • Would need to develop a fixed percentage basin-wide or for specific regions • Does not account for irrigation events that could fill the soil root zone or water stored in the soil root zone
Daily NEH4 method	• Applicable in every state • Accounts for soil type and runoff	• Does not account for irrigation events that could fill the soil root zone or water stored in the soil root zone (may not be represented by Curve Number) • Requires determination of Curve Numbers basin-wide or for specific regions • Could use monthly Curve Numbers to help reflect typical irrigation supply throughout the irrigation season
On-farm soil balance to determine how much of the precipitation can be stored in the crop root zone	• Most accurate for determining effective precipitation • Accounts for irrigation events • Allows crops to use precipitation/irrigation stored in the root zone from previous irrigation/precipitation events.	• Only applicable where accurate irrigation supply records are available • Requires the most processing work, as is typically determined at the ditch or field level • May require daily calculation time steps

Results Comparison of each Method

Effective precipitation was estimated using five of the six methods using data from the ET Demands model for a field growing grass hay near Delta, CO. Daily methods were summed to monthly to allow for a comparison to the monthly methods. An on farm-soil balance was not done because it requires accurate diversion records, which are not available everywhere in the Upper Basin. Below is a list of assumptions used for each method:

- **User Specified Maximum Daily method**: a daily maximum of 2 inches of effective precipitation was used.
- **User-specified Percent of Daily method**: 80 percent of total daily precipitation was estimated as effective.

- **Daily NEH4 method**: the grass hay field was estimated to be in the C hydrologic soil group and was in good hydrologic condition.

Note that each of the effective precipitation methods investigated are capped at the potential ET for the associated time step (daily or monthly) due to none of the methods allowing for precipitation to be stored in the soil root zone.

Figure 2 shows monthly total rainfall and monthly effective precipitation for the grass hay field for 2010 to 2015 for the growing season months (i.e. winter months are not included in the graph). This period of record was selected as it has both low and high total precipitation years. Table 2 shows the percent of growing season precipitation estimated to be effective in each year for each of the methods.

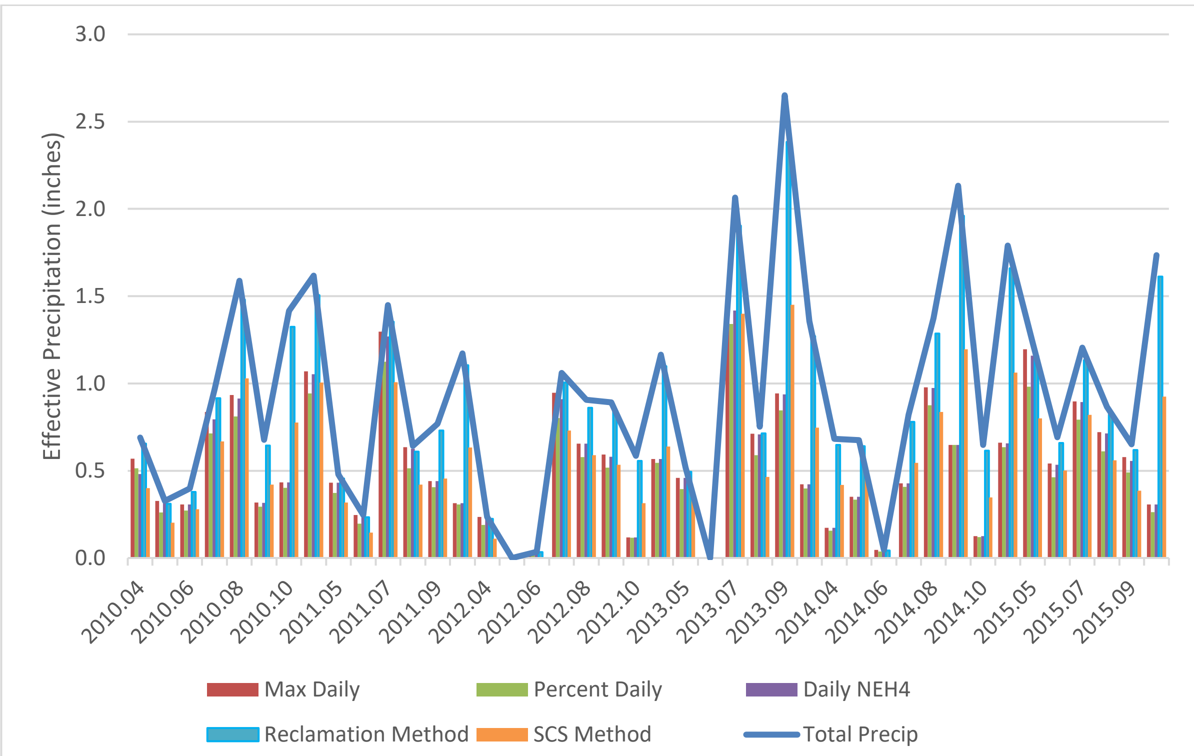

Figure 2. Monthly Effective Precipitation

Table 2. Percent of Growing Season Precipitation estimated to be effective for each year for all five methods

