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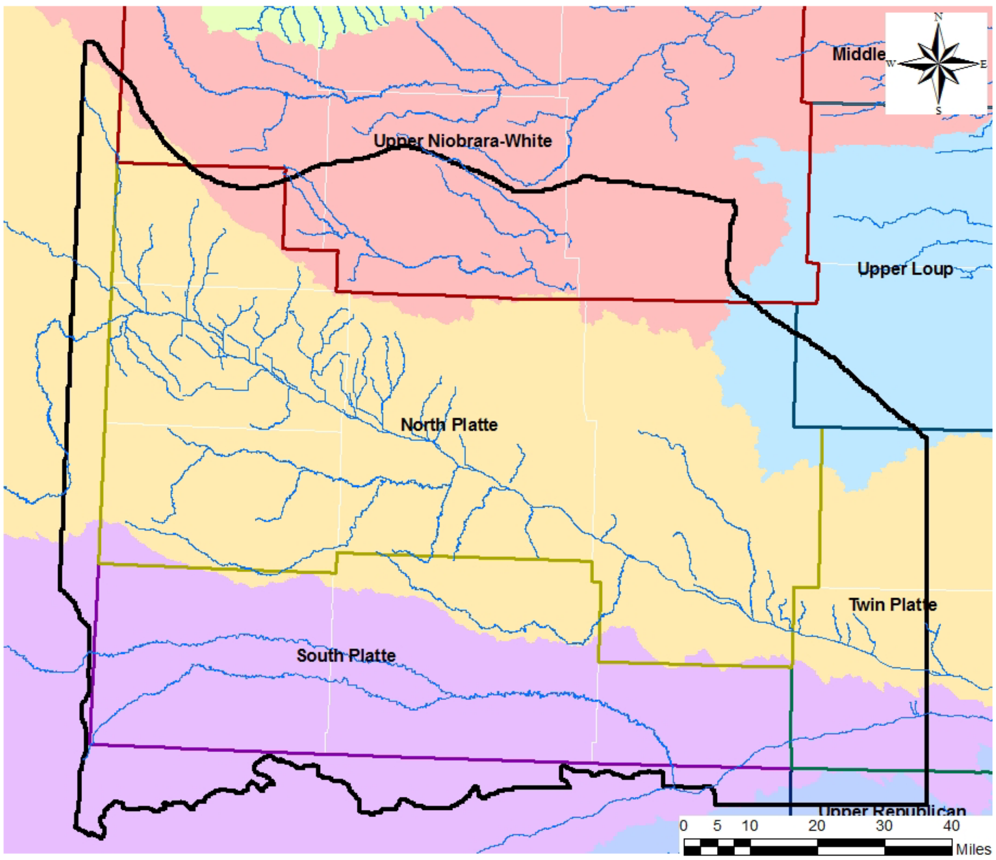
The Western Water Use Model: Regionalized Soil Water Balance Model



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1. Introduction

1.1. Authorization

The Flatwater Group, Inc. (TFG) has prepared this report as authorized in the contract between the North Platte Natural Resources District (NP-NRD) and TFG originally dated 26 January 2010.

1.2. Purpose and Scope

The NP-NRD, in conjunction with the South Platte NRD (SP-NRD) and the Nebraska Department of Natural Resources (DNR), is developing the Western Water Use Management (WWUM) Model Project (Project) for use in evaluating management actions aimed at achieving the goals of the districts' Integrated Management Plans (IMPs). The WWUM Model consists of a surface water operations model, a ground water flow model, and a regionalized soil water balance model. Through this Project, results from the three models are integrated to identify actions likely to achieve the goals identified in the IMPs.

This report focuses on the processes and application of the regionalized soil water balance (RSWB) model. The report discusses general methodologies and how this model was applied in various locations across the WWUM Model domain. Summaries of selected ground water pumping and recharge depths are also provided. In the Appendix, information is presented to allow a new user to setup and run the regionalized soil water balance model. In addition, a copy of the source code for the programs which constitute this model is included.

The primary role of the RSWB was to ensure that water supplies and water uses were accounted for within a balanced water budget. The water budget was represented by precipitation (P), applied irrigation water (AI), evapotranspiration (ET), deep percolation[1] (DP), runoff (RO), and changes in soil water moisture content (SWC).

1.3. Acknowledgements

A number of individuals from several different entities supported the development of the WWUM Model. The list below identifies a number of those individuals:

Project Manager – Thad Kuntz (Adaptive Resources, Inc., originally with the NP-NRD at the inception of the project)

Surface Water Model Development – Kara Sobieski (Wilson Water Group, LLC. (WWG), originally with Leonard Rice Engineers, Inc. at the inception of the project)

Ground Water Model Development – Richard Luckey (High Plains Hydrology, LLC (HPH))

[1] Deep percolation is defined as water which infiltrates beyond the bottom of the root zone.

Regionalized Soil Water Balance Model Development – Marc Groff, Isaac Mortensen, and Shane Dolph (The Flatwater Group, Inc)

Development of Land Use Coverages – Mark Mitisek and Shane Michael (Leonard Rice Engineers, Inc (LRE))

Development of Stream Baseflow Targets – Jesse Bradley (DNR)

Development of Water Level Targets – Thad Kuntz

While not a formal member of the WWUM Modeling team, the author would also like to recognize the efforts of Dr. Derrel Martin (University of Nebraska - Lincoln) for his guidance and assistance in developing the procedures described in this report. Dr. Martin developed the CropSim model which provides the results upon which the RSWB model relies (Martin, 1984).

In addition to the individuals listed above, support from the technical staffs at the NP-NRD, SP-NRD, and DNR were invaluable. Jeff Sprock (NP-NRD), Kyle Liebeg (originally with the SP-NRD at the inception of the project, now with Adaptive Resources, Inc), and Rick Vollertsen (DNR) all provided key information and/or provided assistance with data manipulation which contributed to the success of this project. Lastly, this project would not have been possible without the support of Ron Caeck (Manager of the NP-NRD) along with his board of directors, Rod Horn (Manager of the SP-NRD) along with his board of directors, and Brian Dunnigan (Director of DNR).

2. Study Area

Figure 1 shows the geographic extent of the study area which covers approximately 11,100 mi^2 across the southern two-thirds of the Nebraska Panhandle and extends minimally into Wyoming and Colorado. As reflected on the figure, precipitation from 1955 through 2010 has averaged from approximately 15 inches in the west to 18 inches in the eastern part of the study area. Detailed information for the WWUM Model study area can be found under separate cover in the Project's ground water flow model report (Luckey, 2013).

The Project focuses on the area in the Platte River Basin upstream of Lake McConaughy to the Wyoming state line in the NP-NRD as well as the Lodgepole Creek area in the SP-NRD. As of 2010, over 558,000 acres are irrigated for crop production in the NP- and SP- NRDs (LRE, 2012).

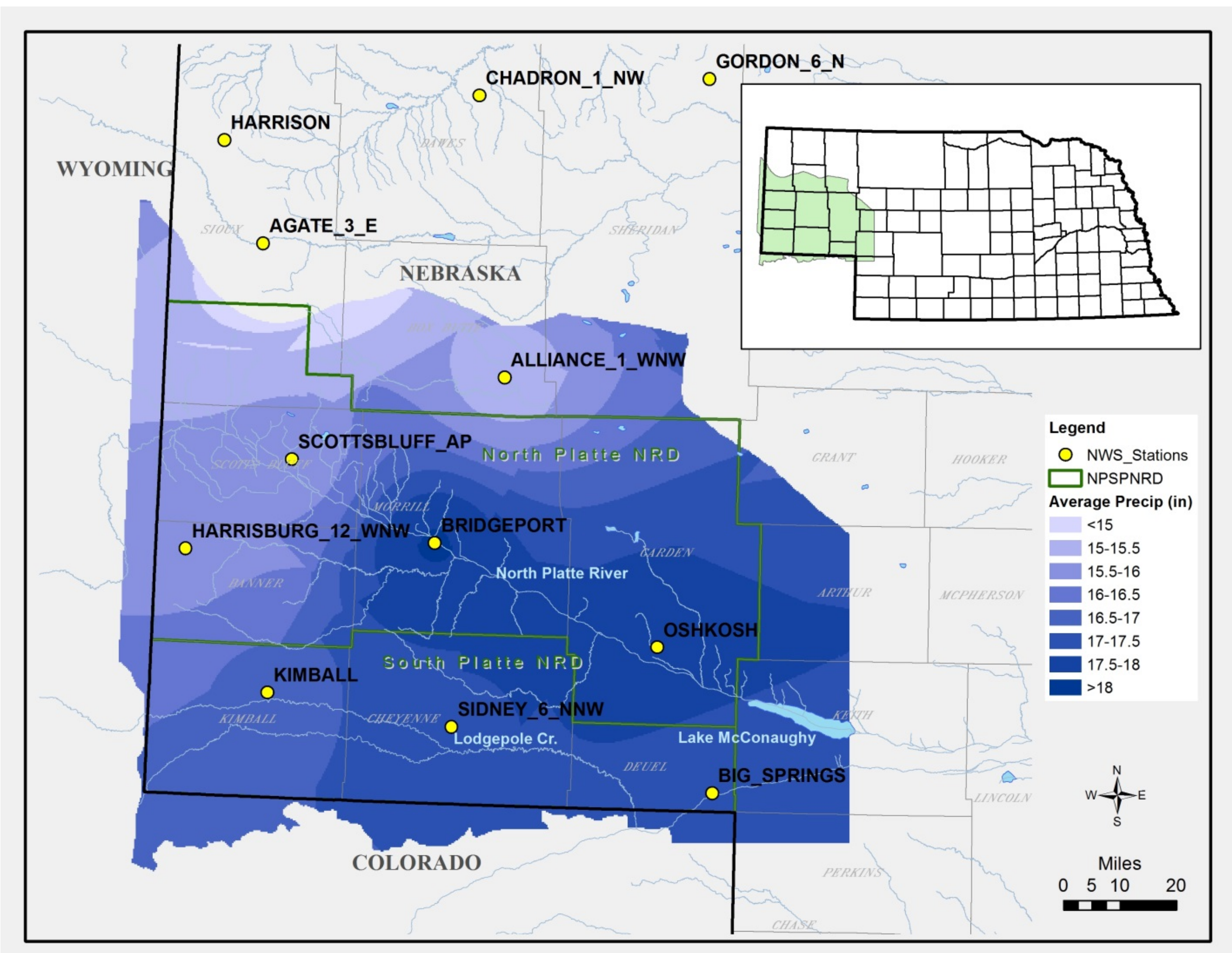

Figure 1. Study area showing annual average precipitation from 1955-2010.

3. Conceptual Model

The complete hydrologic cycle as modified by irrigation and other human activity serves as the conceptual model for this Project. Figure 2 is a schematic illustration of the hydrologic cycle for a system where use of water for irrigation is important. This figure provides visual context for discussion of how the system is modeled.

The intended use of the model drives what physical characteristics of the study area are important to properly represent. In the case of the RSWB model, information about the area's climate, soils, land use, and farming practices are important characteristics to address when attempting to estimate the amount of water needed to irrigate crops, to develop estimates of the amount of ground water recharge resulting from deep percolation, and to develop estimates of runoff contributions to total stream flow.

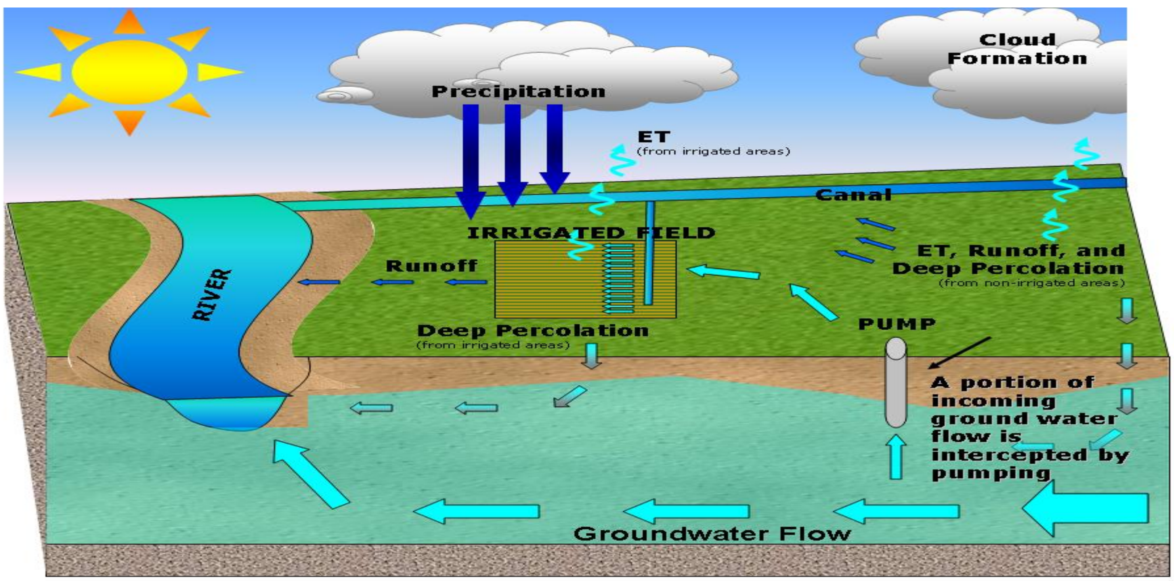

Figure 2. Illustration of hydrologic cycle in which irrigation is important.

Nebraska in general has a continental climate exhibiting large temperature variations season to season as well as year to year. Additionally, the semi-arid conditions of the study area provide high evaporative demands due to ample sunshine and hot, dry winds. In order to account for the highly variable climate in the study area, the RSWB model incorporated a reference crop based methodology. The reference crop (tall crop; alfalfa, in this case) was used to represent the evaporative demand of the climate, and in this process, provided a method to standardize crop water use to climatic conditions.

Soils in the study area include eolian sand forming the sandhills in the northeast part of the study area, shallow loamy soils located along topographically steep upland areas, and deep well drained loamy soils located along valley floors and more level upland areas. Land use is often directly tied to soil type in this area. Both the sandhills and steeper upland areas are well suited to be used as rangeland. The more gently sloping soils and the deeper loamy soils are well suited to crop production. To account for this variability, the RSWB model used an approach sensitive to key soil properties (e.g. water holding capacity, the hydrologic soil group) and made use of annually updated land use files which reflected the areas migration from being nearly all rangeland to currently a predominant combination of rangeland, dryland[2] farming, and irrigated crop production.

Just as land use has changed over the course of time in this area, so to have the related production practices. As technology has advanced, both the types of crops and the methods by which given crops are produced have evolved. Of particular importance to this study are the changes which have occurred related to irrigation. The use of ground water as compared to surface water as a source for irrigation has increased. The methods by which irrigation water is applied to crops has changed and become generally more efficient in terms of the amount of water applied compared to the amount of water consumed by crops. The methods employed by the RSWB model attempted to capture the major effects of these changes by trending CropSim results developed using different production practice inputs and additionally by trending irrigation application efficiencies over time.

[2] The term "dryland" refers to production under rain-fed only conditions. No irrigation water is applied to lands classified as dryland.

4. Model Construction

The RSWB model consists of seven programs that incorporate the distributed CropSim results and irrigation data; develop ancillary irrigation estimates; adjust water balance parameters; organize results into properly formatted groundwater model input files; and generate water balance summary reports. These programs are listed below along with a summary for each. Figure 3 shows the relationship between the programs and their primary outputs.

1. Irrigation application and demand (IAD)
2. Water Supply Partitioning Program (WSPP)
3. Make Well
4. Make Recharge
5. Compile Well
6. Compile Recharge
7. WSPP Report

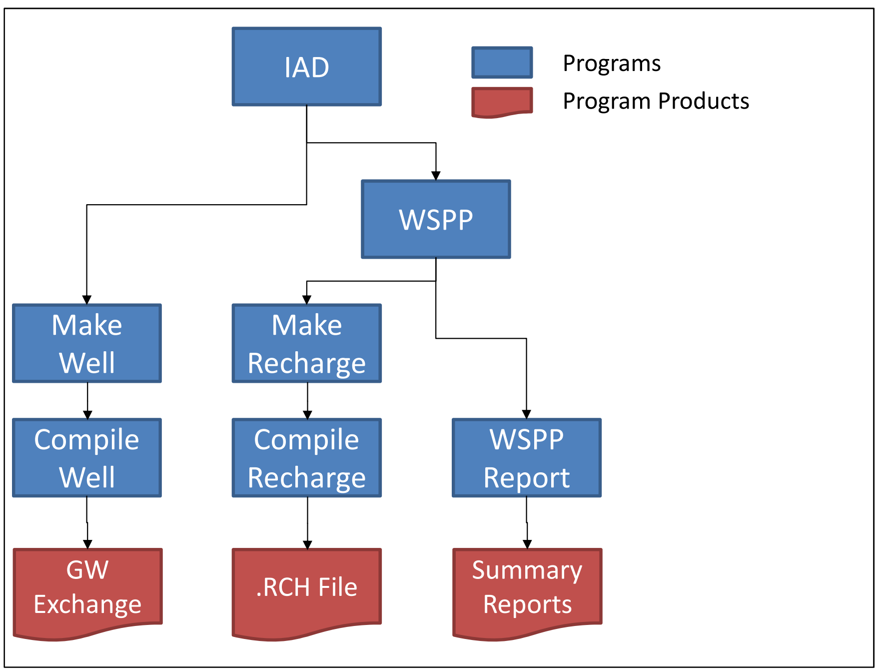

Figure 3. RSWB Model Programs

Output classified as "GW Exchange" was provided to LRE who combined this information with estimates of commingled pumping they developed. The LRE pumping information was provided to HPH for inclusion in the ground water flow model. The ".RCH File", which combines all sources of recharge, was provided directly to HPH for inclusion in the ground water flow model. Information from "Summary Reports" was used to build quality control spreadsheets for reviewing RSWB model output.

Generalized schematics showing major conceptual components are provided to assist a user interested in reviewing source code. The descriptions provide an overview of the inputs required for each program[3].

4.1. Irrigation Application and Demand (IAD)

The irrigation application and demand program uses parcel based (as opposed to model cell based) land use, either historically applied irrigation volumes or estimates of required irrigation volumes to meet crop water needs, the parcel net irrigation requirement (NIR)[4], and application efficiency (AE)[5] to determine the volume of irrigation water that is delivered to each cell as well as the depth of irrigation that is applied to each crop. The volume and depths of water that are applied are passed to the next set of programs summarized by cell and by certificate as illustrated in Figure 4.

[3] Refer to the Model Inputs section of this report for a more complete discussion of the input parameters and their development.
[4] Net Irrigation Requirement or NIR is the amount of water required for a crop to reach its full yield potential, that is, to achieve full ET.
[5] Application Efficiency or AE is the ratio NIR to the gross amount of water that is actually applied to the crop.

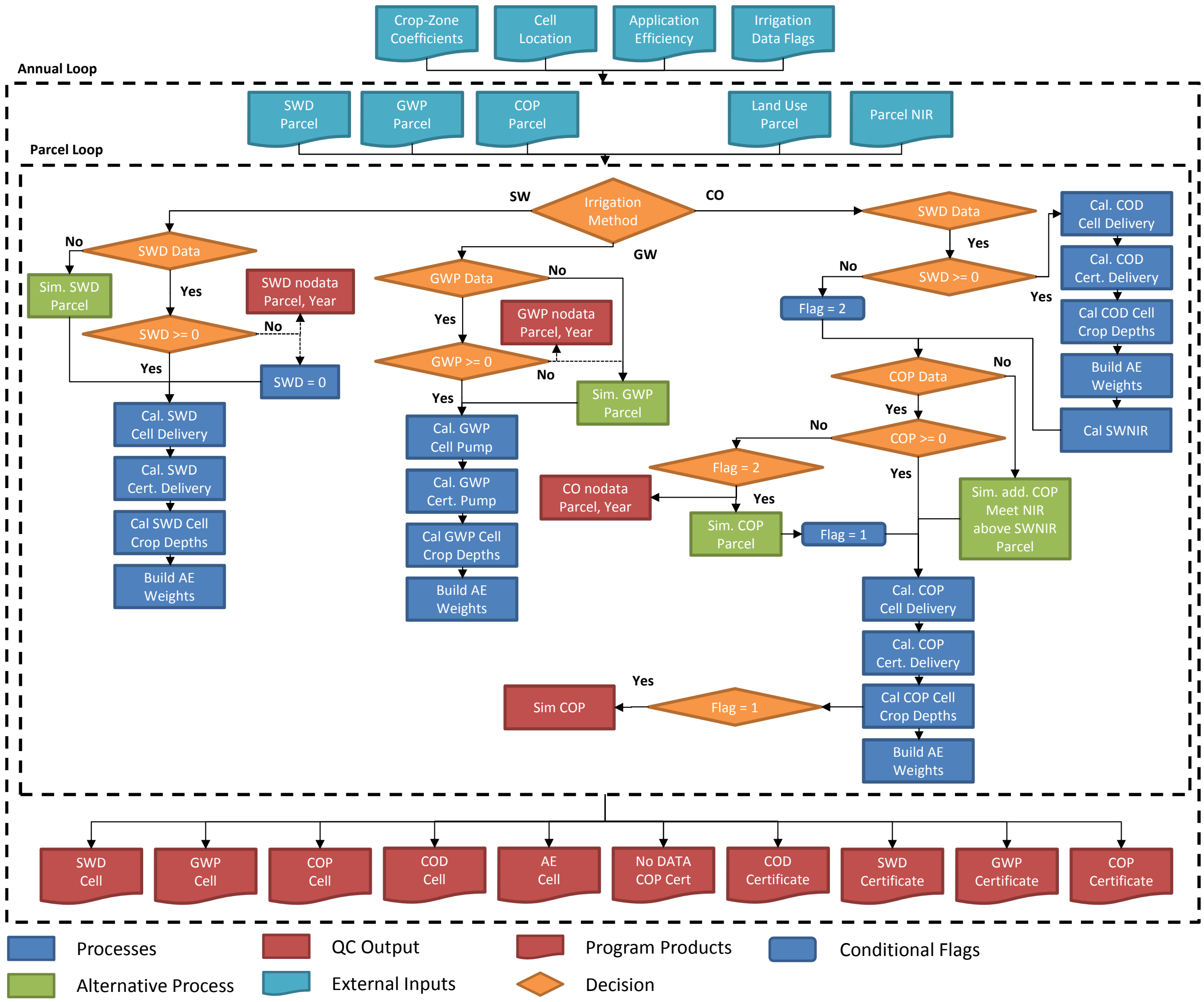

Figure 4. Flow chart depicting the inputs, outputs, and major functions of the IAD program.

