II.4-CONS_USE CONSUMPTIVE USE OPERATION

Introduction

Operation CONS_USE accounts for the impacts of surface water irrigation on streamflow.

This Operation was developed to provide an alternative to the current manual specification of diversion flows to adjust long and short-term streamflow forecasts. The model is a lumped model which assumes an equivalent crop over the irrigated area, limits diversions to the available water and maintains 'return flow'. Design of this Operation relied heavily on coordination with the Sacramento Soil Moisture Accounting (SAC-SMA) Operation in order to maintain the basin water balance.

Irrigation Overview

Irrigation exists where normal rainfall over agricultural lands is inadequate for satisfying crop requirements and water can be supplied from elsewhere. Crop water requirements can be equated to crop evapotranspiration (ET), since virtually all of the water used in plant growth (photosynthesis) leaves the plant into the atmosphere. ET depends on the type of crop, stage in the crop’s growing cycle and meteorological conditions (ASCE 1990). Water can be supplied from surface waters by various methods to meet crop moisture deficiencies. While water can be supplied from ground waters and across watersheds, this operation is limited to basins with self-contained surface water irrigation. In addition water rights and law can influence what water is available in a particular watershed; however this is not addressed in the model.

Consider a possible lumped description of surface water irrigation. The total volume of water required by the crops is the ET less any precipitation (infiltration) over the entire irrigated area. Water is diverted, but is limited by the natural flow in the river. Due to the inefficiencies in transporting water from the river to the crops, more volume is diverted than meets the crop requirements. The inefficiencies in diverting water to the crops include the addition to groundwater storage termed 'return flow' and other losses. A fraction of this diversion, 'return flow', returns to the river after some delay. Other losses refers to any diverted water not accounted for by crop demand or 'return flow' and would include deep aquifer recharge and evaporation during transport to the fields. This description of surface water irrigation is shown in Figure 1.

Evapotranspiration (ET) Estimation

Several methods exist for the empirical estimation of crop ET. These include temperature, pan evaporation, radiation and combination methods, referring to the data requirements of each method. All methods use empirical coefficients to compute crop ET which depends on the crops and climate of a region (ASCE 1990). Internally

Operation CONS_USE uses a temperature method for ET estimation, the SCS Blaney-Criddle method which has been used in the Western United States (see Chapter II.4-CONS_USE-ET). Since more accurate mean areal potential evapotranspiration time series may become available the option to input this time series is included.

Consumptive Use Model

An agricultural diversion model was designed which emulates the lumped description shown previously. The option exists in the model to input potential ET or utilize the internal SCS Blaney-Criddle ET estimation method. If potential ET is input it is multiplied by a daily empirical coefficient to obtain the actual crop ET as shown in Equation 1. Daily empirical coefficients are linearly interpolated from mid-month coefficients determined during calibration.

$$ET = k * PE \qquad (1)$$

where ET is the actual crop ET (L)
PE is the potential ET (L)
k is the empirical crop and meteorological coefficient

For the internal SCS Blaney Criddle option, ET is computed from mean daily temperature, daily percent of annual daylight hours and daily empirical coefficients (ASCE 1990). This calculation is shown in Equation 2:

$$ET = k * t * p / 100 \qquad (2)$$

where t is the mean daily temperature (T)
p is the daily percent of annual daytime hours

Temperature, latitude and Julian day must be input while mid-month empirical coefficients are determined during calibration. See Chapter II.4-CON_USE-ET for a description of the SCS Blaney Criddle method.

At this point there must be coordination between Operations. Since ET is specified in Operation CONS_USE for the growing season the ET specified in Operation SAC-SMA must be set to zero to maintain the water balance. This should be done with the irrigation area set up as its own sub-basin. This will keep the tension water contents from depleting (Burnash, 1996) and better reflect the soil characteristics of the irrigated area.