Year	SCS Method	Reclamation Method	Max Daily	Percent Daily	Daily NEH4
2010	62%	94%	61%	54%	78%
2011	63%	94%	70%	61%	86%
2012	61%	95%	70%	60%	83%
2013	59%	92%	54%	48%	79%

2014	60%	94%	43%	40%	74%
2015	62%	94%	60%	52%	79%

Figure 3 shows cumulative monthly total rainfall and cumulative monthly effective precipitation for the same field.

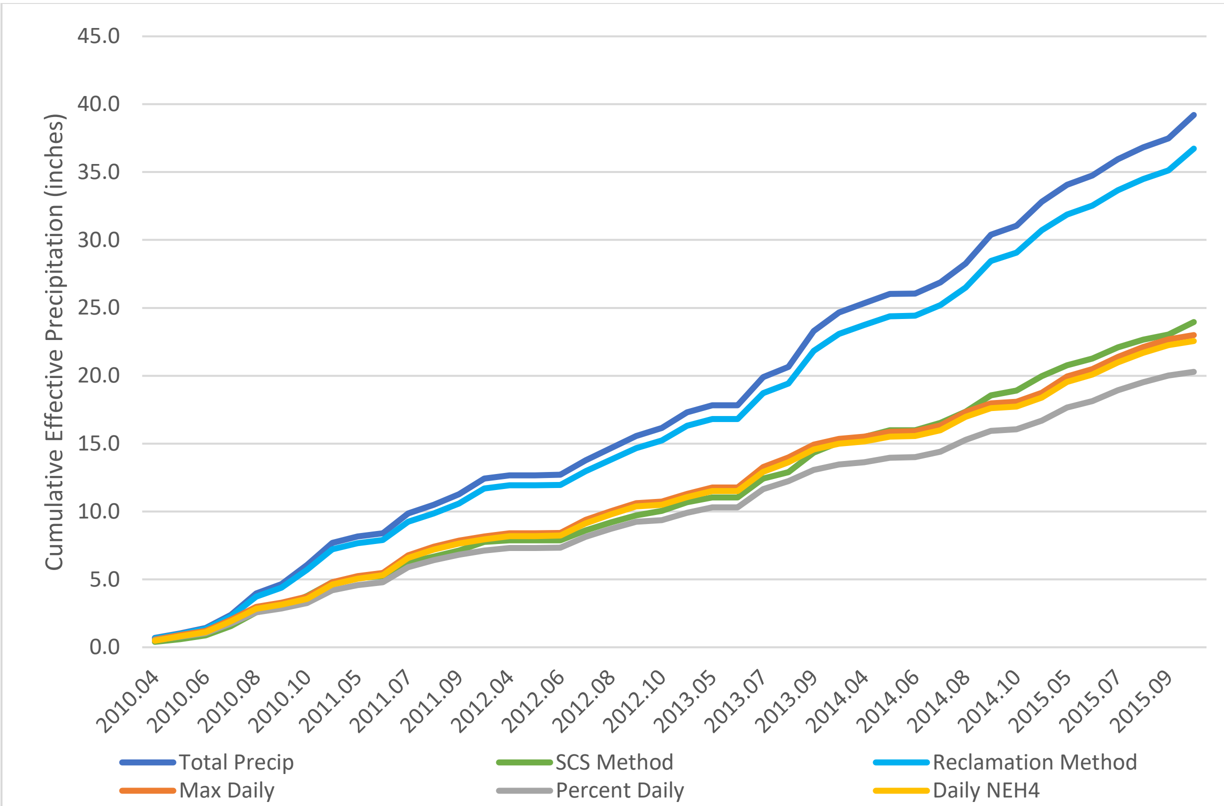

Figure 3. Cumulative Effective Precipitation

Figures 2 and 3 and Table 2 show that the Reclamation method tended to report substantially higher effective precipitation than the SCS method, and the daily effective precipitation methods. The monthly methods could overestimate for large precipitation events. The daily methods most commonly report lower monthly effective precipitation when the rain occurs in larger events, rather then when it occurs in smaller, more frequent events. For example, Figure 4 shows daily total precipitation for July 2014 and Figure 5 shows daily total precipitation for August of 2015. Note that July had less frequent but more intense (larger) events, while August had more frequent, but less intense (smaller) events. Both months had similar total monthly precipitation amounts. Table 3 shows the estimates of monthly effective precipitation for all the methods for July 2014 and August 2015.