The terms shown on Figure 4 are defined more fully on Table 4-1.

Table 4-1. Definition of Terms Shown on Figure 4

Term	Definition
Cell	Model grid unit
Parcel	Tract of land; Field
Cert / Certificate	Indicates a Certified Irrigated Tract defined as any tract of land in the NP- or SP- NRD, contiguous or not, owned by a person that is irrigated from a single source or from multiple sources that are interconnected by a common carrier and that have been certified by the NRD to allow for irrigation according to the process described in the NRD's rules and regulations
SWD	Surface water deliveries
GWP	Ground water pumping
COP	Co-mingled pumping
COD	Co-mingled deliveries
Cal.	Indicates routines to calculate a monthly distribution of applied irrigation water
Sim.	Indicates routines developed to simulate a supply of irrigation water
AE	Application Efficiency[6]
SWNIR	Net irrigation requirement met by surface water deliveries

The IAD program divided the volume of water applied to a parcel among the cells and crops that comprised that parcel. The methodology involved differs slightly by irrigation source. A portion of the applied water was determined outside of the IAD program from either historical records or previously developed estimates. However, this information was not always complete. To account for parcels classified as irrigated, but for which no record of water application was previously developed, the volume and depth of water applied to the parcel was estimated to meet an adjusted NIR (Equation 1). This depth was then converted to a volume by multiplying the per acre depth by the crop coverage acreage (Equation 2).

$$IWD_{crop,irr} = NIR * \frac{ADJ_{NIR}}{AE_{irr}} \qquad (1)$$

$IWD_{crop,irr}$	the depth of irrigation water applied to the crop
NIR	net irrigation requirement
ADJ_{NIR}	NIR adjustment factor
AE_{irr}	application efficiency

[6] Refer to page 32 for discussion regarding how AE is considered in the RSWB model.

$$IWD_{cell} = \sum IWD_{crop} * Acs_{crop,irr} \quad (2)$$

IWD_{cell}	the volume of irrigation water that is applied to the cell
$Acs_{crop,irr}$	number of acres being grown of the crop with the irrigation source

The composite AE assigned to a particular cell was also determined during this step. AE is dependent on the irrigation application method used. A cell may be overlain by multiple parcels that use varying application methods. Therefore, the composite AE for each cell was determined by proportioning overlying parcel AEs by the total volume of water applied to each cell from each overlying parcel.

To determine surface water deliveries to lands irrigated only with surface water, information provided by to TFG by LRE was queried to create a flag file[7] which indicated the availability of either historical or externally estimated surface water data for a given area/year combination. If the flag file indicated that surface water delivery data was not previously developed for specific areas (e.g. the NP-NRD), surface water irrigation was estimated using the method described in Equations 1-2 for all parcels in that area in that year. If the flag file indicated that surface water delivery data was previously developed for a given area/year combination, any parcel within that defined area for which an explicit surface water delivery volume was not specified was assumed to have a surface water delivery volume of zero. A record of these types of parcels was maintained in the SWD no-data file. Summaries of the delivered volumes were then made at both the cell and certificate level.

Similar to the approach taken for surface water irrigation, to determine ground water pumping on lands irrigated only with ground water, information from the Irrigation Flag file was queried to determine if there was either historical or externally estimated pumping data for a given area/year combination. If the flag file indicated that ground water pumping data was not previously developed for specific areas (e.g. the NP-NRD), volumes and depths of ground water pumping were simulated using Equations 1-2 for all parcels in that area in that year. If the flag file indicated that ground water pumping data was previously developed for a given area/year combination, any parcel within that defined area for which an explicit ground water pumping volume was not specified was assumed to have a pumping volume simulated using Equations 1-2. A record of these types of parcels was maintained in the GWP no-data file. Finally, summaries of pumping were made at both the cell and certificate level.

For surface water deliveries and ground water pumping related to lands which are irrigated with a commingled supply of both surface and ground water, the approaches described above for surface water and ground water were combined. First surface water deliveries were developed as described above. Next, the parcel's remaining NIR is computed based on the delivered surface water. The ground water computations are then made as described above, with the exception that the reduced NIR values were used in Equation 1. Should a parcel classified as being commingled not have surface water

[7] Referred to as the Irrigation Flag file. Table A-1 in Appendix A lists the annual flag settings.

deliveries associated to it, that parcel is treated as being irrigated only with ground water and the parcel identifier and year are output to the CO no-data file. As the final step, cell and certificate summaries were then created.

Once the cell and certificate summaries from all of the parcels within a year were created, the results were written to the SWD, GWP, COP, and COD files for the cell and certificate. The annual composite cell AE was also written for each cell.

4.2. Water Supply Partitioning Program (WSPP)

The purpose of WSPP was to adjust the parameters of the water balance from the idealized conditions in CropSim[8], through calibration, to more accurately reflect the condition experienced in the field. WSPP incorporated either the estimated irrigation amounts developed in the IAD program or an irrigation data set developed outside of the model (e.g. metered well pumping records). This is done in combination with the distributed CropSim data and the land use information as represented on Figure 5.

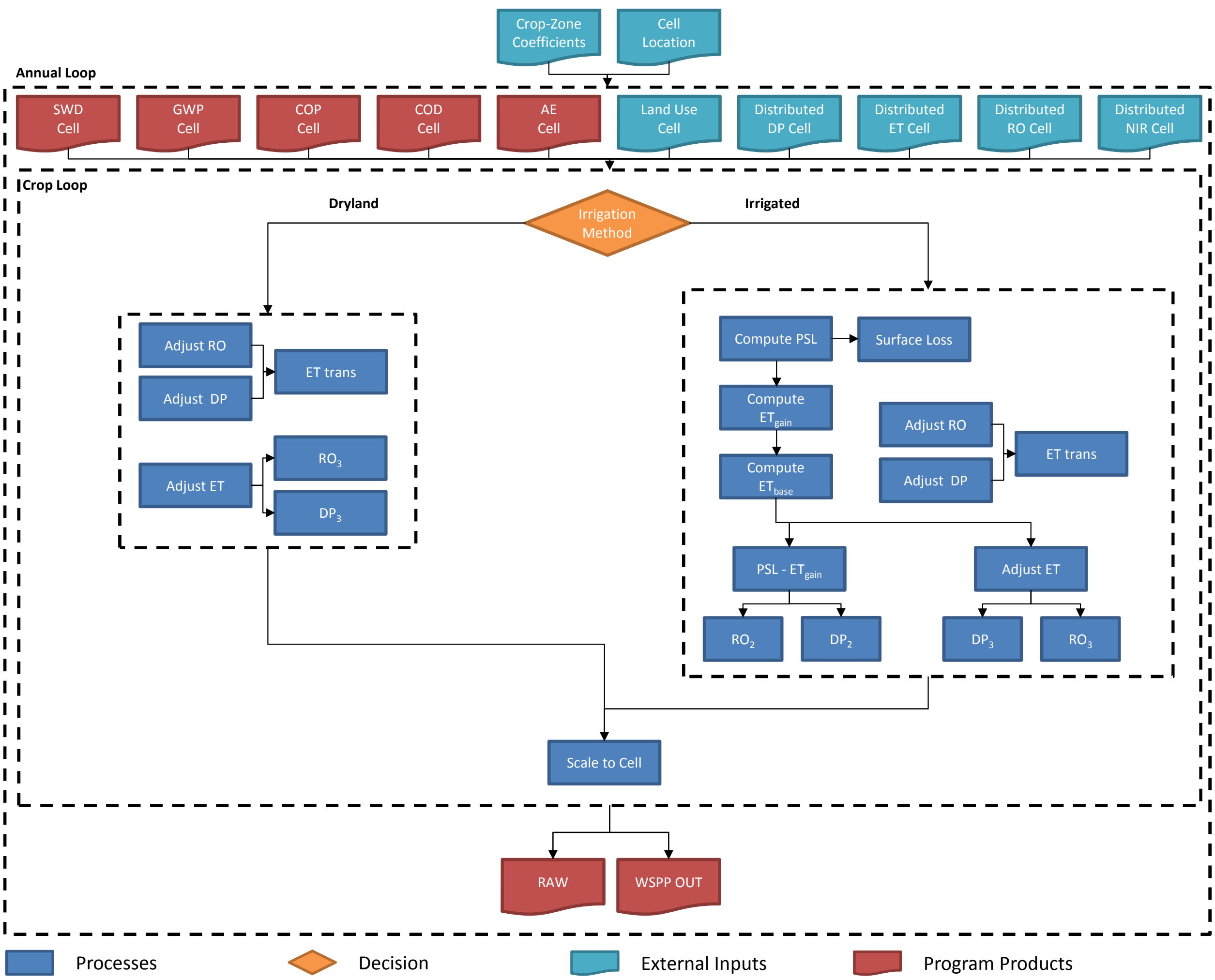

Figure 5. Flow chart depicting the inputs, outputs and major functions of the WSPP program

The terms shown on Figure 5 are defined more fully on Table 4-2.

[8] The "…idealized conditions in CropSim" statement refers to the fact results from CropSim reflect ideal growing conditions. For example, no consideration is given to uneven water application, insect damage, or damage from tillage operations for example – all of which occur in the real world and serve to reduce yield (i.e. ET).

Table 4-2. Definition of Terms Shown on Figure 5

Term	Definition
Cell	Model grid unit
SWD	Surface water deliveries
GWP	Ground water pumping
COP	Co-mingled pumping
COD	Co-mingled deliveries
RO	Runoff
DP	Deep percolation; recharge
ET	Evapotranspiration
PSL	Post surface loss irrigation
RAW	Detailed output file
WSPP OUT	Annual cell volumes for deep percolation and runoff

All adjustments made to any water balance parameter must maintain the water balance show in Equation 3. Precipitation and change in SWC content were kept constant throughout the WSPP routine.

$$P + NIR - ET - DP - RO = \Delta SWC \quad (3)$$

P	precipitation
ET	evapotranspiration
DP	deep percolation
RO	runoff
ΔSWC	change in soil water moisture content

Each crop type simulated using the WSPP routine can be evaluated under multiple irrigation methods. Calculations were first made for dryland conditions. An adjustment was made to the dryland ET to reflect the difference between the idealized conditions from CropSim and those observed in the field (Equation 4).

$$ET_{dry,adj} = ET * ADJ_{ET,dry} \quad (4)$$

$ET_{dry,adj}$	adjusted dryland ET
$ADJ_{ET,dry}$	dryland ET adjustment factor

The change in ET was converted to runoff and/or deep percolation; apportioned by a zoned coefficient which defined the ratio of runoff to deep percolation (Equations 5-7).

$$\Delta ET_{dry} = ET - ADJ_{ET,dry} \quad (5)$$
$$RO_3 = \Delta ET_{dry} * DryET2RO \quad (6)$$
$$DP_3 = \Delta ET_{dry} - RO_3 \quad (7)$$

ΔET_{dry}	change in dryland ET
DryET2RO	partitioning factor used to split the change in dryland ET to deep percolation and runoff
DP_3	change in deep percolation from a change in ET
RO_3	change in runoff from a change in ET

Likewise, runoff and deep percolation adjustment factors were used to make adjustments to the volume of each respective parameter coming out of CropSim. Changes in these parameters were converted to non-beneficial consumptive use (ET) (Equations 8-10).

$$RO_1 = RO * ADJ_{RO} \quad (8)$$
$$DP_1 = DP * ADJ_{DP} \quad (9)$$
$$ET_{trans} = (DP - DP_1) + (RO - RO_1) \quad (10)$$

RO_1	adjusted CropSim runoff
DP_1	adjusted CropSim deep percolation
ET_{trans}	CropSim runoff and deep percolation converted to non-beneficial ET

Working forward from Equation 3, the dryland water balance calculation can now be re-written as shown in Equation 11 below.

$$P - ET_{dry,adj} - DP_1 - DP_3 - RO_1 - RO_3 - ET_{trans} = \Delta SW \quad (11)$$

To calculate the water balance parameters for the irrigated crop, WSPP uses distributed CropSim output for ET from the irrigated crop and ET from the dryland crop. In addition, the depth of irrigation applied to the crop developed in the IAD program was also used. Similar to the dryland calculation, the water balance coming out of CropSim (Equation 3) is maintained, keeping precipitation and change in SWC constant. Furthermore, as described in Equations 8-10, a potential adjustment can be made to runoff and deep percolation.

The depth of irrigation water delivered to the crop that was calculated in the IAD program is applied to the field. ET gain is the increase in beneficial consumptive use from the application of irrigation water. The marginal increase in ET from the application of irrigation water is subject to diminishing returns. ET gain is calculated using a Cobb-Douglas response function given by Equation 12. This equation is a seasonal equation that estimates the increase in ET resulting from irrigation.

$$ET_{gain} = \begin{cases} CIR * \left(1 - \left(1 - \frac{ISPSL}{GIR}\right)^{\frac{1}{\beta}}\right) & ISPSL < GIR \\ ET_{sea,max,irr} - ET_{\ sea,max,dry} & ISPSL \geq GIR \end{cases} \quad (12)$$

ET_{gain}	increase in ET from the application of irrigation water
CIR	consumptive irrigation requirement, the additional amount of ET that a plant must use to maximize its yield potential over a dryland crop defined in Equation 13

$$CIR = ET_{sea,max,irr} - ET_{sea,max,dry} \quad (13)$$

GIR	gross irrigation requirement, the amount of water that needs to be applied in order to meet the net irrigation requirement
β	water use efficiency term defined by Equation 14

$$\beta = \frac{CIR}{GIR} \quad (14)$$

ISPSL	seasonal post surface loss irrigation
$ET_{sea,max,irr}$	ET needed to meet the max yield potential for an irrigated crop during the growing season
$ET_{sea,max,dry}$	dryland ET utilized during the growing season

Equation 12 implies that as the depth of irrigation water applied to the crop approaches zero the marginal ET approaches 1. Whereas, as the applied water approaches the GIR, the marginal increase in ET goes to zero, with any additional increases in irrigation beyond GIR resulting in no increase in beneficial consumptive use.

This Cobb-Douglas production function was based upon seasonal conditions. The applied water, dryland ET, and irrigated ET were summed over the months where the NIR is greater than zero. The resultant ET gain was then distributed back to the months based upon: 1) ISPSL > 0 and $ET_{irr} > ET_{dry}$, 2) ISPSL > 0 and $ET_{irr} < ET_{dry}$, and finally any remaining ET gain by 3) ISPSL = 0 and $ET_{irr} > ET_{dry}$. Then it was added to the non-irrigated ET to determine the monthly total ET. Finally, an adjustment of the irrigated ET was made to account for difference between the idealized conditions in CropSim and those observed in the field.

Next, a surface loss was calculated to determine the portion of applied water that was lost directly to non-beneficial consumptive use. This value was based upon the method used to irrigate. The remaining applied water in excess of the surface losses and ET, while maintaining the change in SWC from the distributed CropSim output; was divided between runoff (RO_2) and deep percolation (DP_2).

The results from the irrigated calculation can be summarized in Equation 15 and are equivalent to the results found in equation 3 for an irrigated crop.

$$P + IWD_{crop,irr} - ET_{irr,adj} - SL - DP_1 - DP_2 - DP_3 - RO_1 - RO_2 - RO_3 - ET_{trans} = \Delta SWC \quad (15)$$

The results were then scaled to the cell level by multiplying the water balance results by the number of crop acres serviced by the irrigation method within the cell. Finally, the cell totals were calculated by summing all of the crop irrigation-method combinations present within the cell.

Figure 6. Make Well Flow Chart.

4.3. Make Well

The Make Well program combined the various forms of pumping data into annual files formatted for a data transfer to LRE. Certificate based pumping estimates were converted to a well basis by dividing the total certificate pumping evenly among the wells associated with the certificate. The total pumping volume for a given well was computed by summing the assigned well pumping volumes from all certificates associated to that well. The well's total pumping was summed and reported. Supplementary pumping[10] information was also read in and summed to the cells in which it occurred.

4.4. Compile Well

The Compile Well program was a simple program developed to combine the annual pumping files with the correct headers into a single file for the data exchange with LRE. A program schematic would not materially assist in reviewing Compile Well's source code.

[10] Supplementary pumping refers to estimates of pumping that were created outside of the RSWB Model, but were merged into the dataset TFG provided to LRE for incorporation into the pumping file for the ground water model.

4.5. Make Recharge

The Make Recharge program compiled the various sources of recharge data into annual files formatted for use in the groundwater model. These sources included direct agricultural recharge, indirect agricultural recharge (i.e. additional recharge from runoff as it leaves a field and makes its way to a stream), canal recharge, and supplementary recharge[11]. Indirect agricultural recharge was a function of the agricultural runoff from a cell, a loss per mile variable and the distance from the cell to the stream gauge at the end of the runoff zone. Runoff loss was divided into non-beneficial consumptive use (ET) and recharge. Runoff which was not lost to ET or recharge was considered to have become stream flow.

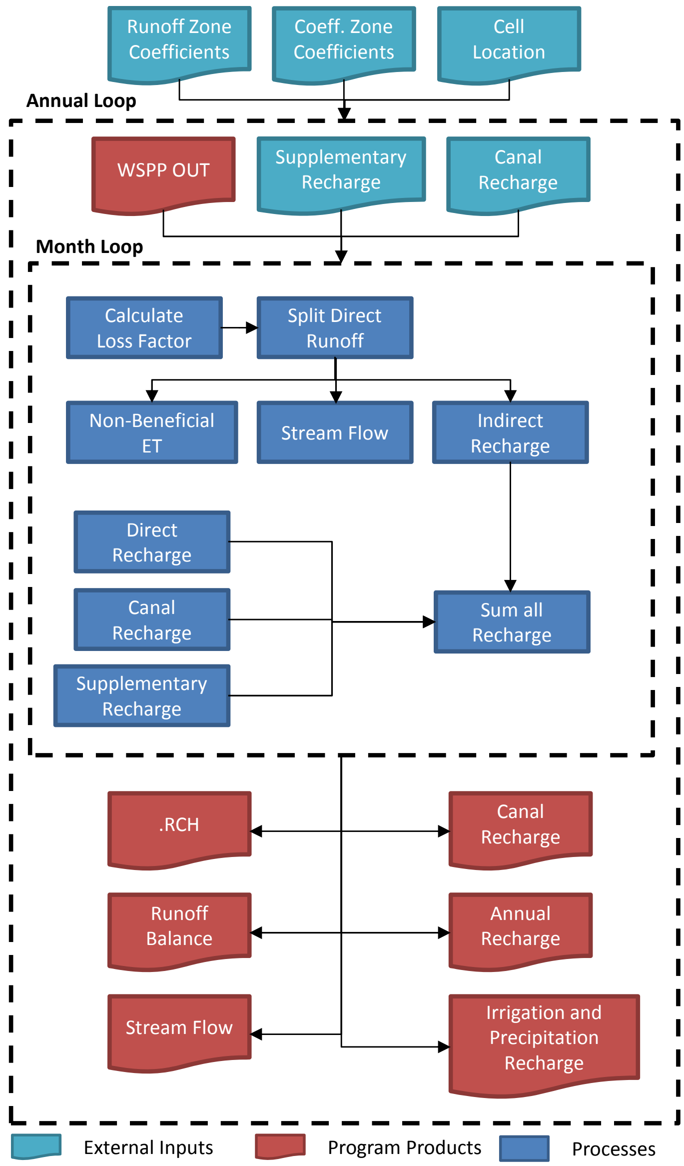

Figure 7. Make Recharge Flow Chart.

4.6. Compile Recharge

The Compile Recharge program was a simple program developed to combine the annual .RCH files with the appropriate headers into a single file ready to be input into the ground water model. A program schematic would not materially assist in reviewing Compile Recharge's source code.

[11] Supplementary recharge refers to estimates of recharge that were created outside of the RSWB Model, but were merged into the recharge dataset provided to the ground water model.

4.7. WSPP Report

The WSPP report program was also a simple program developed to compile the water balance parameters into several summary files. Summary files could be organized by crops, irrigation sources, and/or model areas.

5. Model Inputs

5.1. Model Grid

Defining the area to be modeled (i.e. the model domain) is a first step in model development. For the RSWB model, the WWUM ground water flow model grid was adopted. This grid contains 247,520 forty-acre cells in 520 columns and 476 rows (see Figure 8).

Figure 8. WWUM model grid and active cells.

Development of the water balance parameters was dependent upon several factors: soils, land use, climate, and location. Each of these factors were identified and characterized for all cells in the grid.