Another item of coordination involves precipitation input. While precipitation is shown in the previous irrigation diagram and could be used to satisfy crop ET, precipitation is already input for Operation
SAC-SMA. The choice was made to exclude precipitation from the CONS_USE operation. First this maintains the water balance with Operation SAC-SMA. Second precipitation is scarce over the irrigated area. Finally the percentage of irrigated area in relation to the entire watershed is typically small. Further evaluation of precipitation impacts needs to be made on basins where the percentage of irrigated area is large. Excluding precipitation, ET is

multiplied by the irrigation area to determine the crop demand. An equivalent crop is assumed over the entire irrigated area. Equation 3 illustrates this formulation:

$$CD = ET * A \qquad (3)$$

where CD is the crop demand (L3)
A is the irrigated area (L2)

The diversion is the crop demand divided by an irrigation efficiency as shown in Equation 4. Irrigation efficiency is another parameter which is determined in calibration. Since precipitation is not included in the computations for crop demand, this diversion will not match the observed diversion during periods of rainfall. However complete diversion information is most often unavailable.

$$DQ = CD / e \qquad (4)$$

where DQ is the net diversion (L3)
e is the irrigation efficiency

Irrigation contributes to additional groundwater supply called 'return flow'. To account for the delay in getting back to the river, 'return flow' is modeled as a single, well-mixed reservoir. Inflow is a percentage of the net diversion, while outflow is first-order decay of storage as shown in Equations 5, 6 and 7. The accumulation and decay rates are calibration parameters, while an initial 'return flow' storage would need to be specified at the beginning of a simulation.

$$d(RFstor)/dt = RFin - RFout \qquad (5)$$

$$RFin = DQ * c1 \qquad (6)$$

$$RFout = RFstor * c2 \qquad (7)$$

where RFstor is the return flow storage (L3)
RFin is the return flow in (L3)
Rfout is the return flow out (L3)
c1 is the return flow accumulation rate
c2 is the return flow decay rate (1/T)

Adjusted runoff is natural plus 'return flow' out less diversion flows as shown in Equation 8:

$$Q = NQ + RFout - DQ \qquad (8)$$

where Q is the adjusted flow (L3)
NQ is the natural flow (before diversions, L3)

For accounting purposes losses in transport to evaporation or to the subsurface aquifer can be computed as shown in Equation 9:

$$OL = DQ - CD - Rfin \qquad (9)$$

where OL is the other losses (transport, subsurface, L3)

There are constraints associated with the consumptive use calculations. First, a minimum flow requirement must be met before diversion requirements are fulfilled. If the minimum flow requirement can not be satisfied by the natural runoff and 'return flow' out, then there can be no diversion. The final constraint is that the 'return flow' accumulation rate must be less than The mathematical form of these constraints is shown in Equations 10, 11 and 12:

$$Q > Mflow \text{ if } (NQ+RFout) > Mflow \qquad (10)$$

$$Q = (NQ+RFout) \text{ if } (NQ+RFout) < Mflow \qquad (11)$$

$$c1 < 1 - e \qquad (12)$$

where Mflow is the minimum streamflow

Figure 2 is an illustration of all of the equations together on the previously shown irrigation diagram. Note that the differential equation for return flow storage has been converted to its finite difference explicit form with a daily time step.

Time Series Input and Output

Required input is natural flow; mean daily, mean areal temperature; daily mean areal precipitation; and possibly potential ET. Since natural flow is required as input to the consumptive use model the resulting Operation has to follow any Operations that compute the natural flow, including routing Operations. The primary output from Operation CONS_USE would be adjusted and diversion flow, while secondary output includes the 'return flow' in, 'return flow' out, other losses, crop demand and crop ET.

Parameter Estimation

Local information will need to be gathered to assist in the initial estimation of consumptive use model parameters. The irrigated area in your basin may be determined from U.S. Geological Survey (USGS) annual Water Resources Data publications for each state. These same periodicals can indicate if significant water is lost to major aquifers. State water bureaus can be contacted to find out the type of crops and methods of irrigation in a region. The ASCE reference listed at the end of this paper contains information on reference crop ET at several locations.

What follows is the initial CONS_USE parameter estimation for the Shelley Local (SHYI1X) calibration. General basin information is shown in table 1. Area and period of record information was obtained from the USGS 1996 Idaho Water Resources Data publication (Brennan 1996). The remaining information was obtained utilizing the NWS calibration assistance program which accesses GIS coverages containing elevation, normal annual precipitation and forest cover.