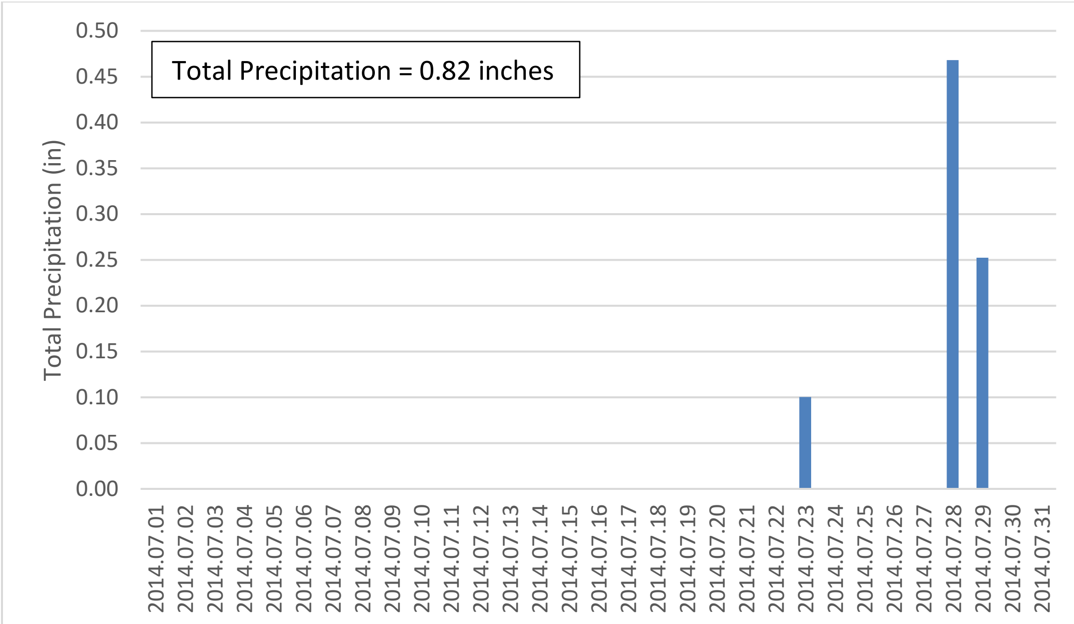

Figure 4. Daily total rainfall for July 2014

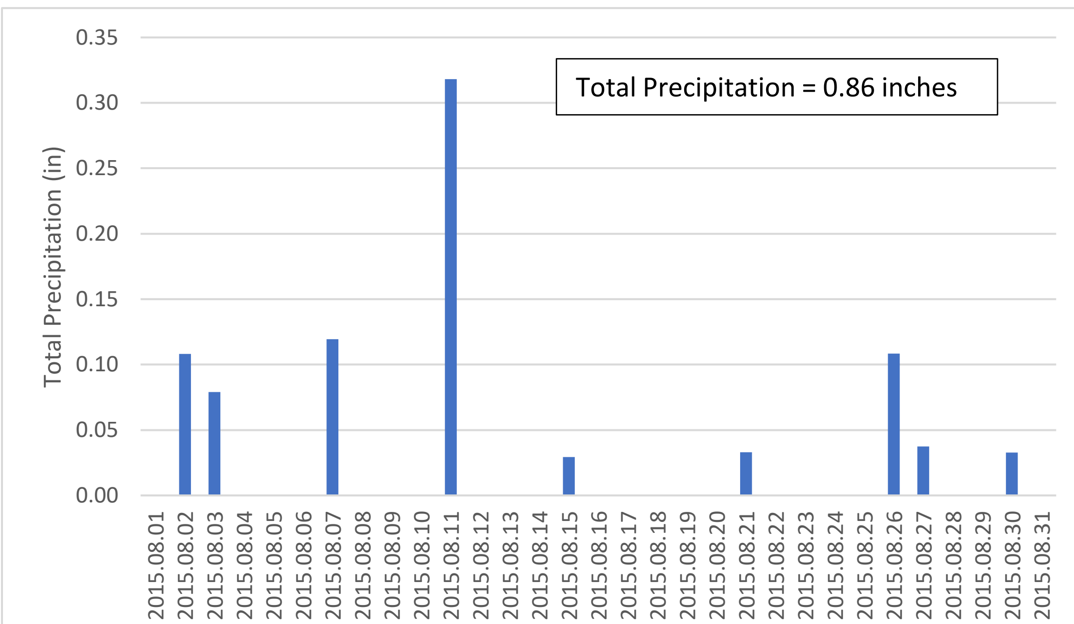

Figure 5. Daily total rainfall for August 2015

Table 3. Effective Precipitation (inches) for July 2014 and August 2015

	SCS Method	Reclamation Method	Max Daily	Percent Daily	NEH4 Daily
2014-07	0.54	0.78	0.43	0.41	0.43
2015-08	0.56	0.82	0.72	0.61	0.71