5.2. Soils

Soil characteristics influence how crops respond to climatic and management conditions. Soils can be thought of as acting like miniature reservoirs that store and release water for vegetative growth (ET), allow the water to drain as recharge, or restrict the water from infiltrating thus resulting in runoff.

Within the RSWB model, a cell's assigned soil type served as a link to results from the CropSim model. To build this link, each cell in the grid was assigned a CropSim soil type. This was accomplished in a three step process. The first step was to identify the soils present in the simulated area. Statsgo2, from the Natural Resources Conservation Service (NRCS), is a data base that contains the spatial distribution of soil for the entire state. As shown on Figure 9, within the RSWB model domain are numerous Statsgo2 soil classifications are present.

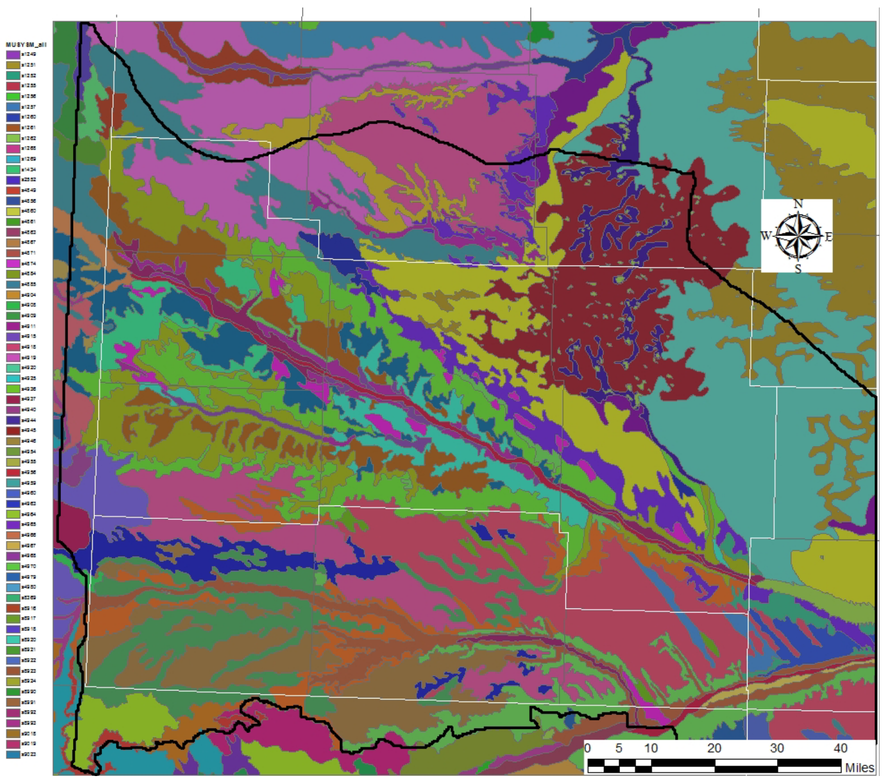

Figure 9. NRCS STATSGO II soil coverage for the WWUM model.

To simplify the modeling process, the soils were grouped together with soils that exhibited similar properties. To maintain congruency with the CropSim modeling practice, the three characteristics used to define the groupings were: water holding capacity; hydrologic soil group; and distance to ground water. This process reduced the numerous Statsgo2 soil classifications down to 28 soil classifications which are shown below on Figure 10 using soil classification nomenclature consistent to those used within the CropSim model.

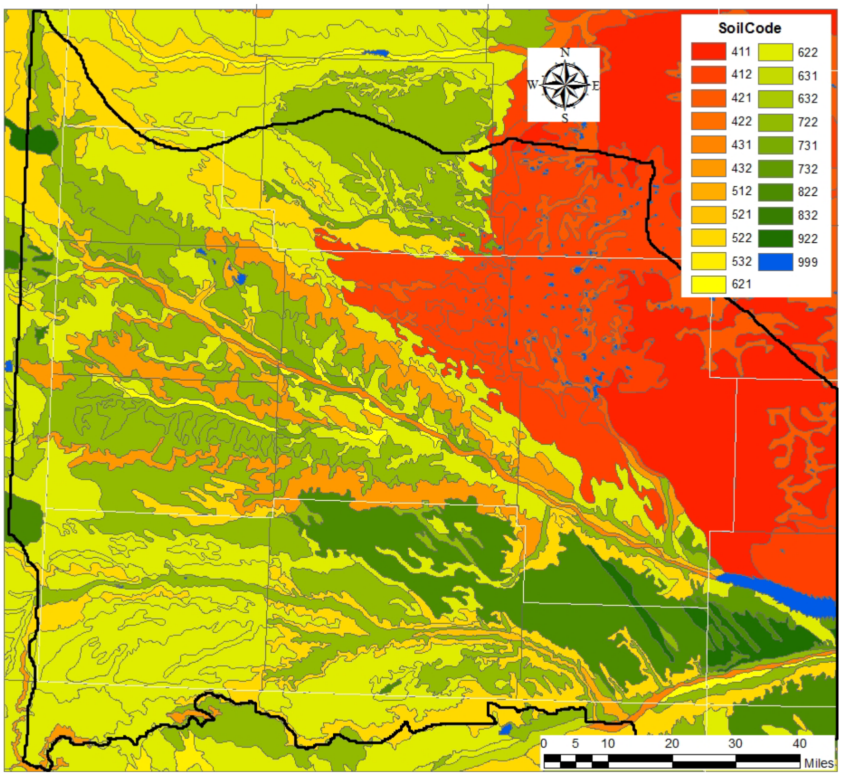

Figure 10. CropSim soil class coverage for the WWUM model.

Once all of the soils were assigned a CropSim soil classification, the predominant soil classification in each cell was determined. First, the CropSim soil classification map (Figure 10) was intersected with the model grid. Next, the area that is covered by each soil type was calculated. Finally, the soil classification covering the largest area was identified and assigned to the cell.

The total number of soils to use in a model is determined by the complexity and detail needed to support the intended use of the model. For the WWUM model, it was deemed that three soil classifications would provide the required resolution to address intended uses. The three soil classifications chosen, based on their prevalence in the model domain, were classes 412, 622, and 722 (Figure 11).

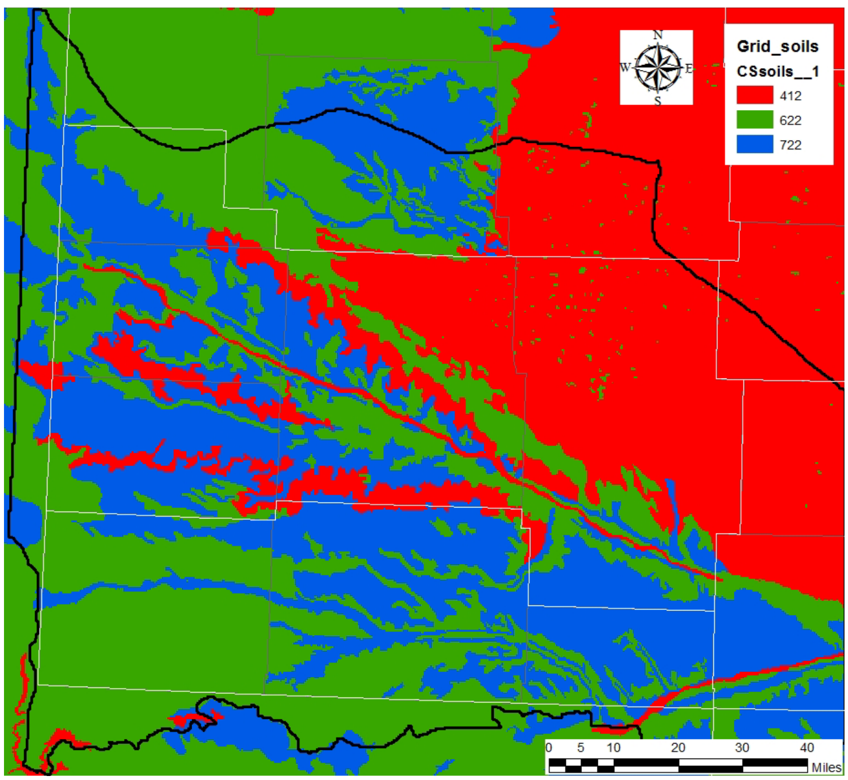

Figure 11. Simplified CropSim coverage for WWUM model.

5.3. Climate

Climatic conditions also greatly influence vegetative growth; and thus, are a significant input into the CropSim model. Weather data was collected from twelve weather stations in and around the model domain (Figure 12).

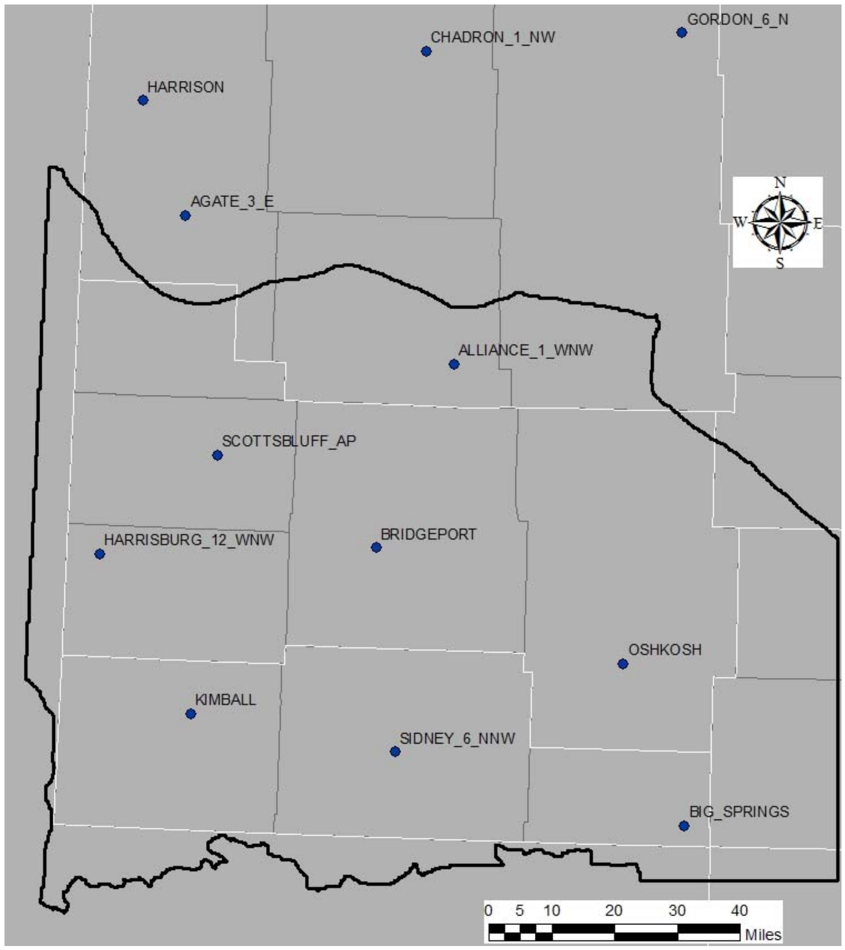

Figure 12. Location of NWS weather stations used for weather data in the CropSim simulations.

The information was reviewed for completeness and reliability. Following quality control efforts, the information was prepared into .WEA files for use in the CropSim model.

5.4. CropSim

The RSWB model is predicated around the results of a point source soil water balance model call CropSim. Dr. Derrel Martin with the University of Nebraska-Lincoln's Department of Biological Systems Engineering developed the CropSim model to aid in the estimation of ET, deep percolation, and runoff that occurs on a range of cropped and naturally vegetated systems in primarily agricultural regions. CropSim employs climatic, soil, phenology, and management information to simulate vegetative production. Additional documentation detailing the methodologies and algorithms used by CropSim is available from Dr. Martin.

The CropSim model was used to simulate the growth of 10 different crops: corn, sugar beets, edible dry beans, alfalfa, winter wheat, potatoes, sorghum, sunflower, fallow and pasture; under both irrigated and non-irrigated scenarios. This was done for all three soil classes defined for the region at each individual weather station. The result was a monthly water balance summary for precipitation, runoff (RO), deep percolation (DP), net irrigation requirement (NIR), and evapotranspiration (ET).

With the monthly water balance developed for each weather station, the next step was to spatially distribute the results. This was accomplished using the inverse weighted distance (IWD) technique for the three nearest stations. The IWD process was applied to each vegetation type for the relevant cell soil assignment for each water balance parameter under both irrigated and dryland conditions. One file was created for each irrigated and dryland condition for every combination of crop, year, and water balance parameter.

5.5. Model Regions

The RSWB model domain was divided into regions. There were two types of regions: operational regions and input regions.

<u>Operational Regions</u>

Operational regions were developed to incorporate the various sources and forms of data and to ensure continuity with overlapping model areas. Six different operational regions were developed to simulate the hydrology in the WWUM model domain (Figure 13). Within each of these regions several of the factors integral to developing the pumping and recharge files differed by their creation process. These factors included land use, applied irrigation volumes, ground water pumping volumes, and recharge.

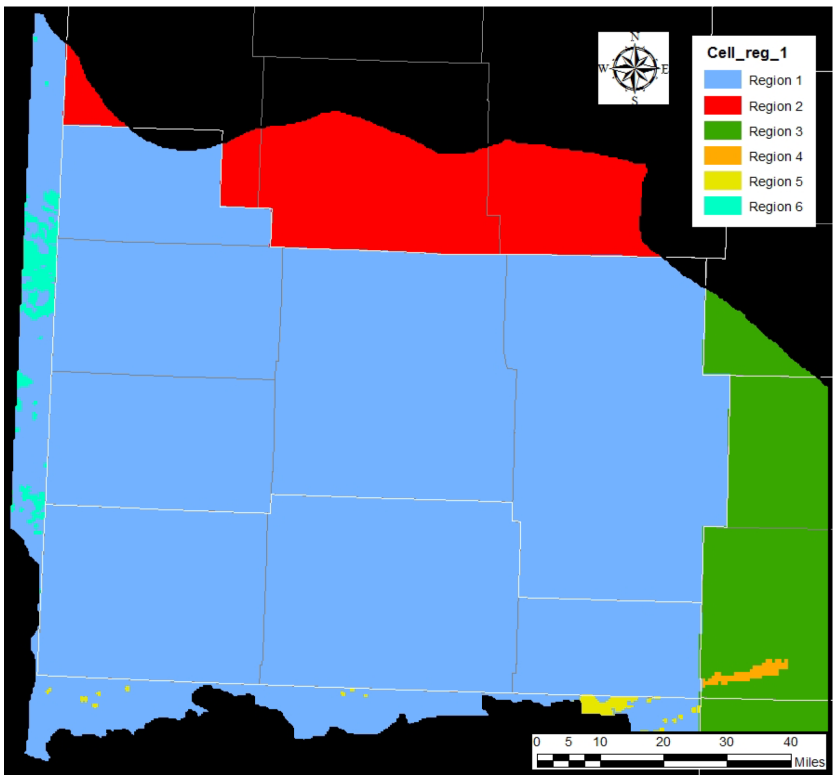

Figure 13. Operational Regions in the WWUM model.

Region 1

The lands in the NP-NRD and SP-NRD combined with the dryland pasture in Wyoming and Colorado comprised Region 1.[12]

There were two types of land use files used in Region 1; parcel based and cell based. The result was a list of non-dryland pasture agricultural lands identified by an LRE issued parcel identifier and certificate

[12] Refer to the discussion for Regions 5 and 6 for information on non-dryland pasture acreage in Colorado and Wyoming

reference. Each parcel was characterized by irrigation source and application method. The top four types of vegetation as developed by LRE and the portion of the parcel they covered were identified.

The parcel based land use file was converted into a cell based land use file for processing through the RSWB model. Using ARCGIS®, the model grid was overlaid on the parcels and the acreage of each crop-irrigation source combination was summed for each cell. The remaining land was assigned as dryland pasture. For the special case of the cells partially contained in both Region 1 and Region 6, the portions of the cells within Region 1 were assigned dryland pasture.

Irrigation volumes were generated for all parcels according to each irrigation source. Pumping and surface water amounts were developed separately for the North Platte and South Platte NRDs. Access to irrigation records for each source in each year were compiled within the Irrigation Flags file. If the flag was missing, all irrigation from that source and basin was assumed to be simulated to meet an adjusted NIR.

TFG received monthly values of surface water irrigation water delivered to farm headgates in a text file from WWG. TFG processed this information to arrive at monthly deliveries made to specific parcels. To accomplish this, a table received from LRE with Headgate ID to Parcel ID relationships was used. The data was combined with the landuse parcel information (LRE) and the monthly NIR depth values (TFG) to generate the prorated monthly surface water delivery values as follows using Equation 16. Where NIR values were 0 or null but surface water was delivered, the ratio of surface water irrigated acres was used to prorate the delivery values.

$$\frac{Parcel\ (acres) * Parcel\ (NIR\ depth)}{Headgate\ (acres) * Headgate\ (NIR\ depth)} * Headgate\ Delivery = Parcel\ Delivery \qquad (16)$$

The surface water volume included any water applied to co-mingled lands. Any lands classified as being irrigated only with surface water that did not have an assigned delivery volume was assumed to have received zero delivery.

The process used to estimate ground water pumping was dependent upon whether the lands were irrigated only with ground water (ground water only lands) or if they received both surface water and ground water (co-mingled lands). TFG developed the pumping estimates for lands irrigated only with ground water. These values were derived using one of two methods: metered values were used directly; or pumping volumes were estimated based on modeled crop water needs. In the case where metered values were used, TFG processed groundwater only irrigation values received as annual metered pumping volumes by meter certificate. The files were received as 3 sets of text files (NP-NRD, SP-NRD, and Pumpkin Creek) from LRE. These annual certificate volumes were divided into monthly certificate values based on the percentages in Table 4 in the WWUM Model Historical Crop Consumptive Use Analysis (LRE, 2012a). The data was combined with the land use parcel information (LRE) and the monthly NIR depth values (TFG) to generate the prorated monthly parcel ground water only pumping volumes with Equation 17 .

$$\frac{Parcel\ (acres)*Parcel\ (NIR\ depth)}{Certificate\ (acres)*Certificate\ (NIR\ depth)} * \ Certificate\ Pumping\ Values = Parcel\ Pumping\ Volume \qquad (17)$$

This process was completed separately for the NP-NRD, SP-NRD and the Pumpkin Creek areas, resulting in 3 sets of input text files. Pumping data for the NP-NRD was only available for 2009 and 2010, so only those years were included for all three datasets. For the years 1953-2008, the second methods of estimating ground water pumping was used which involved meeting crop water needs via adjusted NIR values as has been previously discussed.

Co-mingled pumping estimates were developed by LRE in conjunction with WWG to account for any surface water deliveries. TFG received three text files (one each for NP-NRD, SP-NRD, and Pumpkin Creek areas) containing estimates of commingled pumping organized by certificate. TFG combined that information with the landuse parcel information (LRE) and the monthly NIR depth values (TFG) to generate the prorated monthly parcel co-mingled pumping values using Equation 18.

$$\frac{Parcel\ (acres)*Parcel\ (NIR\ depth)}{Certificate\ (acres)*Certificate\ (NIR\ depth)} * Comingled\ Certificate\ Pumping\ = Comingled\ Parcel\ Pumping \quad (18)$$

This process was completed separately for the NP-NRD, SP-NRD and the Pumpkin Creek areas, resulting in 3 sets of input text files. In the event that a parcel that was designated as being co-mingled had neither surface water nor pumping records provided, TFG developed ground water only pumping estimates for the parcel using the methodology previously discussed to meet the crop water needs of the parcel.

To aid in partitioning applied irrigation volumes among the water balance terms previously discussed, application efficiencies are needed. AE defines the relationship between the gross volume of irrigation applied and the volume of irrigation consumed by the plant and is commonly a function of the type of system used to apply the irrigation water. Two different system type classifications were simulated for the purpose of specifying application efficiency: flood and sprinkler. Flood irrigation was simulated to have an AE of 0.65 for all years. For the sprinkler type, AE was set at 0.70 for the years 1953-1975. Then, to represent improving technology and irrigators becoming more efficient; the AE trended from 0.70 in 1975 to 0.85 in 1995 following a linear path. Post 1995, the remaining years were simulated with an AE of 0.85.[13]

The many-to-many relationships between parcels and certificates necessitated processing the certificate based pumping information down to a parcel level. [14] To distribute pumping back to individual wells, the parcel level pumping was summed together by parcel and uniformly distributed back to all related certificates. Those certificate volumes were then summed together by certificate and uniformly distributed back to all related wells.

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[13] Refer to Table A-2 in Appendix A for the annual AE values used.
[14] A certificate can serve many parcels and a parcel could be covered by many certificates.

Using the developed irrigation data in combination with the land use data, the recharge in Region 1 was estimated using the IAD, WSPP, and Make_RCH programs.

Region 2

Region 2 was defined by the borders of the Upper Niobrara White Natural Resources District (UNW-NRD). An independent model was previously developed to investigate the hydrology of the UNW-NRD. The data developed in that study was incorporated into this model.

The UNW-NRD model was developed on a 640 acre grid size. This grid was divided into 16 identical 40 acre cells for the WWUM model. Land use for the UNW-NRD model was developed by the Nebraska Department of Natural Resources on a cell basis. The land use information contained acreage summarized by crop by irrigation source.

No pumping or diversion records were available in Region 2, therefore all irrigation volumes were estimated based on an adjusted NIR to meet crop water demand. On the co-mingled lands, all demands for irrigation water were assumed to have been met by surface water deliveries. Classifications of irrigation system types did not occur in the UNW-NRD model, therefore, all surface water deliveries were assumed to be flood irrigated and all ground water pumping was assumed to be applied by sprinklers. The technologic boost improving AE for ground water pumping was linearly trended from 0.65 in 1970 to 0.85 in 1993, being assigned 0.65 prior to 1970 and 0.85 after 1993.