Table 2 contains irrigation area information supplied by the same

USGS publication mentioned previously (Brennan 1996). Contact with the U.S. Bureau of Reclamation in Boise, Idaho, indicated the type of crops and irrigation methods in this region. A specific study on the Snake River Aquifer created by the USGS with the Idaho Bureau of Reclamation indicates which watersheds contribute to the recharging of the aquifer (Norvitch 1969).

Now that information about the basin and its irrigation characteristics are known, initial parameter estimation can begin. First determine the irrigated area. Although Operation CONS_USE models only surface water irrigation and assumes no transfers between basins, a general rule can be followed which accounts for these impacts with the minimum error. The rule is to only include those areas irrigated from within the basin by surface waters. This would include areas outside the basin which are irrigated from within the basin. Areas irrigated with water from other basins or from groundwater would be excluded. Errors associated with this methodology would primarily affect the amount of 'return flow' or baseflow. The computation of the irrigated area for SHYI1X follows:

Irrigated Area = 501 - 123 - 8 + 61 = 431 MI2 = 1116 KM2

Once the irrigated area has been determined the areas of the sub-basins in Operation SAC-SMA must be determined. Due to water balance questions mentioned previously, the irrigated portion of the contributing basin should be modeled as its own sub-basin. These computations are shown as follows:

SAC-SMA Irrigated sub-basin = 501 - 123 - 8 = 370 MI2 = 75%
SAC-SMA Non-irrigated sub-basin = 491 - 370 = 121 MI2 = 25%

Notice that the total irrigated area is greater than the area of the contributing local basin. This is often the case due to the transfer of water across basins. The irrigated area outside the contributing local basin should not be modeled by Operation SAC-SMA in this Segment.

The next parameter to be determined is the latitude of the irrigated area. This is used in the daylight hour computations and should reflect the average latitude of the irrigated area, including that which is outside the local area. Local knowledge and thematic maps can be used to ascertain where agriculture occurs in a basin. The latitude of the SHYI1X irrigated area is 43.65, a positive number indicating North.

Irrigation efficiency is estimated primarily from the methods of irrigation used, but can be influenced by the local geology. In the Northwest, typical values of efficiency for gravity (canals) and sprinkler (piping) irrigation are 0.50 and 0.75, respectively (A.G.Crook Company 1993). Since there are extensive networks of canals in the SHYI1X area, an estimate of 0.50 for the efficiency would be appropriate. Due to considerable losses to the Snake River Aquifer, this estimate was reduced to an efficiency of 0.40 for SHYI1X.

For the minimum flow parameter, begin with an initial estimate of 1.0

cmsd. Due to regulation upstream of SHYI1X, this is not a particularly important parameter. In other areas, rivers may have minimum stream flows which they are required to meet and which could be input for Operation CONS_USE.

Computation of the initial estimates of the consumptive use coefficients can be made utilizing the average temperatures from the irrigated area MAT, the monthly percent of annual daytime hours and crop reference ET. The crop reference ET is dependent of crop type and location. For SHYI1X, the crop reference ET was for alfalfa at Kimberly, Idaho (ASCE 1990). The monthly percent of annual daytime hours for a range of latitudes is shown in a table in the same source. Table 3 illustrates these computations. For the months outside the growing season, the empirical coefficients should be set to zero. In Operation SAC-SMA for the irrigated sub-basin, the ET values should be set to zero during the growing season. This preserves the water balance and does not allow depletion of the tension water contents, more accurately reflecting the contents of the irrigated land.

The return flow accumulation rate is closely related to the irrigation efficiency. The maximum allowable rate equals '1 - efficiency'. It is dependent on the methods of irrigation and can be impacted by aquifer losses. For primarily gravity irrigation, the return flow accumulation rate vary between 0.25 and 0.50. The rates for sprinkler irrigation are 0.05 to 0.25. The SHYI1X estimate would be towards the lower end of the gravity range due to aquifer losses, 0.25.

The return flow decay rate is modeled similar to the lower zone contents in Operation SAC-SMA. The boundaries for this value would be LZSK and LZPK, probably closer to LZPK, 0.003.

Return flow initial storage is the only carry over value in Operation CONS_USE. The procedure for computing an initial value for October 1 is shown in table 4. Another way to do this is to simply run the model with any value for a number of years. In the later years of the simulation, typical values of the return flow storage will be shown.