All five effective precipitation methods were estimated assuming that excess effective precipitation was not able to meet crop demands and could not be stored in the soil zone. This is consistent with how many models, including the XCONS model used by Reclamation for the Consumptive Uses and Losses Report, estimate effective precipitation. When the daily methods are simulated to store excess effective precipitation in the soil zone, the effective precipitation estimated by the daily methods increases and is closer to the monthly method estimates, as shown in Table 3. Note that this is inconsistent with how the methods were developed. The results in Table 4 were determined by simulating a soil water balance for the grass hay field. The simulation used an available water capacity of 0.1 inches per inch (based on soil characteristics in the area) and the standard root zone depth of 3.3 feet for grass hay. The field was assumed to be well watered and excess effective precipitation was stored in the root zone before excess irrigation supplies. This method provides another potential option for calculating effective precipitation for the CU Working Group to consider.

Table 4. July 2014 comparison of Effective Precipitation (inches), with and without allowing storage in the soil zone of excess effective precipitation.

<table>
<tr><th></th><th>Total Precipitation</th><th>SCS Method</th><th>Reclamation Method</th><th>Max Daily</th><th>Percent Daily</th><th>Daily NEH4</th></tr>
<tr><td>Effective Precipitation</td><td rowspan="2">0.821</td><td rowspan="2">0.54</td><td rowspan="2">0.78</td><td>0.43</td><td>0.41</td><td>0.43</td></tr>
<tr><td>Effective Precipitation – Allow excess daily Effective Precipitation to be stored in the soil zone</td><td>0.82</td><td>0.66</td><td>0.58</td></tr>
</table>

As another comparison WWG also considered the percent of precipitation that was effective in the 2017 and 2018 CU Comparison in each of the Upper Basin States. Table 5 shows the percent of total growing season precipitation estimated to be effective for agricultural fields in each state and year, calculated using the SCS method.

Table 5. Percent of Growing Season Precipitation estimated to be effective by the SCS method in the 2017 and 2018 CU Comparison.

State	2017	2018
Colorado	71%	70%
New Mexico	80%	79%
Utah	75%	71%
Wyoming	67%	68%

Effective precipitation was typically higher in 2018 as compared to 2017 in all states. 2018 was a dry to average year in all the states and had less total growing season precipitation than 2017.

Discussion

The CU Working Group has discussed effective precipitation multiple times during the Phase 3 project. The consensus seems to be that the Daily NEH4 would yield the most accurate results. The main drawback of the method is the need to make assumptions on soil type, hydrologic soil conditions and associated curve number for fields throughout the Upper Basin.

Using a modified NEH4 method that uses two different curve numbers to account for general irrigation supply availability is a possible option. The curve numbers could be developed regionally, and change based on water supply limitations, similar to the approach currently used for the consumptive use indicator gage method. This option would address specific concerns related to irrigation of Grass Hay meadows in the Upper Basin, where one cutting is typical and water is either no longer available in the mid to late summer, or is not applied so that cattle can graze the fields for the remaining of the growing season.

The CU Working Group also considered using the ET Demands model to determine effective precipitation. ET Demands calculates a soil water balance for each gridMET cell in the Upper Basin to estimate the amount of precipitation that effectively meets crop demands. The potential concern with using the ET Demands model to determine effective precipitation is that similar to other methods, the model assumes a full water supply and models frequent irrigation events. Most of the Upper Basin experiences water shortages every year, so this assumption is not accurate. Similar to discussion on the NEH4 method above, a similar approach could be used in which irrigation events are modeled by the ET Demands model until the indicator gage method indicates that shortages are occurring, in which case irrigation events would be shut off in the model.

If the CU Working Group wants to consider using the NEH4 Daily method, or the ET Demands model, WWG recommends performing a regional study to test one or both approaches. One of the approaches could be adopted for the project in future years depending on the results of the regional study. WWG used the monthly SCS method for the 2019 and 2020 analysis, as the CU Working Group did not provide different direction.