Ground water pumping was developed using a virtual well concept. A well was assumed to be in the middle of any cell which had land use with a classification indicating acreage within the cell was irrigated with ground water. Pumping estimates from the UNW-NRD model were used to create a supplementary pumping file in the WWUM RSWB model. Each WWUM cell whose centroid fell within a UNW-NRD cell was assigned $1/16^{th}$ of the pumping from the UNW-NRD results.

Recharge in the UNW-NRD portion of the WWUM model was also incorporated from the results of the UNW-NRD model. Each WWUM model cell whose centroid fell within a UNW-NRD cell was assigned $1/16^{th}$ of the recharge from the UNW-NRD results. Any recharge that occurred within the UNWNRD cell was spread evenly over all WWUM model cells within that UNW-NRD cell. These results were used to create supplementary recharge files for inclusion of the RSWB model.

Region 3

The COHYST model covered the areas in Twin Platte Natural Resource District (TP-NRD), Upper Republican Natural Resource District (UR-NRD), and Upper Loup Natural Resource District (UL-NRD). Data from the COHYST studies were used to create a parallel model for these lands. This parallel model used the same 40 acre grid as the rest of the WWUM RSWB model. Region 3 does not include the lands irrigated by the Western Canal. [15]

[15] Refer to Region 4 for a discussion of these lands

For these areas, land use data was not developed specifically for the WWUM model; rather, TFG adapted the COHYST model land use data (irrigated land types, acres and crop types) for use in the WWUM model. These areas consisted of WWUM model cells that fall within the Upper Loup, Twin Platte, and Upper Republican NRDs.

The WWUM model cells which overlapped the COHYST model grid but did not have WWUM model land use data were spatially selected. These individual WWUM model cells where then spatially linked to the COHYST grid cell they overlapped. This resulted in each WWUM model grid cell having a corresponding COHYST grid cell associated with it. The COHYST grid cells are 160 acres, while the WWUM grid cells are 40 acres; however, since the grid lines match spatially, there are essentially four WWUM model grid cells per each COHYST grid cell. The COHYST land use information was imported into a database along with the WWUM model grid data (with associated COHYST grid IDs). The datasets were linked together based on the COHYST grid IDs and the COHYST acreage values were divided by four to equally distribute the COHYST data to the corresponding four WWUM model grid cells. These results were organized into four datasets (non-irrigated lands, groundwater irrigated lands, surface water irrigated lands, and comingled lands) for processing.

All irrigation in Region 3 was simulated to meet crop water demands using an adjusted NIR. Similar to the UNW-NRD model, all surface water irrigation was assumed to be flood irrigation, while irrigation from ground water pumping was assumed to be applied via sprinkler. The same trending of the relative application efficiencies that was used in Region 1 was employed in Region 3. On co-mingled lands, surface water supplies were assumed to have been used to meet 50% of the crop water demand with ground water meeting the other 50%.

The pumping results from the model used in the overlapping COHYST area were incorporated into a supplementary pumping file for incorporation into the WWUM RSWB model. This file included all pumping, both ground water only and co-mingled. Similarly, recharge results from the parallel model were integrated into supplementary recharge files for use in the WWUM RSWB model.

Region 4

The service area of Western Canal lies within both the SP-NRD and the TP-NRD. Region 4 consisted of the portion of the Western Canal service area located **only** within the TP-NRD. To ensure continuity in the surface water operations water balance, the TP-NRD portion of the Western Canal needed to be considered in the analysis of the surface water diversions. Any cell that contains irrigated lands within the Western Canal service area located within the TP-NRD is included exclusively in Region 4.

Similar to the approach taken in Region 3, TFG imported the COHYST land use information into a database along with the WWUM model grid data (with associated COHYST grid IDs). The datasets were linked together based on the COHYST grid IDs. Acreage irrigated with surface water within the **entire** Western Canal service area was limited to a permitted acreage cap of 10,312 acres. To maintain this cap, lands classified as having a co-mingled irrigation water supply and located within Region 4 were uniformly re-classified to ground water only lands.

The adjusted COHYST acreage values were then divided by four to equally distribute the adjusted data to the corresponding four WWUM model grid cells. This information was provided to LRE who developed the irrigation estimates for both ground water pumping and surface water deliveries, as well as recharge for all cells in Region 4.

Both the ground water pumping and recharge results were then provided back to TFG. TFG incorporated the pumping results into the RSWB model as a supplementary pumping file. All pumping, both ground water only and co-mingled was included in this file. The recharge data was incorporated into the WWUM RSWB model as supplementary recharge files.

Region 5

Region 5 was comprised of all cells that contained any irrigated lands located in Colorado. These cells are exclusive to Region 5.

Recharge and irrigation volume estimates were developed by LRE and provided to TFG. This data was incorporated into the RSWB model via supplementary pumping and recharge files.

Region 6

Region 6 encompasses only the irrigated acres in Wyoming. The region is unique in that the dryland portion of these cells was part of Region 1.

Recharge and irrigation volume estimates were developed by LRE and provided to TFG. This data was incorporated into the RSWB model via supplementary pumping and recharge files.

Input Regions

Input regions were developed to aid in the spatial calibration of the model. The input regions allow for adjustments to a model sub-area independent of the rest of the model domain in order to reflect significant localized conditions. The RSWB used two types of input regions: coefficient zones and runoff zones.

Coefficient Zones

Coefficient zones represent a geographical group of cells that exhibit similar water balance responses. The RSWB model incorporates 10 coefficient zones. The zones were divided based upon soil class, river basins, and NRD boundaries (Figure 14).

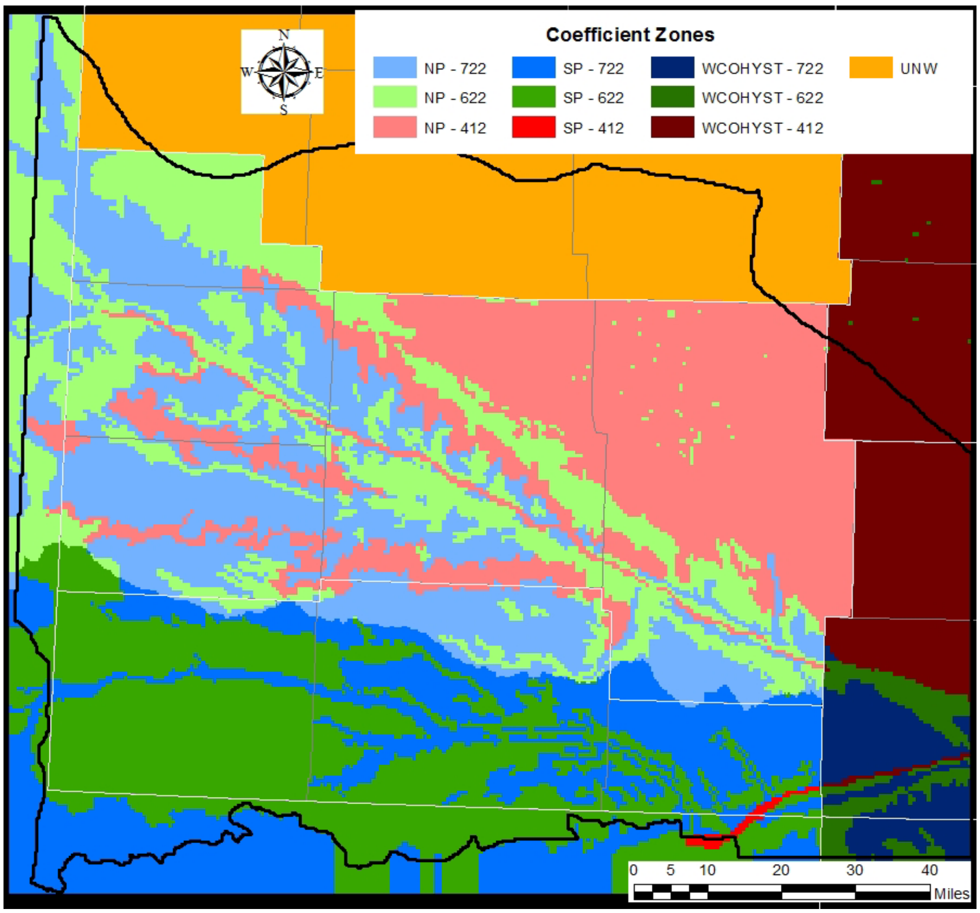

Figure 14. The Coefficient Zones in the RSWB model.

Each coefficient zone contains the RSWB coefficient variables used to adjust the idealized CropSim results to real world conditions. There are eight different coefficient variables assigned to each combination of crop and coefficient zone, and one coefficient variable that is assigned only to the coefficient zone. Those coefficient variables were:

1. Dryland ET ($Adj_{ET,dry}$): Adjusts ET for the difference between results from the CropSim model and realized field conditions for dryland crops

2. Irrigated ET ($ADJ_{ET,irr}$): Adjusts ET for the difference between results from the CropSim model and the realized field conditions for irrigated crops

3. NIR (ADJ_{NIR}): Adjusts the depth of irrigation water applied to the crop

4. CropSim DP (ADJ_{DP}): Adjusts deep percolation (DP) results from the CropSim model with the change being converted to non-beneficial consumptive use

5. CropSim RO (ADJ_{RO}): Adjusts run off (RO) results from the CropSim model with the change being converted to non-beneficial consumptive use

6. Surface Loss – sprinklers (FSL_{Spr}): Specifies a percentage of irrigation water applied via sprinklers that is not used by a crop to non-beneficial consumptive use

7. Surface Loss – gravity (FSL_{Fld}): Specifies a percentage of irrigation water applied via flood irrigation that is not used by a crop to non-beneficial consumptive use

8. Dryland ET to RO (DryET2RO): Specifies the portion of the dryland ET adjustment that is converted to RO with remainder going to DP

9. % to recharge (%2Rch): Specifies the portion of the losses from overland runoff that are converted to DP with the remainder going to non-beneficial consumptive use. This value is independent of crop type.

Tables A-3 and A-4 list the settings used for the above coefficients.

Runoff Zones

Runoff zones are defined by the boundaries of selected watershed boundary delineations. They consisted of the land area that drains to a certain point usually designated by a stream gauge. The RSWB model consists of 22 runoff zones (Figure 15). The runoff zones are used to calibrate the portion of the water balance that became stream flow using a single variable that regulates the runoff loss per mile. All runoff zones used a loss value of two (2) percent per mile.

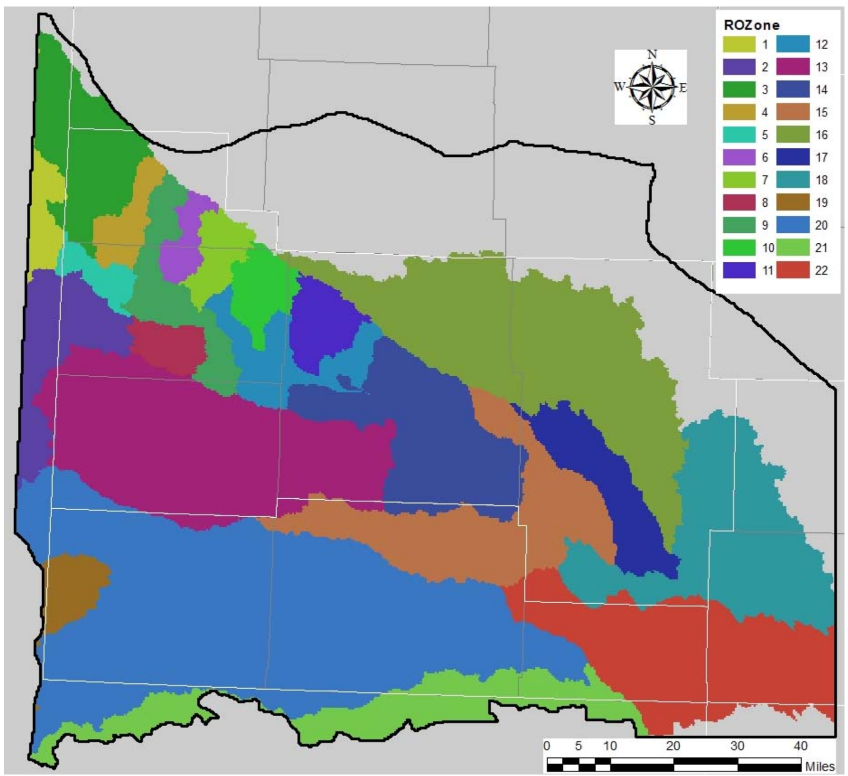

Figure 15. Runoff zone in the RSWB model.

5.6. Canal Recharge

Canal recharge was incorporated to account for seepage losses from the delivery of surface water. LRE developed the canal recharge for Region 1. This data was provided to TFG where it was incorporated into the RSWB model. In Region 2, the canal recharge was developed by the Nebraska DNR. Any canal recharge from the UNW-NRD region was included in the supplementary recharge file from Region 2. In Regions 4-6, any canal recharge was included in their respective supplementary recharge files. There was no canal recharge included for Region 3.

6. Results

This section presents selected results from the RSWB model and provides a comparison of those results to estimates produced by others. Table 6-1 provides an overall summary of the key water balance terms represented in the RSWB model. Parameter values are shown both in terms of depth per acre and percent of total available water (TAW). Depth values shown on the table represent volumes divided by the area of the entire model domain, thus depths of applied ground water (GW) and surface water (SW) are coded as being not applicable (NA). The bold terms indicate the water balance parameters which should balance. The indirect ET and recharge values reflect the portions of direct runoff which do not become stream flow.

The long term averages fell within the range of results from other projects in the model area. Estimated long-term average recharge reflects the results presented in the US Geological Survey Professional Paper 1400-B when discussing results in Box Butte County. Both the magnitude (1.15 in/year) and as a percentage of precipitation (6.6%) fall within the results presented by Pettijohn and Chen (1982) whose range was 1.1-2.8 in/year and 6-16% respectively. Likewise, the results are similar to those reported by Szilagyi, 2005 who estimated that the long term mean annual base recharge over the model area was between 0.1 – 1.2 inches/acres accounting for between 1 to 5 % of the mean annual precipitation. Szilagyi, 2003 also estimated the long term runoff for the area was between 0.15 and 1.2 inches/acre, a range which encompasses the long term average found as part of the RSWB modeling effort.

Table 6-1. Long term water balance results for the WWUM Model domain.

Parameter	Depth (in)	% of TAW
Precipitation (P)	16.38	94.1%
GW Application	NA	1.8%
SW Application	NA	4.1%
Total Applied Water	NA	**100.0%**
Total ET	15.56	89.4%
Direct ET	15.26	**87.7%**
Indirect ET	0.3	1.7%
Total Recharge (DP)	1.15	6.6%
Direct Recharge (DP)	1.03	**5.9%**
Indirect Recharge	0.12	0.7%
Direct Runoff (RO)	1.05	**6.0%**
Stream Flow	0.28	1.6%
Change in Soil Water Content (SWC)	0.07	**0.4%**

Tables 6-2 through 6-5 provide additional detail for the parameters listed on Table 6-1. The final table in this section, Table 6-6, provides a summary of ground water pumping and recharge volumes which were estimated outside of the RSWB model, but were incorporated into the pumping and recharge datasets produced by the RSWB model.

Table 6-2. Annual average precipitation for counties in the WWU model domain (in).

Year	Arthur	Banner	Box Butte	Cheyenne	Deuel	Garden	Grant	Keith	Kimball	Morrill	Perkins	Scotts Bluff	Sheridan	Sioux
1953	18.59	16.44	12.48	17.84	18.59	17.83	17.77	18.68	19.11	15.02	18.56	13.95	13.01	14.18
1954	12.99	13.36	12.46	12.98	13.00	12.60	12.68	13.00	13.66	11.38	12.94	13.97	12.95	13.32
1955	15.99	18.17	12.51	18.68	16.32	16.15	15.80	16.12	18.27	17.51	16.11	17.88	13.03	16.64
1956	14.85	13.18	12.48	12.42	15.59	13.99	14.81	15.68	13.43	11.81	16.16	11.42	13.00	12.10
1957	19.76	24.15	12.56	22.99	19.26	20.26	20.17	19.09	26.90	20.75	18.78	22.25	13.12	19.58
1958	21.81	15.39	12.50	20.42	21.93	20.96	20.54	22.09	19.44	18.41	21.96	14.28	13.03	14.04
1959	15.15	13.67	12.52	13.86	16.12	14.76	15.61	16.13	16.95	14.98	16.79	13.56	13.05	15.21
1960	14.07	11.35	12.47	13.45	13.74	13.99	14.00	13.82	14.47	12.71	13.68	9.77	12.98	11.24
1961	21.46	17.09	15.83	20.46	20.83	20.99	20.75	21.01	22.89	17.92	20.63	14.32	16.58	14.29
1962	19.18	17.23	16.16	18.12	18.08	19.52	18.83	18.30	19.03	19.10	17.76	17.28	16.18	18.02
1963	17.38	13.93	19.69	17.02	17.52	17.38	18.12	17.45	15.91	16.63	17.68	14.26	20.13	14.45
1964	10.43	9.66	8.71	11.46	11.06	10.43	10.09	10.99	10.83	11.82	11.18	8.36	9.64	8.62
1965	24.58	19.90	20.79	23.89	22.53	25.25	24.49	22.70	18.97	23.05	21.67	19.68	21.85	19.09
1966	17.74	14.13	14.96	18.11	18.08	17.24	17.41	18.04	18.60	15.61	18.12	12.22	15.99	11.81
1967	17.18	16.50	18.55	17.79	15.88	17.82	17.78	15.90	17.74	16.95	15.34	16.36	18.65	17.18
1968	17.59	13.36	16.67	18.56	15.16	18.63	18.11	15.21	15.09	16.48	14.04	12.87	17.73	13.45
1969	18.21	14.14	14.99	16.92	17.96	17.70	17.90	18.04	15.16	14.89	17.89	13.69	15.69	12.55
1970	14.67	12.14	14.53	18.06	15.45	14.32	14.60	15.09	14.26	13.52	15.24	11.75	14.78	11.95
1971	19.22	15.76	17.47	16.40	20.05	18.23	18.87	20.15	14.57	16.17	20.61	16.74	17.36	17.04
1972	17.90	15.93	17.80	16.80	17.06	17.92	18.08	17.17	16.27	16.27	16.84	18.38	17.34	17.01
1973	20.04	18.48	20.71	17.46	19.81	20.38	20.54	20.04	20.45	21.33	20.20	17.93	21.16	17.94
1974	10.78	9.59	12.45	11.31	10.53	10.87	11.29	10.47	12.06	9.93	10.42	8.89	12.51	9.94
1975	17.44	12.45	12.44	14.52	19.41	15.53	16.35	19.47	13.84	12.61	20.37	12.22	12.97	10.72
1976	12.48	11.03	13.87	10.31	11.98	12.90	13.16	12.16	12.01	13.08	12.18	10.12	14.40	10.88
1977	17.80	14.45	17.62	16.04	19.19	16.68	17.71	19.15	14.97	14.81	19.90	14.67	17.84	15.11
1978	14.98	16.17	21.01	16.39	13.84	16.60	16.48	13.80	17.55	19.98	13.50	18.13	20.49	17.60
1979	18.35	16.71	18.61	18.24	18.35	18.39	18.70	18.33	18.46	18.11	18.42	16.41	19.17	14.10

Table 6-2. Annual average precipitation for counties in the WWU model domain (in). (continued)

Year	Arthur	Banner	Box Butte	Cheyenne	Deuel	Garden	Grant	Keith	Kimball	Morrill	Perkins	Scotts Bluff	Sheridan	Sioux
1980	13.80	11.63	11.27	11.30	15.27	12.67	13.12	15.37	12.60	12.01	16.10	11.65	11.17	12.14
1981	19.85	16.77	15.14	18.63	19.53	19.08	19.22	19.65	19.47	15.24	19.42	14.62	15.82	13.58
1982	19.67	21.08	18.48	18.19	20.67	19.46	19.26	20.80	22.49	21.94	21.34	21.11	18.10	20.61
1983	18.22	17.43	16.30	16.82	17.68	18.29	18.10	17.84	17.29	17.52	17.62	16.46	16.71	16.17
1984	14.77	16.11	13.29	12.83	15.36	14.33	14.51	15.49	15.79	14.26	15.85	14.39	13.48	13.93
1985	17.75	13.95	12.78	14.21	17.04	17.04	17.19	17.37	16.41	13.09	17.10	12.39	13.34	11.74
1986	16.11	19.78	16.59	17.37	14.65	16.90	16.29	14.69	18.32	17.23	13.94	20.97	15.93	19.51
1987	19.91	18.19	16.10	17.80	21.10	18.90	19.02	21.22	18.80	18.75	21.75	20.52	15.71	16.15
1988	17.40	16.02	13.46	17.31	17.38	17.09	16.74	17.43	17.57	16.23	17.30	15.21	14.12	13.59
1989	10.98	12.91	9.30	12.62	12.15	10.21	10.41	11.99	16.21	9.79	12.39	10.54	9.26	10.28
1990	13.83	18.58	15.45	17.65	14.17	14.44	14.03	13.95	22.26	17.72	14.01	17.17	15.25	15.49
1991	16.31	13.78	12.92	13.61	15.78	15.90	15.74	16.02	11.95	13.67	15.77	14.52	12.99	15.69
1992	21.59	15.92	13.50	17.56	20.35	21.10	20.50	20.78	16.74	17.42	20.15	15.56	14.64	13.85
1993	21.89	19.16	17.64	20.62	21.13	21.61	21.08	21.30	17.96	19.83	20.80	22.42	17.27	20.62
1994	18.54	13.42	13.12	17.24	15.99	18.76	18.01	16.25	12.68	14.31	14.90	14.97	13.35	13.70
1995	19.85	17.82	18.75	19.75	19.12	20.27	19.96	19.15	16.17	19.94	18.79	17.60	19.51	17.59
1996	19.57	15.47	19.63	18.49	21.63	18.48	19.53	21.49	15.77	18.00	22.53	16.00	20.35	14.78
1997	16.22	19.99	15.10	18.36	15.66	16.28	15.94	15.60	21.97	15.72	15.17	19.56	14.75	17.54
1998	17.18	18.95	18.70	18.74	16.88	18.07	17.70	16.82	20.16	20.64	16.71	17.70	19.32	17.02
1999	16.62	15.78	16.44	18.00	17.75	16.66	16.42	17.60	16.11	19.35	18.04	16.34	16.70	16.49
2000	16.01	14.28	18.37	14.45	16.02	16.09	16.66	16.09	15.16	15.91	16.31	14.49	18.55	15.87
2001	18.36	14.22	15.49	20.90	18.55	18.47	18.00	18.34	14.89	18.57	18.18	13.50	16.89	12.42
2002	10.37	9.32	6.68	10.30	12.88	9.08	9.20	12.73	7.64	9.90	13.72	8.79	7.03	8.48
2003	14.64	16.04	13.07	15.47	13.70	15.51	14.65	13.78	17.09	16.91	13.30	12.76	13.96	13.53
2004	18.61	16.16	16.96	17.00	19.01	18.47	18.60	19.11	17.56	18.48	19.40	13.63	18.06	13.81
2005	17.84	21.63	19.13	21.37	15.74	19.50	18.47	15.64	20.52	21.01	14.55	20.65	19.09	19.22
2006	14.42	14.60	11.15	14.51	13.92	14.88	14.00	14.00	12.10	15.97	13.65	13.55	12.08	11.67
2007	18.12	13.26	10.25	17.51	19.14	16.90	16.62	19.17	15.55	14.61	19.38	10.65	11.54	10.20

Table 6-2. Annual average precipitation for counties in the WWU model domain (in). (continued)

Year	Arthur	Banner	Box Butte	Cheyenne	Deuel	Garden	Grant	Keith	Kimball	Morrill	Perkins	Scotts Bluff	Sheridan	Sioux
2008	18.20	14.82	13.77	16.27	18.62	17.87	17.52	18.75	13.15	17.85	18.90	14.74	15.02	12.86
2009	23.69	21.00	20.24	26.20	25.00	23.28	22.87	24.74	21.56	24.25	25.07	20.12	20.71	20.52
2010	19.10	17.44	19.40	19.33	18.08	20.25	19.64	18.16	18.54	22.20	17.77	16.56	20.40	16.58
Ave.	17.24	15.69	15.19	16.91	17.19	17.12	17.06	17.23	16.75	16.54	17.19	15.18	15.62	14.72

Table 6-3. Average depth of ground water pumped per county on ground water only lands (in).