Calibration Strategies

Since irrigation practices change with time, it is suggested that the calibration period of record be constrained to the last 10-15 years. It is recommended that the other models (SAC-SMA, SNOW-17, etc) be calibrated before adding Operation CONS_USE. The latitude and area parameters should not be adjusted. Instead modify the efficiency to increase/decrease diversions for all months. Modify the return flow accumulation rate to increase/decrease volume in the Fall and early Winter. Empirical coefficients for the beginning and ending months will probably need to be lowered since the reference ET is for the entire month instead of the partial month. The remaining empirical coefficients can be tweaked as necessary to obtain the optimum simulation.

Final Comments

Operation CONS_USE can provide for streamflow forecasts and performs well over the long-term, especially in water years with a limited supply of water. On a daily basis it may indicate trends but does not simulate as well. Since the SCS Blaney-Criddle estimation method was originally developed to be used on a monthly basis this is not entirely unexpected. It appears that the exclusion of precipitation from Operation CONS_USE did not adversely affect the test calibrations, including a basin with a large percentage of irrigated area. Finally the ability to modify the diversion flows on a daily basis is being considered.

References

A.G. Crook Company. Technical Appendix for Development of Modified Streamflows, 1928-1989, Columbia River & Coastal Basins. Prepared for Bonneville Power Administration. June, 1993.

American Society of Civil Engineers (ASCE). 'Evapotranspiration and Irrigation Water Requirements'. Manuals and Reports on Engineering Practice. ASCE. No. 70. New York, New York, 1990.

Brennan, T.S., Lehmann, A.K., O’Dell, I. and Tungate, A.M. Water Resources Data – Idaho, Water Year 1995, Volume 1. Great Basin and Snake River Basin Above King Hill. USGS, Idaho District. Boise, Idaho. May, 1996. pp. 121, 140, & 161.

Burnash, R. and Ferral, L. 'Conceptualization of the Sacramento Soil Moisture Accounting Model'. NWS River Forecast System User’s Manual. NWS. Section II.3. July, 1996.

Norvitch R.F., Thomas, C.A. and Madison, R.J. Water Information Bulletin No. 12: Artificial Recharge to the Snake Plain Aquifer in Idaho; an Evaluation of Potential and Effect. Prepared by United States Geological Survey in cooperation with Idaho Department of Reclamation. August, 1969.

Table 1. SHYI1X basin information

```
SHYI1X = SHYI1 - (HEII1R + REXI1R + RIRI1R)

         SHYI1X = Shelley Local Watershed
         SHYI1  = Snake River Near Shelley (9720 MI2)
         HEII1R = Snake River at Heisse (5752 MI2), Routed
         REXI1R = Henry's Fork Near Rexburg (2920 MI2), Routed
         RIRI1R = Willow Creek Near Ririe (627 MI2), Routed
```

Local Area = 9720 - (5752 + 2920 + 627) = 491 MI2

Elevation Range = 4599 - 6380 FT, 50% = 4819 FT

Normal Annual Precipitation (PRISM) = 12.31 IN

Forest Cover = 4%

Limiting Period of Record, RIRI1 (85-95)

Table 2. SHYI1X irrigation information

HEII1 - 104,000 acres irrigated

REXI1 - 205,000 acres irrigated
- 21,000 acres of the above by groundwater
- 5,000 acres additional below gage

RIRI1 - 7,300 acres irrigated

SHYI1 - 637,000 acres irrigated
- 100,000 acres of the above by groundwater
- 39,000 acres additional below gage

Computations - 637,000 - (104,000 + 205,000 + 7,300) = 320,700 acres
- 100,000 - (21,000) = 79,000 acres

SHYI1X - 320,700 acres irrigated (501 MI2)
- 79,000 acres of the above by groundwater (123 MI2)
- 5,000 acres of the above from above REXI1 (8 MI2)
- 39,000 acres additional below gage (61 MI2)
- most prevalent crop, alfalfa
- extensive network of canals to transport water to fields
- considerable leakage into the Snake River Aquifer