Year	Arthur	Banner	Box Butte	Cheyenne	Deuel	Garden	Grant	Keith	Kimball	Morrill	Perkins	Scotts Bluff	Sheridan	Sioux
1953	20.40	26.25	21.82	21.74	22.09	22.52	-	20.65	19.64	23.45	-	22.97	23.34	22.67
1954	25.00	29.36	21.85	25.73	26.90	28.08	-	25.75	26.10	30.28	-	23.42	23.34	25.33
1955	26.51	27.32	21.83	23.49	25.04	28.30	-	24.96	26.00	26.87	-	22.04	23.34	22.67
1956	24.32	29.85	21.81	26.45	24.10	25.81	-	22.90	25.89	26.48	-	25.66	23.34	25.33
1957	19.03	17.25	21.78	15.79	18.12	19.34	-	17.64	13.85	19.48	13.43	16.75	23.34	16.00
1958	15.13	27.71	21.81	16.95	14.70	15.11	-	14.03	19.55	21.26	10.45	22.31	23.34	24.00
1959	26.49	32.76	21.82	25.32	22.97	26.92	-	21.58	25.66	29.11	17.55	26.24	23.34	26.67
1960	26.38	34.85	21.83	25.09	24.06	26.63	-	22.47	26.03	27.91	18.60	27.41	23.34	29.33
1961	18.88	27.05	20.83	18.35	20.75	19.92	-	19.28	17.06	25.79	16.37	23.58	23.27	25.07
1962	21.33	24.09	20.39	18.61	18.39	19.59	-	17.14	18.92	19.61	13.71	19.95	21.12	21.07
1963	28.19	32.55	19.84	24.72	26.94	27.77	-	25.30	26.04	28.95	21.26	24.68	23.40	26.09
1964	31.40	36.37	26.67	27.80	25.70	29.15	-	24.50	29.00	28.02	19.63	29.88	28.52	32.49
1965	19.06	20.60	16.75	17.82	18.07	16.68	-	17.10	21.07	19.38	13.26	16.49	14.26	17.15
1966	21.24	29.81	17.46	18.32	13.35	18.93	-	13.65	20.10	21.06	10.86	22.44	17.97	25.74
1967	23.08	21.03	17.73	20.00	22.19	22.65	-	20.57	19.96	23.08	16.07	20.09	18.40	21.06
1968	23.76	27.88	18.73	20.79	22.51	22.34	-	22.12	23.53	23.31	19.07	24.29	17.79	27.14
1969	23.27	29.66	21.37	24.43	19.77	23.93	-	18.69	25.11	27.53	14.30	26.24	22.68	30.79
1970	27.27	29.36	20.29	20.14	21.66	27.42	-	20.83	22.15	27.03	16.18	24.94	23.56	29.10
1971	23.02	22.07	17.76	24.11	21.20	23.36	-	20.39	23.64	24.64	17.57	20.21	21.40	22.17
1972	21.80	23.36	16.96	20.51	16.62	20.40	-	17.89	20.50	22.44	14.65	18.08	18.29	21.24
1973	26.57	23.53	18.53	22.70	19.42	23.89	-	20.67	18.85	21.17	18.09	20.14	22.26	22.57
1974	32.50	31.05	19.92	27.14	21.26	28.33	22.60	23.06	23.39	26.07	19.64	25.62	23.22	29.76
1975	23.85	27.84	25.43	26.04	18.30	24.91	18.56	19.14	24.35	28.41	16.27	27.71	24.96	30.33
1976	24.78	27.04	20.58	29.96	21.29	25.64	19.85	21.95	23.67	25.15	19.84	26.00	21.03	27.09
1977	20.31	23.95	16.81	21.41	14.95	22.85	15.52	15.09	19.84	23.95	13.05	22.25	16.78	24.77
1978	25.98	23.19	16.67	24.08	22.44	28.30	19.91	22.60	19.15	22.05	19.99	18.87	18.20	20.69
1979	19.02	21.33	13.34	21.64	16.31	18.46	14.99	15.74	17.30	18.99	14.33	18.41	15.88	22.34

Table 6-3. Average depth of ground water pumped per county on ground water only lands (in). (continued)

Year	Arthur	Banner	Box Butte	Cheyenne	Deuel	Garden	Grant	Keith	Kimball	Morrill	Perkins	Scotts Bluff	Sheridan	Sioux
1980	23.61	25.70	22.88	23.68	16.60	23.75	19.94	15.53	20.92	23.89	14.49	23.89	26.79	25.78
1981	16.70	19.84	17.19	17.04	14.59	15.45	14.77	14.21	13.72	20.64	13.63	20.09	19.70	22.12
1982	15.26	14.35	15.11	13.88	12.90	14.51	12.35	12.60	11.02	13.05	11.59	15.19	17.70	16.28
1983	16.96	18.16	16.40	17.36	15.36	15.57	14.44	14.15	16.01	18.15	13.71	20.49	19.01	20.43
1984	20.34	19.28	18.37	20.37	16.58	20.86	17.47	15.81	17.72	19.65	15.27	19.71	19.62	20.47
1985	19.90	25.68	23.92	22.05	18.17	20.73	18.53	17.21	18.46	24.59	17.51	27.84	24.13	28.79
1986	21.03	18.17	18.84	17.63	17.75	19.82	18.30	17.02	16.91	18.32	16.55	16.60	22.51	18.56
1987	17.22	20.01	20.59	18.00	13.58	17.95	14.91	13.07	15.05	17.67	12.39	18.81	24.03	22.13
1988	19.46	22.30	22.16	18.20	15.32	19.23	17.10	14.30	18.02	18.81	13.73	22.76	24.34	25.45
1989	22.35	25.65	27.86	21.50	17.36	25.50	20.62	15.91	19.15	25.11	15.77	26.51	29.40	27.44
1990	21.25	20.20	19.27	16.11	18.80	22.26	17.71	17.39	12.96	18.00	16.85	19.93	20.77	21.83
1991	18.06	21.66	22.12	16.19	16.92	19.16	14.03	15.49	21.20	18.09	14.78	22.32	23.45	20.82
1992	13.03	20.21	21.37	13.31	8.92	11.62	10.22	8.37	15.09	14.41	7.02	19.69	21.85	21.88
1993	12.57	14.90	18.07	10.46	11.56	11.10	10.82	10.98	16.15	14.15	10.47	15.77	20.86	14.77
1994	17.30	19.49	21.65	14.66	15.85	17.36	15.56	14.73	22.63	18.23	13.79	23.26	24.08	21.84
1995	14.95	16.45	19.03	14.52	13.14	14.74	13.46	12.68	19.61	15.30	11.76	20.32	20.09	18.19
1996	11.31	16.69	14.99	13.80	9.75	13.83	10.88	8.79	18.10	15.48	8.49	19.50	16.22	18.05
1997	13.94	14.45	18.95	11.97	11.21	13.88	12.28	10.83	14.97	15.20	9.58	17.36	19.88	16.44
1998	16.83	16.12	19.04	12.62	14.66	15.75	15.25	13.98	15.09	15.36	12.88	22.03	19.44	20.67
1999	13.61	15.27	16.83	10.15	12.04	12.74	14.12	11.44	14.25	11.38	10.62	17.60	17.67	15.77
2000	24.72	22.71	21.28	19.19	20.40	22.29	25.09	18.93	22.30	20.90	17.66	27.10	23.17	24.26
2001	19.57	19.04	16.65	12.01	15.12	15.69	21.08	14.50	19.66	15.99	13.30	21.10	19.07	21.88
2002	27.76	24.20	30.23	19.93	18.82	23.06	30.00	17.66	27.26	24.00	16.18	28.15	31.48	28.77
2003	21.98	17.93	24.78	15.55	17.76	18.16	23.40	17.24	18.34	17.13	16.06	25.13	26.08	24.87
2004	17.65	18.21	21.37	14.49	14.99	16.89	20.15	14.14	17.65	17.74	13.12	24.13	22.57	24.14
2005	18.24	13.45	17.42	13.29	17.79	14.99	19.97	16.68	15.40	13.94	15.74	18.58	19.79	17.97
2006	20.89	18.64	23.97	17.31	19.24	19.99	-	17.80	19.83	19.37	-	24.19	25.40	25.15
2007	16.38	21.11	24.32	14.91	12.48	16.21	-	11.45	19.84	18.30	-	27.34	26.02	26.85

Table 6-3. Average depth of ground water pumped per county on ground water only lands (in). (continued)

Year	Arthur	Banner	Box Butte	Cheyenne	Deuel	Garden	Grant	Keith	Kimball	Morrill	Perkins	Scotts Bluff	Sheridan	Sioux
2008	16.55	17.41	21.26	16.00	15.56	17.22	-	14.64	18.93	15.82	-	22.34	21.21	22.66
2009	13.47	9.73	13.61	5.91	7.93	8.52	-	10.52	6.00	8.27	-	9.54	15.04	11.08
2010	14.67	8.23	15.68	6.19	7.66	9.53	-	11.20	6.14	22.96	-	6.90	17.87	10.36
Ave.	20.62	22.45	20.10	18.75	17.55	20.10	17.31	16.98	19.39	20.89	14.84	21.74	21.71	22.83

Table 6-4. Annual Field Water Balance results for the WWU model domain (AF).

Year	Precipitation	Surface Water	Ground Water	Applied Water	Direct ET	Direct DP	Direct RO	Surface Losses	Field Water Balance
1953	9,717,722	138,046	89,158	9,944,926	8,874,838	383,861	631,442	12,286	42,499
1954	7,552,750	112,530	111,656	7,776,936	7,611,717	239,862	395,332	12,651	(482,626)
1955	9,907,782	105,878	111,153	10,124,813	8,708,871	346,533	676,234	12,317	380,858
1956	7,733,634	119,430	111,966	7,965,030	7,758,110	245,127	415,749	13,984	(467,940)
1957	12,280,889	126,615	86,535	12,494,039	10,108,251	1,026,950	1,035,511	11,931	311,396
1958	10,685,454	145,065	93,522	10,924,041	9,835,574	624,739	587,445	13,509	(137,226)
1959	8,638,211	135,016	129,516	8,902,743	7,795,922	307,403	408,330	15,785	375,303
1960	7,577,853	129,686	140,475	7,848,014	7,832,589	361,123	379,682	16,794	(742,174)
1961	11,087,213	108,745	126,594	11,322,552	9,174,395	822,527	786,280	15,607	523,743
1962	10,697,345	121,938	119,564	10,938,847	9,338,066	1,058,289	660,773	15,593	(133,874)
1963	9,739,854	137,142	161,863	10,038,859	8,378,277	510,607	464,976	19,426	665,573
1964	6,084,098	149,336	194,574	6,428,008	6,578,551	372,893	385,794	22,083	(931,313)
1965	12,969,719	121,668	131,053	13,222,440	9,952,429	1,032,187	840,874	15,082	1,381,868
1966	9,478,271	141,683	145,620	9,765,574	9,216,688	574,214	601,798	18,895	(646,021)
1967	10,135,953	124,703	166,150	10,426,806	9,141,082	858,142	557,600	16,934	(146,952)
1968	9,479,758	135,500	201,271	9,816,529	8,508,854	535,068	591,910	20,116	160,581
1969	9,275,013	148,083	233,674	9,656,770	8,341,071	357,528	523,555	22,611	412,005
1970	8,388,795	143,429	242,189	8,774,413	8,242,627	542,979	571,851	22,748	(605,792)
1971	10,041,770	129,676	240,307	10,411,753	9,118,190	446,667	511,863	20,456	314,577
1972	9,987,937	134,794	230,230	10,352,961	8,840,695	373,726	500,577	20,320	617,643
1973	11,487,720	144,242	269,473	11,901,435	9,637,492	972,776	637,462	22,835	630,870
1974	6,296,542	150,566	354,304	6,801,412	7,358,864	343,505	445,320	28,223	(1,374,500)
1975	8,322,973	150,597	417,346	8,890,916	7,786,128	302,185	520,665	28,820	253,118
1976	7,050,049	147,839	461,647	7,659,535	7,153,771	313,231	466,757	30,438	(304,662)
1977	9,479,645	141,887	396,132	10,017,664	8,878,251	355,640	575,867	26,954	180,952
1978	10,125,117	139,911	434,949	10,699,977	8,984,049	463,316	620,238	27,656	604,718

Table 6-4. Annual Field Water Balance results for the WWU model domain (AF). (continued)

Year	Precipitation	Surface Water	Ground Water	Applied Water	Direct ET	Direct DP	Direct RO	Surface Losses	Field Water Balance
1979	10,417,884	140,545	371,619	10,930,048	9,566,659	423,366	534,397	26,025	379,601
1980	7,262,248	148,176	496,061	7,906,485	7,681,638	506,722	441,578	31,428	(754,881)
1981	10,183,665	138,410	414,663	10,736,738	9,284,013	414,177	631,681	26,577	380,290
1982	11,884,378	133,014	345,632	12,363,024	10,432,380	561,506	861,892	20,121	487,125
1983	10,148,376	160,360	427,118	10,735,854	9,075,881	1,041,932	663,051	24,860	(69,870)
1984	8,496,544	168,082	541,051	9,205,677	8,471,959	442,019	510,930	27,558	(246,789)
1985	8,654,993	213,025	663,239	9,531,257	7,615,223	381,034	537,710	33,888	963,402
1986	10,301,885	145,908	530,360	10,978,153	10,043,406	862,585	808,603	25,589	(762,030)
1987	10,846,053	132,180	527,555	11,505,788	9,947,238	526,107	682,282	24,796	325,365
1988	9,538,595	156,002	579,913	10,274,510	8,907,435	752,586	890,435	28,453	(304,399)
1989	6,746,761	145,119	730,721	7,622,601	6,512,750	237,665	525,136	32,715	314,335
1990	9,804,649	112,568	573,451	10,490,668	9,654,911	359,995	565,635	26,329	(116,202)
1991	8,419,084	131,547	615,988	9,166,619	8,324,838	372,021	576,990	27,796	(135,026)
1992	10,293,773	136,319	510,478	10,940,570	9,493,438	535,755	629,885	25,741	255,751
1993	11,816,587	261,194	469,992	12,547,773	10,700,136	500,785	635,308	27,003	684,541
1994	9,015,224	323,126	637,639	9,975,989	8,403,344	790,756	580,087	36,311	165,491
1995	11,089,206	280,629	568,261	11,938,096	9,589,024	2,280,022	894,450	30,865	(856,265)
1996	10,525,841	318,790	498,716	11,343,347	9,424,708	519,476	643,280	31,698	724,185
1997	10,263,503	303,826	524,632	11,091,961	9,441,987	773,048	928,260	29,306	(80,640)
1998	10,910,204	323,340	576,811	11,810,355	10,070,781	478,382	585,613	32,520	643,059
1999	10,024,662	287,784	486,443	10,798,889	10,045,387	905,969	650,474	27,608	(830,549)
2000	9,210,062	348,146	774,727	10,332,935	8,325,229	584,086	640,872	39,590	743,158
2001	9,964,971	317,564	608,404	10,890,939	9,644,664	888,541	700,037	30,781	(373,084)
2002	5,511,749	247,426	986,871	6,746,046	6,065,187	308,869	455,619	38,112	(121,741)
2003	8,883,794	241,668	807,613	9,933,075	9,252,353	470,077	559,921	33,109	(382,385)
2004	10,132,887	224,668	763,930	11,121,485	9,762,914	315,167	574,230	31,396	437,778
2005	11,608,814	254,825	642,224	12,505,863	10,443,308	844,371	805,589	26,788	385,807
2006	8,144,633	278,488	829,567	9,252,688	8,354,682	322,286	515,757	32,988	26,975

Table 6-4. Annual Field Water Balance results for the WWU model domain (AF). (continued)

Year	Precipitation	Surface Water	Ground Water	Applied Water	Direct ET	Direct DP	Direct RO	Surface Losses	Field Water Balance
2007	8,775,325	275,440	782,174	9,832,939	8,647,611	704,133	598,978	32,414	(150,197)
2008	9,412,462	271,113	716,210	10,399,785	9,562,427	335,830	575,391	29,938	(103,801)
2009	13,420,461	279,049	377,875	14,077,385	11,512,364	1,131,499	837,359	19,319	576,844
2010	11,197,069	284,205	473,873	11,955,147	10,301,805	1,531,955	848,318	21,309	(748,240)

Column Notes:

Surface Water is the volume of surface water considered applied at the farm head gate

Ground Water is the gross volume of water pumped for irrigation

Applied Water is the total of Precipitation+Surface Water+Ground Water

Direct ET is the estimate of ET resulting from Applied Water. It does not consider ET related to transmission losses[16]

Direct DP is the estimate of recharge resulting from Applied Water. It does not consider transmission losses

Direct RO is the estimate of runoff occurring at field boundaries.

Surface Losses are evaporative losses related to irrigation

Field Water Balance is the change in soil water moisture content

[16] Transmission losses refer to volumes of water which originate as Direct RO, but do not become stream flow.

Table 6-5. Annual Runoff Balance (AF).

Year	Direct Runoff	Indirect DP	Stream Flow	Indirect ET
1953	631,442	76,303	361,333	193,806
1954	395,332	47,948	240,143	107,241
1955	676,234	78,830	384,127	213,278
1956	415,749	51,766	251,269	112,714
1957	1,035,511	118,302	555,942	361,267
1958	587,445	71,800	347,786	167,860
1959	408,330	49,899	246,541	111,890
1960	379,682	48,084	229,196	102,402
1961	786,280	89,549	421,790	274,941
1962	660,773	78,863	392,692	189,218
1963	464,976	53,500	301,901	109,576
1964	385,794	46,452	234,944	104,398
1965	840,874	97,599	494,722	248,553
1966	601,798	70,514	345,415	185,868
1967	557,600	67,736	338,479	151,384
1968	591,910	69,177	360,941	161,792
1969	523,555	62,531	317,613	143,411
1970	571,851	65,423	341,103	165,324
1971	511,863	62,328	325,062	124,473
1972	500,577	60,051	313,022	127,503
1973	637,462	74,060	389,786	173,616
1974	445,320	51,133	273,270	120,917
1975	520,665	56,250	309,000	155,414
1976	466,757	53,724	297,822	115,211
1977	575,867	63,918	351,498	160,450
1978	620,238	71,185	394,720	154,333
1979	534,397	63,936	331,730	138,731
1980	441,578	48,087	280,672	112,818
1981	631,681	71,245	374,076	186,359
1982	861,892	98,425	527,670	235,797
1983	663,051	75,715	415,454	171,882
1984	510,930	58,644	323,686	128,599
1985	537,710	59,439	340,362	137,909
1986	808,603	94,370	495,181	219,052
1987	682,282	77,509	434,402	170,371
1988	890,435	96,523	539,383	254,528
1989	525,136	54,577	301,147	169,411
1990	565,635	64,862	342,937	157,836

Table 6-5. Annual Runoff Balance (AF). (continued)

Year	Direct Runoff	Indirect DP	Stream Flow	Indirect ET
1991	576,990	66,026	372,273	138,691
1992	629,885	72,546	382,317	175,022
1993	635,308	73,246	413,035	149,026
1994	580,087	63,332	387,587	129,168
1995	894,450	95,713	554,751	243,985
1996	643,280	69,384	419,979	153,918
1997	928,260	98,897	559,192	270,171
1998	585,613	67,162	384,492	133,960
1999	650,474	73,192	427,212	150,069
2000	640,872	64,470	429,675	146,727
2001	700,037	77,977	449,604	172,457
2002	455,619	45,132	310,748	99,739
2003	559,921	64,625	366,864	128,432
2004	574,230	65,467	381,954	126,808
2005	805,589	91,730	525,502	188,358
2006	515,757	60,109	352,058	103,589
2007	598,978	64,263	389,345	145,370
2008	575,391	67,691	384,836	122,864
2009	837,359	95,332	525,320	216,707
2010	848,318	95,587	555,578	197,153

Column Notes:

Direct RO is the estimate of runoff occurring at field boundaries.