Table 3. SHYI1X empirical coefficient computations

(1) Month	(2) Average MAT (DEGF)	(3) Monthly percent daylight (HR)	(4) SCS Blaney Criddle Raw (k=1) (IN/month) (2)*(3)/100	(5) SCS Blaney Criddle Raw (k=1) (MM/day)	(6) Alfalfa ET Reference Kimberly, Idaho (MM/day)	(7) K Estimate (6)/(5)
Apr	42.80	9.05	3.87	3.28	4.2	1.28
May	52.10	10.25	5.34	4.38	6.1	1.39
Jun	59.60	10.39	6.19	5.24	7.5	1.43
Jul	66.80	10.49	7.01	5.74	7.9	1.38
Aug	64.90	9.71	6.30	5.16	6.9	1.34
Sep	55.90	8.41	4.70	3.98	5.2	1.31
Oct	45.10	7.64	3.45	2.83	3.2	1.13

Table 4. Initial return flow storage estimation for October 1

Determine seasonal reference crop ET, alfalfa:
    1060 MM (ASCE 1990)

Divide by efficiency to get seasonal diversion:
    1060/0.40 = 2650 MM

Multiply by return flow accumulation rate to get the seasonal accumulation of return flow storage:
    2650 * 0.25 = 662.5 MM

Allowing for continual decay of storage take 50% of the seasonal accumulation:
    estimate = 331 MM

Figure 1. Irrigation diagram

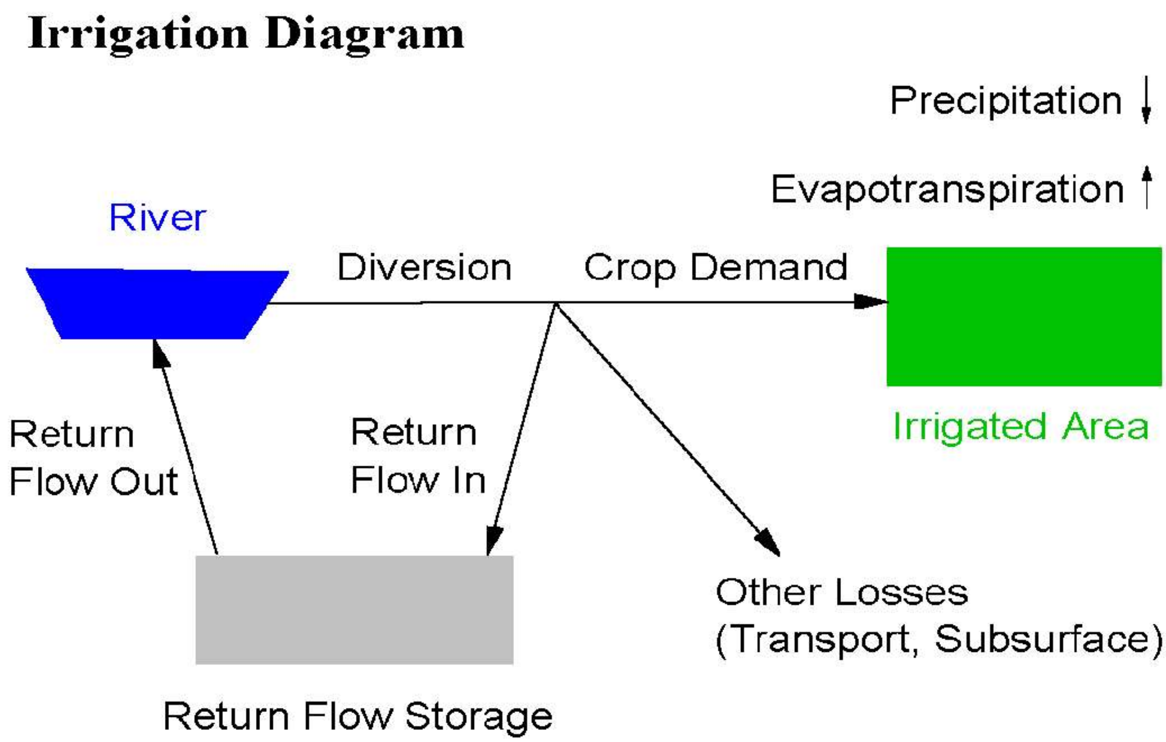

Figure 2. Irrigation diagram with equations