The remaining terms present the results of further partitioning the Direct RO water:

Indirect DP is the volume of transmission loss water resulting in additional recharge

Stream Flow is the volume of Direct RO which results in stream flow at a gage

Indirect ET is the volume of transmission loss water resulting in additional ET

Table 6-6. Supplementary Pumping and Recharge (AF).

Year	Western Pumping	Colorado Pumping	Wyoming Pumping	Western Recharge	Colorado Recharge	Wyoming Recharge	Canal Recharge
1953	3,257	1,831	4,028	3,203	16,345	12,958	547,069
1954	6,578	2,901	9,768	3,909	12,783	12,536	425,765
1955	6,283	3,249	9,100	4,267	11,331	13,451	403,484
1956	6,491	3,906	8,261	3,657	18,256	12,697	483,697
1957	4,966	2,044	6,791	4,620	12,053	14,511	512,485
1958	3,369	4,112	7,171	2,816	17,241	11,504	573,032
1959	6,634	5,708	10,270	4,200	16,422	12,029	544,096
1960	6,399	7,225	11,398	4,417	16,653	13,825	509,504
1961	1,004	7,427	8,945	5,377	12,667	10,922	418,589
1962	1,736	4,604	8,680	4,040	14,894	13,068	524,203
1963	7,755	7,481	13,576	4,742	17,794	13,729	581,640
1964	9,468	10,356	13,854	4,688	21,092	13,019	602,806
1965	2,817	3,265	9,032	4,408	14,348	9,297	508,510
1966	6,279	5,427	11,839	4,413	19,307	10,688	602,165
1967	7,249	5,036	12,252	5,829	14,778	14,475	502,941
1968	7,117	8,788	14,020	5,310	20,404	11,999	579,044
1969	6,407	10,043	14,897	4,572	21,899	14,603	632,495
1970	3,612	10,030	16,195	6,064	20,281	16,259	602,860
1971	9,612	7,896	14,884	4,808	18,091	12,276	562,359
1972	10,139	4,674	14,144	5,430	20,184	15,176	580,090
1973	9,195	7,629	14,392	5,273	21,310	13,472	619,832
1974	11,864	13,926	19,318	6,423	24,920	17,846	648,708
1975	4,560	15,690	14,157	4,500	24,223	16,320	624,418
1976	11,902	14,311	21,076	5,899	23,867	16,227	628,761
1977	9,864	12,377	19,043	5,062	22,849	15,461	565,688
1978	11,079	12,026	19,591	5,640	22,432	17,644	554,446
1979	3,435	12,044	14,324	6,200	23,214	19,877	553,688
1980	8,441	17,340	16,407	4,800	23,534	22,314	604,426
1981	5,077	14,285	13,877	5,093	20,370	18,979	533,850
1982	4,541	11,432	9,890	4,335	18,607	14,946	506,598
1983	2,423	13,991	14,028	6,068	18,233	15,162	587,510
1984	2,107	14,933	15,724	6,781	20,831	19,884	623,746
1985	1,100	26,811	12,534	6,495	26,912	17,245	689,759
1986	6,861	15,398	12,291	5,456	21,425	18,049	599,673
1987	6,588	21,912	10,114	4,887	22,357	14,332	522,575
1988	7,660	28,180	12,090	5,828	25,195	16,114	606,624
1989	7,210	33,918	12,735	4,991	23,869	15,587	540,173
1990	8,101	28,638	12,271	6,221	18,124	17,830	403,910

Table 6-6. Supplementary Pumping and Recharge (AF). (continued)

Year	Western Pumping	Colorado Pumping	Wyoming Pumping	Western Recharge	Colorado Recharge	Wyoming Recharge	Canal Recharge
1991	6,403	27,280	14,886	5,420	19,332	16,652	498,048
1992	1,516	30,401	8,281	5,105	20,098	13,266	429,542
1993	5,207	20,081	10,564	4,010	18,315	14,593	498,839
1994	10,189	29,574	17,080	5,548	24,267	15,801	597,936
1995	6,909	26,497	11,376	5,124	19,233	14,340	512,513
1996	3,133	25,223	11,369	4,181	22,742	14,125	593,533
1997	3,853	21,988	12,744	6,359	19,667	16,280	550,208
1998	4,689	25,137	12,510	5,468	22,776	16,489	590,435
1999	3,251	21,683	12,011	5,780	20,204	14,649	545,109
2000	10,499	36,032	20,656	6,635	26,421	15,850	651,600
2001	8,051	31,659	15,033	6,479	23,324	18,588	574,352
2002	13,727	46,231	16,945	6,456	21,792	15,369	409,826
2003	13,465	35,183	16,236	7,046	18,443	16,074	405,374
2004	10,524	36,830	11,784	5,871	18,677	16,558	364,105
2005	10,650	25,460	13,531	6,879	16,241	17,040	438,370
2006	13,340	32,977	15,331	7,495	21,774	17,736	510,316
2007	8,892	40,400	12,874	5,387	22,657	16,179	483,029
2008	7,221	30,696	12,874	6,477	21,096	16,129	504,021
2009	7,323	24,634	11,656	6,008	19,300	15,620	483,140
2010	3,569	23,125	12,676	6,707	19,941	15,510	540,787

Column Notes:

Western Pumping / Western Recharge are the ground water pumping and recharge values, respectively, computed outside of the RSWB model for the Western Canal service area within the TP-NRD. Refer to the Region 4 discussion in Section 5.5.

Colorado Pumping / Colorado Recharge are the ground water pumping and recharge values, respectively, computed outside of the RSWB model for lands located in the State of Colorado. Refer to the Region 5 discussion in Section 5.5.

Wyoming Pumping / Wyoming Recharge are the ground water pumping and recharge values, respectively, computed outside of the RSWB model for lands located in the State of Wyoming. Refer to the Region 6 discussion in Section 5.5.

Canal Recharge is the estimate of recharge resulting from seepage of irrigation water directly from canals.

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Appendix A- Coefficient Variable Settings:

Table A-1. Irrigation Flag File Settings

Year	NP-NRD GWP	SP-NRD GWP	NP-NRD SWD	SP-NRD SWD	NP-NRD COP	SP-NRD COP
1953	0	0	1	1	1	1
1954	0	0	1	1	1	1
1955	0	0	1	1	1	1
1956	0	0	1	1	1	1
1957	0	0	1	1	1	1
1958	0	0	1	1	1	1
1959	0	0	1	1	1	1
1960	0	0	1	1	1	1
1961	0	0	1	1	1	1
1962	0	0	1	1	1	1
1963	0	0	1	1	1	1
1964	0	0	1	1	1	1
1965	0	0	1	1	1	1
1966	0	0	1	1	1	1
1967	0	0	1	1	1	1
1968	0	0	1	1	1	1
1969	0	0	1	1	1	1
1970	0	0	1	1	1	1
1971	0	0	1	1	1	1
1972	0	0	1	1	1	1
1973	0	0	1	1	1	1
1974	0	0	1	1	1	1
1975	0	0	1	1	1	1
1976	0	0	1	1	1	1
1977	0	0	1	1	1	1
1978	0	0	1	1	1	1
1979	0	0	1	1	1	1
1980	0	0	1	1	1	1
1981	0	0	1	1	1	1
1982	0	0	1	1	1	1
1983	0	0	1	1	1	1
1984	0	0	1	1	1	1
1985	0	0	1	1	1	1
1986	0	0	1	1	1	1
1987	0	0	1	1	1	1

Table A-1. Irrigation Flag File Settings (continued)

Year	NP-NRD GWP	SP-NRD GWP	NP-RND SWD	SP-NRD SWD	NP-NRD COP	SP-NRD COP
1988	0	0	1	1	1	1
1989	0	0	1	1	1	1
1990	0	0	1	1	1	1
1991	0	0	1	1	1	1
1992	0	0	1	1	1	1
1993	0	0	1	1	1	1
1994	0	0	1	1	1	1
1995	0	0	1	1	1	1
1996	0	0	1	1	1	1
1997	0	0	1	1	1	1
1998	0	0	1	1	1	1
1999	0	0	1	1	1	1
2000	0	0	1	1	1	1
2001	0	0	1	1	1	1
2002	0	0	1	1	1	1
2003	0	0	1	1	1	1
2004	0	0	1	1	1	1
2005	0	0	1	1	1	1
2006	0	0	1	1	1	1
2007	0	0	1	1	1	1
2008	0	0	1	1	1	1
2009	1	1	1	1	1	1
2010	1	1	1	1	1	1

Notes:

Flag Definitions:

0 – Records Not Available

1 – Records Available

GWP – Ground Water Pumping meter records

SWD – Surface Water Delivery records

COP – Commingled Ground Water Pumping meter records

Table A-2**.** Annual AE **Values**

Year	AE Flood	AE Sprinkler
1953	0.65	0.7
1954	0.65	0.7
1955	0.65	0.7
1956	0.65	0.7
1957	0.65	0.7
1958	0.65	0.7
1959	0.65	0.7
1960	0.65	0.7
1961	0.65	0.7
1962	0.65	0.7
1963	0.65	0.7
1964	0.65	0.7
1965	0.65	0.7
1966	0.65	0.7
1967	0.65	0.7
1968	0.65	0.7
1969	0.65	0.7
1970	0.65	0.7
1971	0.65	0.7
1972	0.65	0.7
1973	0.65	0.7
1974	0.65	0.7
1975	0.65	0.7
1976	0.65	0.71
1977	0.65	0.71
1978	0.65	0.72
1979	0.65	0.73
1980	0.65	0.74
1981	0.65	0.74
1982	0.65	0.75
1983	0.65	0.76
1984	0.65	0.77
1985	0.65	0.77
1986	0.65	0.78
1987	0.65	0.79
1988	0.65	0.8
1989	0.65	0.8

Table A-2. Annual AE **Values**

Year	AE Flood	AE Sprinkler
1990	0.65	0.81
1991	0.65	0.82
1992	0.65	0.83
1993	0.65	0.83
1994	0.65	0.84
1995	0.65	0.85
1996	0.65	0.85
1997	0.65	0.85
1998	0.65	0.85
1999	0.65	0.85
2000	0.65	0.85
2001	0.65	0.85
2002	0.65	0.85
2003	0.65	0.85
2004	0.65	0.85
2005	0.65	0.85
2006	0.65	0.85
2007	0.65	0.85
2008	0.65	0.85
2009	0.65	0.85
2010	0.65	0.85

Table A-3. Settings of Coefficient Variables sensitive to crop type

Zone	Crop	$ADJ_{ET, dry}$	$ADJ_{ET, irr}$	ADJ_{NIR}	FSL_{Spr}	DryET2RO	FSL_{Fld}	ADJ_{DP}	ADJ_{RO}
1	1	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
1	2	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
1	3	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
1	4	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
1	5	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
1	6	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
1	7	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
1	8	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
1	9	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
1	10	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
1	11	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
1	12	0.98	0.95	0.95	0.02	0.50	0.05	1.00	1.00
2	1	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
2	2	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
2	3	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
2	4	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
2	5	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
2	6	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
2	7	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
2	8	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
2	9	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
2	10	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
2	11	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
2	12	0.98	0.95	0.95	0.02	0.50	0.05	1.00	1.00
3	1	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
3	2	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
3	3	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
3	4	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
3	5	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
3	6	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
3	7	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
3	8	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
3	9	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
3	10	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
3	11	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
3	12	0.90	0.95	0.95	0.02	0.50	0.05	1.00	1.00
4	1	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
4	2	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00

Table A-3. Settings of Coefficent Variables sensitive to crop type. (continued)

Zone	Crop	$ADJ_{ET, dry}$	$ADJ_{ET, irr}$	ADJ_{NIR}	FSL_{Spr}	DryET2RO	FSL_{Fld}	ADJ_{DP}	ADJ_{RO}
4	3	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
4	4	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
4	5	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
4	6	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
4	7	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
4	8	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
4	9	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
4	10	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
4	11	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
4	12	1.00	0.95	0.95	0.02	0.95	0.05	0.65	1.00
5	1	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
5	2	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
5	3	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
5	4	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
5	5	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
5	6	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
5	7	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
5	8	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
5	9	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
5	10	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
5	11	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
5	12	1.00	0.95	0.95	0.02	0.50	0.05	0.65	1.00
6	1	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
6	2	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
6	3	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
6	4	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
6	5	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
6	6	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
6	7	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
6	8	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
6	9	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
6	10	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
6	11	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
6	12	0.90	0.95	0.95	0.02	0.50	0.05	1.00	1.00
7	1	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
7	2	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
7	3	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
7	4	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
7	5	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
7	6	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00

Table A-3. Settings of Coefficent Variables sensitive to crop type. (continued)

Zone	Crop	$ADJ_{ET, dry}$	$ADJ_{ET, irr}$	ADJ_{NIR}	FSL_{Spr}	DryET2RO	FSL_{Fld}	ADJ_{DP}	ADJ_{RO}
7	7	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
7	8	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
7	9	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
7	10	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
7	11	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
7	12	1.00	0.95	0.95	0.02	0.95	0.05	0.65	1.00
8	1	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
8	2	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
8	3	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
8	4	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
8	5	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
8	6	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
8	7	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
8	8	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
8	9	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
8	10	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
8	11	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
8	12	1.00	0.95	0.95	0.02	0.50	0.05	0.65	1.00
9	1	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
9	2	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
9	3	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
9	4	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
9	5	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
9	6	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
9	7	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
9	8	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
9	9	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
9	10	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
9	11	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
9	12	0.90	0.95	0.95	0.02	0.50	0.05	1.00	1.00
10	1	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
10	2	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
10	3	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
10	4	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
10	5	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
10	6	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
10	7	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
10	8	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
10	9	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
10	10	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00

Table A-3. Settings of Coefficent Variables sensitive to crop type. (continued)

Zone	Crop	$ADJ_{ET, dry}$	$ADJ_{ET, irr}$	ADJ_{NIR}	FSL_{Spr}	DryET2RO	FSL_{Fld}	ADJ_{DP}	ADJ_{RO}
10	11	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00
10	12	0.95	0.95	0.95	0.02	0.50	0.05	1.00	1.00

Notes:

Crop Codes:

1 – Corn
2 – Sugar Beets
3 – Edible Beans
4 – Alfalfa
5 – Winter Wheat
6 – Potatoes
7 – Sorghum
8 – Sunflower
9 – Soybean
10 – Small Grains
11 – Fallow
12 – Pasture

Table A-4. Adjustment coefficients independent of crop.

Zone	%2Rch
1	0.50
2	0.50
3	0.50
4	0.05
5	0.10
6	0.50
7	0.05
8	0.10
9	0.50
10	0.50

Appendix B- Model User's Setup Reference:

General Input Files:

Application Efficiency (1 file)

The application efficiency contains the annual application efficiency values for flood irrigation and sprinkler irrigation methods.

Cell Location (1 file)

Within the cell location file, the relationship between the cell and the different input zones is defined. The file contains the cell followed by the relevant coefficient zone, runoff zone, and the distance between the cell centroid and the stream gauge at the collection point for the runoff zone.

Canal Directories (1 file)

This file directs the program to the various sources of canal recharge. It contains the folder within the canal directory that contains a specific source of canal recharge followed by the name of the specific source.

Canal Recharge (annual files, 1 set per entry in the canal directories file)

The canal recharge files contain the volume of recharge from canal seepage. The file contains the cell where the seepage occurs, the year, the annual total, followed by the monthly volumes.

Coefficient Zone Coefficients – crop (1 file)

This coefficient zone file contains the water balance adjustment coefficients for each zone crop combination.

Coefficient Zone Coefficients (1 file)

This coefficient zone file contains the water balance adjustment coefficients for only each zone. This file is utilized once the water can no longer be identified by crop.

Co-Mingled Pumping (annual and river basin files)

These co-mingled pumping files contain the monthly volume of ground water pumping that is applied to co-mingled lands. The file consists of the year, the LRE parcel ID, the irrigation certificate ID, and an array of 12 monthly pumping volumes (AF). One line should be present for each co-mingled parcel. There should also be one file for the NP basin and another for the SP basin.

Distributed DP (annual, crop, and irrigated or dryland files)

These files contain the monthly depth (in) of deep percolation for each cell in the grid. One file exists for each combination of crop, irrigated or dryland, and year.

Distributed ET (annual, crop, and irrigated or dryland files)
These files contain the monthly depth (in) of evapotranspiration for each cell in the grid. One file exists for each combination of crop, irrigated or dryland, and year.

Distributed NIR (annual and crop files)
These files contain the monthly depth (in) of net irrigation requirement for each cell in the grid. One file exists for each combination of crop and year.

Distributed Precipitation (annual files)
These files contain the monthly depth (in) of precipitation for each cell in the grid. One file exists for each year.

Distributed RO (annual, crop, and irrigated or dryland files)
These files contain the monthly depth (in) of runoff for each cell in the grid. One file exists for each combination of crop, irrigated or dryland, and year.

Ground Water Pumping (annual and river basin files)
These ground water only pumping files contain the monthly volume of ground water pumping that is applied to co-mingled lands. The file consists of the year, the LRE parcel ID, the irrigation certificate ID, and an array of 12 monthly pumping volumes (AF). One line should be present for each co-mingled parcel. There should also be one file for the NP basin and another for the SP basin.

Irrigation Flags (1 file)
The Irrigation Flags defines the presence of irrigation data for the three irrigation sources and the two river basins through the use of data flags. The file has a flag for: NP GWP, SP GWP, NP SWD, SP SWD, NP COP, and SP COP.

Land Use – Cell (annual files)
The land use file occupies two purposes. The first is to define the active cells in the model and the second outlines the crop and irrigation mixture in the cell. Each line defines one cell. The cell and the year are followed by 4 sets of 12 stating the number of acres that are present in each crop-irrigation combination.

Land Use – Parcel (annual files)
The parcel land use file is used to determine the volume of irrigation water that is applied to each parcel. This file is used to characterize the source of irrigation and method of application. The file also contains the crop mixture and the portion of the parcel that each crop covers. These file also include the relationship between the parcel, the certificate, and the cell segments that comprise the parcel.

Parcel CropSim – NIR (annual and crop files)
These files contain the monthly depth (in) of net irrigation requirement for each parcel, first in the North Platte Basin, Followed by the South Platte Basin. One file exists for each combination of crop and year.

Runoff Zone Coefficients (1 file)
The runoff zone coefficient file contains parameter 'loss per mile' which is used to control the amount of runoff that becomes stream flow as opposed to becoming non-beneficial consumptive use or recharge.

Surface Water Deliveries (annual files)
These surface water delivery files contain the monthly volume of ground water pumping that is applied to co-mingled lands. The file consists of the year, the LRE parcel ID, the irrigation certificate ID, and an array of 12 monthly pumping volumes (AF). One line should be present for each co-mingled parcel. There should also be one file for the NP basin and another for the SP basin.

Supplementary Pumping Directories (1 file)
This file directs the program to the various sources of supplementary pumping. It contains the folder within the source directory followed by the name of the specific source.

Supplementary Pumping (annual, 1 set for each entry in the Supplementary Pumping DIR)
These files contain the supplementary pumping data. Each file contains the cell, year, annual pumping volume, followed by the monthly pumping volumes.

Supplementary Recharge Directories (1 file)
This file directs the program to the various sources of supplementary recharge. It contains the folder within the source directory followed by the name of the specific source.

Supplementary Recharge (annual, 1 set for each entry in the Supplementary Recharge DIR)
These files contain the supplementary recharge data. These files contain the cell, the year, the annual recharge volume, followed by the monthly recharge volume.

Well-Certificate (annual, river basin)
The well certificate files contain the relationship between the certificate, the parcel, and the wells that feed the certificates. Each file contains the year, the certificate ID, the LRE parcel ID, the number of wells that feed the certificate, the cell the well is located within, the well ID, and the well capacity.

Irrigation Application and Demand (IAD)

Parameters:

Startyr	Beginning year of simulation	1953
Endyr	Ending year of simulation	2010
Ncerts	Maximum number of certificates	20000
Nparcs	Maximum number of parcels	20000
Nzones	Number of coefficient zones	10
Count	Maximum number of cell a parcel exists within	50

Directories:

COPDIR	location of co-mingled pumping file
DelDir	location of surface water delivery files
PumpDir	location of the ground water only pumping data
INDIR	location of the general input files
OUTDIR	location of the output file
ParceUse	location of the parcel land use files
NIRDATA	location of the parcel NIR data

Inputs:

Cell Location (General Input)
Coefficient Zone Coefficients – crop (General Input)
Application Efficiency (General Input)
Irrigation Flags (General Input)
Land Use - Parcel (General Input)
Ground Water Pumping (General Input)
Co-Mingled Pumping (General Input)
Surface Water Deliveries (General Input)
Parcel CropSim – NIR (General Input)

Outputs:

No data – Surface water delivery (1 file)

The No data SW file contains a list of the surface water only parcels, in years where the data is said to exist, which do not have a corresponding volume of surface water applied to them. Each instance lists the LRE parcel ID and the year that it occurred.

No data – Co-mingled (1 file)

The No data COP file contains a list of the co-mingled parcels, in years where the stat is said to exist, which do not have a corresponding volume of either surface water or ground water pumping applied to them. Each instance lists the LRE parcel ID and the year that it occurred.

No data – Co-mingled pumping (annual files)
To assure that all of the pumping data is properly exchanged and no volumes are double counted; any instance where the co-mingled pumping, in years where the data is said to exist, is simulated to meet an adjusted NIR is recorded to these files.

No data – Ground water only pumping (1 file)
The No data GW file contains a list of the ground water only parcels, in years where the data is said to exist, which do not have a corresponding volume of surface water applied to them. Each instance lists the LRE parcel ID and the year that is occurred.

Co-mingled deliveries – cell (annual files)
The co-mingled deliveries – cell files contain all of the surface water deliveries to co-mingled lands. Additionally, the files contain the depth of water that is delivered to each cell for the individual crops. The file consist of the cell, year, annual volume of water deliveries, monthly volume of surface water deliveries, and for each crop the annual depth followed by the monthly depths applied.

Co-mingled deliveries – certificate (annual files)
The co-mingled deliveries – certificate files contain all the total volume of co-mingled water that diverted through the certificate. The files contain the cell, certificate ID, year, annual volume, and the monthly volumes.

Co-mingled pumping – cell (annual files)
The co-mingled pumping – cell files contain all of the ground water pumping applied to co-mingled lands. Additionally, the files contain the distribution of the volume of water that is delivered to the cell for the individual crops. The files consist of the cell, year, annual volume of water pumped, monthly volume of water pumped, and for each crop the annual depth followed by the monthly depths applied.

Co-mingled pumping –certificate (annual files)
The co-mingled pumping – certificate files contain the total volume of co-mingled water that was pumped from a certificate. The file contains the cell, certificate ID, year, annual volume, and the monthly volumes.

Ground water pumping – cell (annual files)
The ground water pumping – cell files contain all of the ground water pumping applied to ground water only lands. Additionally, the files contain the distribution of the volume of water that is delivered to the cell for the individual crops. The files consist of the cell, year, annual volume of water pumped, monthly volume of water pumped, and for each crop the annual depth followed by the monthly depths applied.

Ground water pumping – certificate (annual files)
The ground water pumping – certificate files contain the total volume of ground water only that was pumped from a certificate. The file contains the cell, certificate ID, year, annual volume, and the monthly volumes.

Surface water deliveries – cell (annual files)
The surface water deliveries – cell files contain all of the surface water deliveries to surface water only lands. Additionally, the files contain the volume of water that is delivered to each cell for the individual crops. The file consist of the cell, year, annual volume of water deliveries, monthly volume of surface water deliveries, and for each crop the annual depth followed by the monthly depths applied.

Surface water deliveries – certificate (annual files)
The co-mingled deliveries – certificate files contain all the total volume of surface water only water that was diverted through the certificate. The files contain the cell, certificate ID, year, annual volume, and the monthly volumes.

Application efficiency – cell (annual files)
As the calculations are made on a parcel basis, it is possible that multiple parcels exist within a single cell. The method of irrigation application can differ between parcels despite have the same source. To account for this, a weighted application efficiency is computed. The file includes the cell and resultant application efficiency for each cell.

Water Supply Partitioning Program (WSPP)

Parameters:

Startyr	Simulation starting year	1953
Endyr	Simulation ending year	2010
Ncells	Total number of cells in the grid	247520
Nzones	Number of coefficient zones	10
LandUse	Name of the LandUse files	'WWLU'
DPonly	0-irrigated 1-dryland	

Directories:

LUInfo	Location of the cell land use files
INDIR	Location of the general input files
OUTDIR	Location of the results files
DPDATA	Location of the distributed deep percolation data
RODATA	Location of the distributed runoff data
ETDATA	Location of the distributed evapotranspiration data
NIRDATA	Location of the distributed net irrigation requirement data

Inputs:

Cell location (General Input)
Coefficient Zone Coefficients – crop (General Input)
Distributed DP (General Input)
Distributed ET (General Input)
Distributed NIR (General Input)
Distributed RO (General Input)
Land Use – Cell (General Input)

Application Efficiency (IAD)
Co-mingled Deliveries – cell (IAD)
Co-mingled Pumping – cell (IAD)
Ground Water Pumping – cell (IAD)
Surface Water Deliveries – cell (IAD)

Outputs:

WSPP OUT

The deep percolation and runoff from the adjusted water balance for each active cell in the model are written to the WSPP out file. The file contains the cell, year, annual deep percolation, 12 monthly deep percolation values, the annual runoff value, and 12 monthly runoff values.

RAW

The RAW records all cell calculations in the WSPP program. It is utilized to create various summaries and maps depicting the results of the model. The raw file includes the cell, year, month, crop, irrigation source, coefficient zone, runoff zone, and crop-irrigation source acres. Additionally the volume of the following water balance elements was included: ground water pumping, surface water deliveries, evapotranspiration, runoff, deep percolation, surface losses, change in pumping, ET gain, change in ET, ET base, DP 1-3, RO 1-3, an extra water variable, and the ET transfer value.

Make_Well

Parameters:

Startyr	Simulation beginning year	1953
Endyr	Simulation ending year	2010
Ncerts	> Maximum number of certificates	20000
Ncells	Number of cells in grid	247520
Nwells	> Maximum number of wells	225000
Ncols	Number of columns in grid	520
Misc	0 – No supplementary Pumping; 1 – Supplementary Pumping	

Directories:

INDIR	Location of the general input files
OUDIR	Location of the result files
WELLDIR	Location of the well-certificate files
MISCDIR	Location of the supplementary pumping files

Inputs:

Co-mingled Pumping – Certificate (IAD)
Ground Water Pumping – Certificate (IAD)
No data – Co-mingled pumping (Annual) (IAD)
Supplementary Pumping Directories (General Input)
Supplementary Pumping Files (General Input)
Well-Certificate (General Input)

Outputs:

Annual Well File (annual files)
The annual well file is a formatted subset of the complete .WEL file. One file exists for each year containing the maximum number of well within any stress period for the year followed by the correctly formatted annual results.

Co-mingled Pumping – cell (annual files)
The co-mingled pumping – cell file contain the total amount of co-mingled pumping that occurs within the cell. It is created by summing the co-mingled pumping from all of the wells that feed the co-mingled portion of certificates. The files contain the year, month, cell, pumped volume (cfd), row, column, and the row-column index.

Co-mingled Pumping – well (annual files)
The co-mingled pumping – well files contain the total volume of co-mingled pumping from individual wells. The files contain the year, month, cell that contains the well, well ID, pumped volume (cfd), row, column, and row-column index.

Exchange Output (annual files)
The exchange output file contains all of the pumping information that is passed to LRE. It consists of ground water only pumping, TFG simulated co-mingled pumping, and all pumping from regions 2-6. The results are reported on a cell basis. The files contain the year, month, cell, well ID, a negative pumping volume (cfd), row, col, and row-column index.

Ground Water Pumping – cell (annual files)
The ground water pumping – cell file contain the total amount of ground water pumping that occurs within the cell. It is created by summing the ground water only pumping from all of the wells that feed the ground water only portions of certificates. The files contain the year, month, cell, pumped volume (cfd), row, column, and the row-column index.

Ground Water Pumping – well (annual files)
The ground water pumping – well files contain the total volume of ground water only pumping from individual wells. The files contain the year, month, cell that contains the well, well ID, pumped volume (cfd), row, column, and row-column index.

NoSimParc (1 file)
The NoSimParc indicates that the certificates that were not part of the simulation process. The file includes the year, LRE parcel ID, and certificate ID.

Supplementary Pumping (annual files)
The supplementary pumping files contain cell totals for all pumped amount from regions 2-6. The files contain the year, month, cell, a dummy variable (-99), pumped volume (cfd), row, column, and row-column index.

Total Pumping – cell (annual files)
The Total pumping – cell file contain the total volume of pumping that occurs within the cell. It is created by summing the pumping from all of the wells within a cell. The files contain the year, month, cell, pumped volume (cfd), row, column, and the row-column index.

Total Pumping – well (annual files)
The total pumping – well files contain the total volume of pumping from individual wells. The files contain the year, month, cell that contains the well, well ID, pumped volume (cfd), row, column, and row-column index.

Well Check (annual files)
The well check file is a quality control on the pumping volume. The file consists of the cell, layer, row, column, year, month, number of days within the month, the total pumping (AF/day), and total pumping (cfd).

Compile Well

Parameters:

Startyr	Beginning year of the simulation	1953
Endyr	Ending year of the simulation	2010

Directories:

OUTDIR	Location of the results files

Inputs:

Annual Well File (Make_Well)
Co-mingled Pumping – Well (Make_Well)
Exchange Output (Make_Well)
Ground Water Pumping – Well (Make_Well)
Supplementary Pumping (Make_Well)
Total Pumping – Well (Make_Well)

Outputs:

Well File (1 file)
This file is the correctly formatted and complete .WEL file. This file is inclusive of all years in the simulation and is built by combining all of the Annual Well Files in order. The file contains the year, month, cell, well ID, pumping volume (cfd), row, column, and row-column index.

All Ground Water Pumping (1 file)
This file combines all the annual Total Pumping – Well files into a single file that contains all the ground water pumping for the entire simulation period. The file contains the year, month, cell, well ID, pumping volume (cfd), row, column, and row-column index.

Ground Water Only Pumping (1 file)
This file combines all the ground water only pumping data from the Ground Water Pumping – Well files for the entire simulation period. The file contains the year, month, cell, well ID, pumping volume (cfd), row, column, and row-column index.

Co-Mingled Only Pumping (1 file)
The Co-Mingled Only Pumping file combines all of the Co-mingled Only Pumping – Well files to create a single file containing the co-mingled pumping from the entire simulation period. The file contains the year, month, cell, well ID, pumping volume (cfd), row, column, and row-column index.

Ground Water Exchange (1 file)
The Ground Water Exchange file is created by combining all of the Exchange Output files into a single file for the entire simulation period. The file contains the year, month, cell, well ID, pumping volume (cfd), row, column, and row-column index.

Supplementary Pumping Only (1 file)

The Supplementary Pumping Only contains all pumping from regions 2-6. It is built by combining the Supplementary Pumping files into a single file for the entire simulation period. The file contains the year, month, cell, well ID, pumping volume (cfd), row, column, and row-column index.

Make_Recharge

Parameters:

Startyr	Beginning year of the simulation	1953
Endyr	Ending year of the simulation	2010
Ncells	Number of cells in the grid	247520
Ncols	Number of columns in the grid	520
Nrows	Number of rows in the grid	476
Nzones	Number of coefficient zones	10
Rzones	Number of runoff zones	22
Csize	cize of the cell	40
CnlRch	0 – no canal data; 1 – canal data	
MscRch	0 – no supplementary recharge; 1– supplementary recharge	

Directories:

INDIR	Location of the general input file
OUTDIR	Location of the results files
CANALDIR	Location of the canal recharge files
MISCDIR	Location of the supplemental recharge files

Inputs:

Cell Location (General Input)
Coefficient Zone Coefficients (General Input)
Runoff Zone Coefficients (General Input)
Canal Directories (General Input)
Canal Recharge (General Input)
Supplementary Directories (General Input)
Supplementary (General Input)
WSPP Out (WSPP)

Outputs:

Annual Recharge (annual files)

This file provides a summary of the various recharge and runoff sources and destinations. The file includes the cell, year, month, total recharge, direct recharge, runoff transfer to recharge, canal recharge, stream flow, supplementary recharge, runoff transfer to non-beneficial evapotranspiration, and direct runoff.

Annual .RCH (annual files)

The annual recharge files contain the formatted .RCH file information for a single year. The file incorporates all of the recharge in the model, and deploys it in the accurate .RCH format .

Canal Recharge (annual files)

The Canal Recharge file is a quality check of the canal recharge values. The file contains the cell, row, col, year, month, the number of days in the month, the canal recharge (AF), and the canal recharge (Ft/day).

Irrigation and Precipitation Recharge (annual files)

This file is a quality check file that investigates the total of all recharge, and what source they are from. The file contains the cell, runoff zone, row, col, year, month, number of days in the month, direct recharge from WSPP, direct runoff from WSPP, canal recharge, supplementary recharge, loss per mile, miles to gauge, recharge partitioning rate, cell recharge (ft/day), and non-canal recharge (ft/day).

Recharge Values (1 file)

The annual recharge file compiles a list of the annual recharge in all cells and years. The file contains the cell, year, and recharge value (in).

Runoff Balance (annual files)

The runoff balance file is a quality control file that depicts the partitioning of direct runoff into evapotranspiration, recharge, and stream flow. The file includes the cell, year, month, direct runoff, runoff transfer to recharge, stream flow, and runoff transfer to non-beneficial evapotranspiration.

Stream Flow (annual files)

The stream flow file is used to develop as summary of the portion of the direct runoff that becomes stream flow. The file includes the cell, runoff zone, row, column year, month, number of days in the month, stream flow (AF), direct runoff, loss per mile, miles to gauge, and stream flow (AF/day).

Compile Recharge

Parameters:

Startyr	Beginning year of the simulation	1953
Endyr	Ending year of the simulation	2010

Directories:

OUTDIR	Location of the results files

Inputs:

Annual .Rch (Make_Recharge)

Outputs:

.Rch

The .Rch file is the recharge file formatted for use in the ground water model. This file is created by putting the appropriate headers on the file, then combining the properly formatted annual .Rch files for the entire simulation period.

WSPP Report

Parameters:

StartYr	Starting year of simulation	1953
EndYr	Ending year of simulation	2010
Cozones	Number of coefficient zones	10
Rozones	Number of runoff zones	22
Ncells	Number of cells in the grid	247520

Directories:

INDIR
OUTDIR
RAWDIR
PrecDIR

Inputs:

Investigation Area Groups
Investigation Area IDs
Coefficient Zone Coefficients (General Input)
Cell Location (General Input)
Runoff Zone Coefficients (General Input)
Distributed Precipitation (General Input)
RAW (WSPP)

Outputs:

Water Balance Summaries

The water balance summaries are an overview product that summarizes the water balance parameters based upon constraints defined by the user. The program can develop summaries by geographical regions such as model area, county, coefficient zone, runoff zone, or other defined area. The summaries can also be created based upon crop, irrigation type, or other combination. The file reads in the variables listed in the RAW program description (See WSPP).

Appendix C- Sample Calculation:

The following example will go through the calculations for cell 159988 in the year 2009. The row column index for this cell is 308-348.

Cell Characteristics from the Irrigated Parcel Land Use File:

LRE Parcel ID:	4026
Certificate:	2429
Number of cells containing Parcel:	11
Parcel Acres in Cell:	40
Total size of Parcel:	122 acres
Irrigation Source:	Groundwater only
Irrigation Method:	Flood
Crop:	Corn
Coverage:	100%

From the Cell Location file:

Coefficient Zone:	2
Runoff Zone:	15
Miles to Stream Gauge:	9.60

From Coefficient-Crops file for Corn in zone 2:

Dry ET Adjustment:	0.95
Irrigated ET Adjustment:	0.95
NIR Adjustment:	0.95
Fraction of Surface Loss Sprinkler:	0.02
Deep Percolation Adjustment:	1.00
Runoff Adjustment:	1.00
Dry ET to Runoff:	0.50

From Coefficient file for zone 2:

Percent to Recharge:	0.50

From Runoff Zone Coefficients file for RO zone 18:

Loss per Mile:	0.02

Cell Soil File:

CropSim Soil Class: 622

The first step is to determine the three closest weather stations to the centroid of the cell. Using the ***NAD_1983_StatePlane_Nebraska_FIPS_2600_Feet*** projection in ArcGIS the following information was found:

Cell Location: 953700, 599940 ft

Using Equation 19, the three shortest distances were found

$$dist = \sqrt{(cell_x - stat_x)^2 + \left(cell_y - stat_y\right)^2} \tag{19}$$

$cell_x$	x-location of the cell (ft)
$cell_y$	y-location of the cell (ft)
dist	distance between the cell centroid and the station (ft)
$stat_x$	x-location of the station (ft)
$stat_y$	y-location of the station (ft)

Three nearest stations:

Station 1:	Oshkosh		
Location 1:	1001653.344,	586559.4463	ft
Distance 1:	49785.16406	ft	
Stations 2:	Sidney		
Location 2:	809761.2913,	512326.3563	ft
Distance 2:	168506.68750 ft		
Station 3:	Big Springs		
Location 3:	1053151.317,	450415.6411	ft
Distance 3:	179577.56250	ft	

An inverse weighted distance is used to calculate the distributed CropSim data. The weighting factor is calculated by Equations 20-22.

$$x_i = \frac{1}{dist_i^p} \tag{20}$$

x_i the i^{th} station weight

$dist_i$	the distance between the cell centroid and $station_i$ (ft)
p	the weighting

$$x_{sum} = \sum_{i=1}^{n} x_i \qquad (21)$$

x_{sum}	the total weight of all stations
n	the total number of stations

$$weight_i = \frac{x_i}{x_{sum}} \qquad (22)$$

$weight_i$	the weight of the station on the cell's CropSim values

The weight for each station is as follows:

Station 1:	0.85900
Station 2:	0.07498
Station 3:	0.06602

Searching through the CropSim results for each station to get the water balance parameters for an irrigated corn crop grown in a 622 soil in 2009 yields the following results in Table C-1 through Table C-3:

Table C-1. 2009 water balance for irrigated corn on a 622 soil – Oshkosh, NE (in)

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
ET	0.26	0.33	0.85	1.33	1.84	5.23	7.81	7.19	4.05	0.39	0.52	0.24	30.04
NIR	0.00	0.00	0.00	0.00	0.00	0.00	5.10	4.25	1.70	0.00	0.00	0.00	11.05
DP	0.00	0.00	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.30
RO	0.00	0.00	0.00	0.95	0.80	1.66	0.00	0.10	0.00	0.02	0.00	0.00	3.53
Precipitation	0.43	0.42	0.42	3.23	3.25	7.08	1.52	2.61	1.55	2.11	0.05	0.37	23.04

Table C-2. 2009 water balance for irrigated corn on a 622 soil – Sidney, NE (in)

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
ET	0.35	0.35	0.58	1.33	1.47	4.26	7.54	7.27	5.11	0.98	0.39	0.17	29.8
NIR	0.00	0.00	0.00	0.00	0.00	0.00	4.25	4.25	2.55	0.00	0.00	0.00	11.05
DP	0.00	0.00	0.00	0.00	0.00	1.36	0.00	0.00	0.00	0.00	0.00	0.00	1.36
RO	0.00	0.00	0.00	2.01	0.21	3.85	0.00	0.36	0.00	0.00	0.00	0.00	6.43
Precipitation	0.36	0.38	0.16	5.59	1.60	9.93	1.90	3.32	1.95	1.49	0.24	0.56	27.48

Table C-3. 2009 water balance for irrigated corn on a 622 soil – Big Springs, NE (in)

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
ET	0.34	0.35	0.65	1.82	1.95	4.79	7.56	7.34	2.32	0.48	0.49	0.23	28.32
NIR	0.00	0.00	0.00	0.00	0.00	0.00	4.25	5.1	0.00	0.00	0.00	0.00	9.35
DP	0.00	0.00	0.00	0.00	0.00	0.52	0.00	0.00	0.00	0.14	0.02	0.00	0.68
RO	0.00	0.00	0.00	1.1	0.41	1.49	0.01	0.01	0.01	0.18	0.00	0.00	3.21
Precipitation	0.31	0.23	0.25	4.09	2.94	6.38	2.19	2.21	2.86	3.12	0.17	0.47	25.22

Additionally, the CropSim ET was gathered for dryland crops on a 622 soil in 2009. The dryland ET was used as an estimate for a rainfed crop. The station results are shown in Table C-4 through Table C-6.

Table C-4. 2009 ET for dryland corn on a 622 soil – Oshkosh, NE (in**)**

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
ET	0.24	0.64	0.42	1.33	1.84	5.23	4.40	2.62	1.17	0.68	0.65	0.18	19.40

T**able C-5**. 2009 ET for dryland corn on a 622 soil – Sidney, NE (in)

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
ET	0.14	0.61	0.16	1.33	1.47	4.26	5.53	3.45	1.52	0.91	0.75	0.28	20.41

Table C-6. 2009 ET for dryland corn on a 622 soil – Big Springs, NE (in)

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
ET	0.39	0.38	0.25	1.82	1.95	4.79	5.44	2.30	0.69	0.74	0.76	0.19	19.7

These values are weighted appropriately to yield the following distributed CropSim results (Table C-7 and Table C-8).

Table C-7. 2009 water balance for irrigated corn on a 622 soil – Cell 159988 (in)

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
ET	0.27	0.33	0.82	1.36	1.82	5.13	7.77	7.21	4.02	0.44	0.51	0.23	29.91
NIR	0.00	0.00	0.00	0.00	0.00	0.00	4.98	4.31	1.65	0.00	0.00	0.00	10.94
DP	0.00	0.00	0.00	0.00	0.00	0.39	0.00	0.00	0.00	0.01	0.00	0.00	0.40
RO	0.00	0.00	0.00	1.04	0.73	1.81	0.00	0.11	0.00	0.03	0.00	0.00	3.73
Precipitation	0.42	0.40	0.39	3.46	3.11	7.25	1.59	2.64	1.67	2.13	0.07	0.39	23.52

Table C-8. 2009 ET for dryland corn on a 622 soil – Cell 159988 (in)

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
ET_{dry}	0.24	0.62	0.39	1.36	1.82	5.13	4.55	2.66	1.16	0.70	0.66	0.19	19.91

To acquire the parcel NIR, the weighted cell NIRs were summed (Equation 23). The relationship between the parcel and the cells can be found in Table C-9; while, the NIR results for the cells in parcel 4026 and the parcel values are found in Table C-10.

$$NIR_{parcel} = \sum_{i=1}^{n} NIR_{cell,i} * \frac{Ac_{cell,i}}{Ac_{parcel}} \quad (23)$$

NIR_{parcel}	NIR value for the entire parcel (in)
$NIR_{cell,I}$	NIR value for the i^{th} cell (in)
$Ac_{cell,\ i}$	Number of acres in the i^{th} cell that are part of the parcel
Ac_{parcel}	Number of acres in the parcel

Table C-9. Parcel-cell acreage split – Parcel 4026, 2009

Cell	Acres
159466	3.88
159467	6.92
159468	4.22
159469	0.14
159986	17.21
159987	37.05
159988	40
159989	1.65
160507	0.29
160508	9.75
160509	0.89
Total	122

Table C-10. 2009 NIR for irrigated corn – Parcel 4026 (in)

Cell	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
159466	0.00	0.00	0.00	0.00	0.00	0.06	4.97	4.19	1.65	0.00	0.00	0.00	10.87
159467	0.00	0.00	0.00	0.00	0.00	0.06	4.97	4.19	1.65	0.00	0.00	0.00	10.87
159468	0.00	0.00	0.00	0.00	0.00	0.06	4.98	4.19	1.65	0.00	0.00	0.00	10.88
159469	0.00	0.00	0.00	0.00	0.00	0.00	4.14	5.04	0.92	0.00	0.00	0.00	10.10
159986	0.00	0.00	0.00	0.00	0.00	0.06	4.97	4.19	1.65	0.00	0.00	0.00	10.87
159987	0.00	0.00	0.00	0.00	0.00	0.06	4.97	4.19	1.65	0.00	0.00	0.00	10.87
159988	0.00	0.00	0.00	0.00	0.00	0.00	4.98	4.31	1.65	0.00	0.00	0.00	10.94
159989	0.00	0.00	0.00	0.00	0.00	0.00	4.14	5.04	0.92	0.00	0.00	0.00	10.10
160507	0.00	0.00	0.00	0.00	0.00	0.00	4.97	4.31	1.65	0.00	0.00	0.00	10.93
160508	0.00	0.00	0.00	0.00	0.00	0.00	4.98	4.31	1.65	0.00	0.00	0.00	10.94
160509	0.00	0.00	0.00	0.00	0.00	0.00	4.99	4.30	1.65	0.00	0.00	0.00	10.94
Parcel 4026	0.00	0.00	0.00	0.00	0.00	0.03	4.96	4.25	1.64	0.00	0.00	0.00	10.89

The volume and depth of water that is applied to the crop can either be estimated to meet an adjusted NIR or use historical values. Table C-11 shows the volume of water that was pumped onto Parcel 4026.

Table C-11. 2009 GW only pumping – Parcel 4026 (AF)

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Pumping	0.00	0.00	0.00	0.00	0.00	0.00	23.81	23.66	14.20	0.00	0.00	0.00	61.67

The following calculations take place in the Irrigation Application and Demand program.

1. Calculate the total pumping per cell. Equation 24 is used for this portioning, as the crop coverage is assumed to be uniform across all cell. The results can be found in Table C-12.

$$Pump_{cell} = Pump_{parcel} * \frac{Ac_{cell}}{Ac_{parcel}} \tag{24}$$

$Pump_{cell}$ Volume of water applied to the cell (AF)

$Pump_{parcel}$ Volume of water applied to the parcel (AF)

Table C-12. 2009 GW only pumping – Cell 159988 (AF)

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Pumping	0.00	0.00	0.00	0.00	0.00	0.00	7.81	7.76	4.66	0.00	0.00	0.00	20.22

2. Next the volume of water is divided among the various crops in the cell weighted by NIR and the portion of the parcel acres within the cell (Equation 25-26).

$$NIR_{den} = \sum_{i=1}^{n} NIR_i * \frac{CC_i}{\sum_i^n CC_i} \tag{25}$$

NIR_{den} weighted NIR value based upon crop coverage (in)

NIR_i CropSim NIR for crop i (in)

CC_i the portion of the parcel that is grown as crop i (%)

n the number of crops being grown on the parcel

$$AppWat = \begin{cases} \frac{Pump_{cell}}{Ac_i} * \frac{NIR_i}{NIR_{den}} * \frac{CC_i}{\sum_i^n CC_i} & NIR_{den} > 0 \\ \frac{Pump_{cell}}{Ac_i} * \frac{CC_i}{\sum_i^n CC_i} & NIR_{den} \leq 0 \end{cases} \tag{26}$$

AppWat the volume of water applied to the crop (ft)

Since there is only one crop being irrigated in this cell Table C-13 and Table C-14 show the depth of all pumping to the cell.

Table C-13. 2009 GW only pumping corn – Cell 159988 (ft)

Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Corn	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.19	0.12	0.00	0.00	0.00	0.51

Table C-14. 2009 GW only pumping corn net irrigation – Cell 159988 (in)

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Irr_{net}	0.00	0.00	0.00	0.00	0.00	0.00	2.10	2.08	1.25	0.00	0.00	0.00	5.43

3. The Net irrigation is calculated (Equation 27).

$$Irr_{net} = \begin{cases} AppWat * AE * \frac{12}{NIR_{adj}} & NIR > 0 \\ 0 & NIR \leq 0 \end{cases} \tag{27}$$

Irr_{net}	net irrigation (in)
AE	application efficiency
NIR_{adj}	NIR adjustment factor

4. Volumes are summed to the cell (Equation 28) and certificate (Equation 29). Because the a single parcel engulfs the entire cell, the values shown in Table C-15 represent both the cell totals and the amount of pumping that this parcel adds to the certificate pumping from this cell. If multiple parcels in different certificates were present, the amount would be split by the above mentioned calculations.

$$GW_{cell} = \sum_{i=1}^{n} AppWat_i * Ac_i \tag{28}$$

GW_{cell}	total groundwater pumping for the cell (ft)
n	number of crops grown on the parcel

Table C-15. 2009 GW only pumping – Cell 159988 (ft)

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
GW_{cell}	0.00	0.00	0.00	0.00	0.00	0.00	7.81	7.76	4.66	0.00	0.00	0.00	20.22

$$GW_{cert} = \sum_{j=1}^{m} \sum_{k=1}^{p} \sum_{i=1}^{n} Wat_i * Ac_i \tag{29}$$

GW_{cert}	total groundwater pumping for the certificate (ft)
m	number of parcels fed by certificate
n	number of crops grown on the parcel
p	number of cells in the parcel

5. Calculate the volume of water (Equation 30) and number of acres (Equation 31) of each crop grown in the cell to get the depth of water applied (Equation 32). Table C-16 through Table C-18

$$GW_{crop,i} = \sum_{j=1}^{m} AppWat_{i,j} * Ac_{i,j} \tag{30}$$

$GW_{crop,i}$	total volume of water applied to crop i in a cell (Ac ft)
m	number of parcels with land area in the cell

Table C-16. 2009 GW only pumping corn – Cell 159988 (Ac ft)

Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Corn	0.00	0.00	0.00	0.00	0.00	0.00	7.81	7.76	4.66	0.00	0.00	0.00	20.22

$$GW_{ac,i} = \sum_{j=1}^{m} Ac_{i,j} \quad (31)$$

$GW_{ac,i}$ total number of crop i acres within the cell

Table C-17. 2009 GW only corn acres – Cell 159988

Crop	Acres
Corn	40

$$GW_{cropin,i} = \frac{GW_{crop,i}}{GW_{ac,i}} \quad (32)$$

$GW_{cropin,i}$ average depth of water applied to all acres of crop i in the cell

Table C-18. 2009 GW only pumping corn– Cell 159988 (ft)

Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Corn	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.19	0.12	0.00	0.00	0.00	0.51

6. Calculate the application efficiency for the cell. With the possibility of having two different parcels that contain two different irrigation application methods, a weighted AE must be produced to accurately pass information between the IAD program and the WSPP program. The application efficiency is weighted by the number of parcel acres within the cell, the net irrigation applied to the crop, and the crop coverage. The weighting factors are also summed for the cell (Equations 33-35). The results show that the weighted application efficiency is 0.65 (Table C-19) as there is only one parcel and it uses the sprinkler irrigation application method.

$$WAE = \sum_{j=1}^{m} \left(AE * \sum_{i=1}^{n} Ac_j * Irr_{net} * \frac{CC_i}{\sum_{i=1}^{n} CC_i} \right) \quad (33)$$

$$WAE_w = \sum_{j=1}^{m} \left(\sum_{i=1}^{n} Ac_j * Irr_{net} * \frac{CC_i}{\sum_{i=1}^{n} CC_i} \right) \quad (34)$$

WAE weighted application efficiency
WAE_w application efficiency weighting sum
m the number of parcels with area within the cell
n the number of crops being grown on the parcel

$$AE_{cell} = \frac{WAE}{WAE_w} \quad (35)$$

AE_{cell} application efficiency for all irrigation water in the cell.

Table C-19. 2009 GW application efficiency – Cell 159988 (Ac in)

Parameter	Value
AE	0.65

7. Finally the results the results are summed on a certificate basis to be passed to the Make_Well program. Table C-20 shows that there were eight parcels that were part of Certificate 2429 in 2009. The table also shows the monthly distribution of the ground water pumping.

Table C-20. 2009 Monthly pumping – Certificate 2429 (AF)

LRE Parcel ID	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
4023	0.00	0.00	0.00	0.00	0.00	0.00	7.57	7.43	4.53	0.00	0.00	0.00	19.53
4024	0.00	0.00	0.00	0.00	0.00	0.00	19.29	20.34	11.29	0.00	0.00	0.00	50.92
4025	0.00	0.00	0.00	0.00	0.00	0.00	29.96	32.65	17.39	0.00	0.00	0.00	80.00
4026	0.00	0.00	0.00	0.00	0.00	0.00	23.81	23.66	14.20	0.00	0.00	0.00	61.67
4027	0.00	0.00	0.00	0.00	0.00	9.42	24.02	21.58	11.82	0.00	0.00	0.00	66.84
4422	0.00	0.00	0.00	0.00	0.00	0.00	19.82	21.42	11.44	0.00	0.00	0.00	52.68
4423	0.00	0.00	0.00	0.00	0.00	0.00	4.62	4.75	2.71	0.00	0.00	0.00	12.08
4517	0.00	0.00	0.00	0.00	0.00	0.00	21.84	28.55	11.50	0.00	0.00	0.00	61.89
Total	0.00	0.00	0.00	0.00	0.00	9.42	150.93	160.38	84.88	0.00	0.00	0.00	405.61

The following calculations are used to estimate the direct water balance parameters within the WSPP model.

1. The dryland are made to set the dryland ET variable. Since this cell contain 100% irrigated corn; none of the calculations are necessary. The dryland corn ET can be seen in Table C-8.

2. From Table C-16 and Table C-18 we know the volume of irrigation being applied to the field, and the depth that it equates to being applied on the corn crop in cell 159988. Table C-7 and Table C-8 show the water balance parameters for the irrigated crop and the dryland ET. While, Table C-19 shows the application efficiency of the cell.

3. The gross irrigation factor. The surface loss factor is the portion of the irrigation water that is lost on the surface to evaporation, drift, interception, etc… Due to the changes in efficiency from technological improvements of irrigation systems, these values are changing with time. Their values were linked to the application efficiency of the cell. Equations 36-37 explain how these values are determined. While Table C-21 shows the results.

$$GIR_{factor} = \begin{cases} \frac{1}{0.95} & AE_{cell} > 0.75 \\ \frac{1}{0.75} & AE_{cell} < 0.65 \\ \frac{1}{0.85} & 0.65 < AE_{cell} < 0.75 \end{cases} \quad (36)$$

GIR_{factor} Gross irrigation requirement factor

$$Fsl = \begin{cases} Fsl_{spr} & AE_{cell} > 0.75 \\ Fsl_{fld} & AE_{cell} < 0.65 \\ \frac{Fsl_{spr}+Fsl_{fld}}{2} & 0.65 < AE_{cell} < 0.75 \end{cases} \quad (37)$$

Fsl Fraction surface loss

Fsl_{spr} Fraction surface loss – sprinkler

Fsl_{fld} Fraction surface loss – flood

Table C-21. Gross Irrigation Factor and fraction of surface loss – Cell 159988 (Ac in)

Parameter	Value
GIR_{factor}	1 / 0.75
Fsl	0.05

4. The CropSim results are read into the model. Adjustments are made to the runoff and deep percolation coming directly out of CropSim. Any adjustment here is transferred directly to non-beneficial consumptive use (Equation 38-40). Since the DP and RO adjustments both equal 1.00 there is no transfer. The results are show in Table C-22.

$$RO_1 = RO_{CS,irr} * ADJ_{RO} \tag{38}$$

RO_1	Adjusted CropSim runoff
$RO_{CS,irr}$	CropSim irrigated runoff
ADJ_{RO}	Runoff adjustment factor

$$DP_1 = DP_{CS,irr} * ADJ_{DP} \tag{39}$$

DP_1	Adjusted CropSim deep percolation
$DP_{CS,irr}$	CropSim irrigated deep percolation
ADJ_{DP}	Deep percolation adjustment factor

$$ET_{trans} = RO_{CS,irr} * (1 - ADJ_{RO}) + DP_{CS,irr} * (1 - ADJ_{DP}) \tag{40}$$

ET_{trans}	Transfer from runoff and or deep percolation to non-beneficial ET

Table C-22. Water Balance parameters at the beginning of the GW calculations– Cell 159988 (in)

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
ET_{irr}	0.27	0.33	0.82	1.36	1.82	5.13	7.77	7.21	4.02	0.44	0.51	0.23	29.91
NIR	0.00	0.00	0.00	0.00	0.00	0.00	4.98	4.31	1.65	0.00	0.00	0.00	10.94
DP_1	0.00	0.00	0.00	0.00	0.00	0.39	0.00	0.00	0.00	0.01	0.00	0.00	0.40
RO_1	0.00	0.00	0.00	1.04	0.73	1.81	0.00	0.11	0.00	0.03	0.00	0.00	3.73
ET_{trans}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

5. A partitioning value is determined based upon the runoff and deep percolation coming out of the CropSim program (Equation 41). This partitioning variable is used to split the ET adjustment and excess precipitation between deep percolation and runoff. The results of the partition variable can be seen in Table C-23. The partitioning variable is bounded by RO_{min} = 0.20 and RO_{max} = 0.80.

$$RODP_{wt} = \begin{cases} Min\left(Max\left(\frac{RO_{CS,irr}}{RO_{CS,irr}+DP_{CS,irr}}, 0.20\right), 0.80\right) & RO_{CS,irr} + DP_{CS,irr} > 0 \\ ET2RO_{dry} & RO_{CS,irr} + DP_{CS,irr} \leq 0 \end{cases} \tag{41}$$

$RODP_{wt}$	Runoff and deep percolation partition variable
$ET2RO_{dry}$	Dryland partitioning of the ET adjustment between runoff and deep percolation

Table C-23. 2009 GW only pumping corn net irrigation – Cell 159988 (ft)

Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
$RODP_{wt}$	0.50	0.50	0.50	0.80	0.80	0.80	0.50	0.80	0.50	0.80	0.00	0.00

6. The post surface loss irrigation is the amount of water that when applied either infiltrates or becomes direct runoff (Equation 43). The surface losses include the water that is lost to non-beneficial ET, drift, interception, etc… (Equation 42). The results can be seen in Table C-24.

$$SL_n = \begin{cases} 0 & GWapp_n < 0 \\ GW_{app,n} * Fsl & GWapp_n > 0 \end{cases} \tag{42}$$

$$PSL_n = \begin{cases} 0 & GWapp_n < 0 \\ GW_{app,n} - SL_n & GWapp_n > 0 \end{cases} \tag{43}$$

n	Month
SL_n	Surface Loss
$GW_{app,n}$	Applied ground water only pumping
PSL_n	Post surface loss irrigation

Table C-24. Applied water, surface losses, and post surface loss irrigation for corn – Cell 159988 (in)

Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
GW_{app}	0.00	0.00	0.00	0.00	0.00	0.00	2.34	2.32	1.40	0.00	0.00	0.00	6.07
SL	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.12	0.07	0.00	0.00	0.00	0.30
PSL	0.00	0.00	0.00	0.00	0.00	0.00	2.22	2.21	1.33	0.00	0.00	0.00	5.76

7. The next set of equations is dependent upon irrigation water being applied to the crop and there being a need for irrigation water to be applied to the crop. The post surface loss irrigation The irrigated ET, dryland ET, the applied water, and the post surface loss irrigation is summed during the growing season. The growing season is defined as those months with a positive NIR. While the crop may be growing in earlier months, there is no ET gain from the application of irrigation water. The Results are shown in Table C-25.

T**able C-25.** Growing Season Totals – Cell 159988 (in)

Crop	Total
Applied Water	6.07
PSL	5.76
ET_{dry}	8.78
ET_{irr}	19.00

8. The ET gain as a result of applied irrigation is the next step. Using a Cobb-Douglas production function the ET gain is a function of the depth of post surface loss irrigation and the total amount of water that is necessary to meet the net irrigation requirement (Equations 44-47). The seasonal ET gain is show in Table C-26.

$$ET_{gain} = \begin{cases} Min\left(CIR * \left(1 - \left(1 - \frac{PSL_{sea}}{GIR}\right)^{\frac{1}{\beta}}\right), GW_{app,sea} * AE_{cell}\right) & PSL_{sea} < GIR \\ ET_{irr,sea} - ET_{dry,sea} & PSL_{sea} > GIR \end{cases} \tag{44}$$

ET_{gain}	Increase in ET from the application of irrigation water
CIR	Consumptive irrigation requirement
PSL_{sea}	Seasonal sum of the post surface loss irrigation
β	Water use efficiency term
$ET_{irr,sea}$	Seasonal sum of irrigate ET
$ET_{dry,sea}$	Seasonal sum of dryland ET
GIR	Gross irrigation requirement
$GW_{app,sea}$	Seasonal applied irrigation

$$CIR = ET_{irr,sea} - ET_{dry,sea} \tag{45}$$

$$GIR = NIR_{sea} * GIR_{factor} \tag{46}$$

$$\beta = \frac{CIR}{GIR} \tag{47}$$

NIR_{sea}	The seasonal depth of the net irrigation requirement

Table C-26. Growing Season Totals – Cell 159988 (in)

Crop	Total
NIR_{sea}	10.94
CIR	10.22
GIR	14.59
β	0.70
ET_{gain}	3.94

9. The ET gain then needs to be distributed back to the months. This is done using three sets of monthly criteria. If there is any ET gain remaining after one set of criteria, the remainder is subject to the next criterion. All of the calculations for cell 159988 in 2009 fall under the first criteria.
    a. PSL greater than 0 and ET_{irr} greater than ET_{dry}. The ET gain is then distributed weighted by the relative difference between ET_{irr} and ET_{dry}. The total ET gain within a month is limited to the depth of water applied to the crop (ET gain < PSL).
    b. PSL greater than 0 and ET_{dry} greater than ET_{irr}. The ET gain is then distributed weighted by the relative PSL. The total ET gain within a month is limited to the depth of water applied to the crop (ET gain < PSL).
    c. PLS was 0 and the ET_{irr} was greater than the ET_{dry}. The ET gain is distributed weighted by the relative ET_{irr}.

Using the rules defined above, all of the ET gain will be experienced in the months 7-9. The ET difference in those months is summed and the ET gain is weighted based upon the ET difference in the month divided by the total ET difference. The results are shown in Table C-27.

Table C-27. ET gain distribution for corn – Cell 159988 (in)

Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
ET gain	0.00	0.00	0.00	0.00	0.00	0.00	1.19	1.69	1.06	0.00	0.00	0.00	3.94

10. The ET base is the component from either dryland or irrigated ET which is expected when no irrigation is applied. The ET base is defined by Equations 48. The total ET is then found by summing the ET base with the ET gain. Table C-28 shows the results.

$$ET_{base,n} = \begin{cases} ET_{irr,n} & PSL \leq 0 \\ ET_{dry,n} & PSL > 0 \quad ET_{irr,n} > ET_{dry,n} \\ ET_{irr,n} & PSL > 0 \quad ET_{irr,n} < ET_{dry,n} \end{cases} \tag{48}$$

ET_{base} The non-irrigated ET

Table C-28. ET base and ET for corn – Cell 159988 (in)

Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
ET base	0.27	0.33	0.82	1.36	1.82	5.13	4.55	2.66	1.16	0.44	0.51	0.23	3.94
ET	0.27	0.33	0.82	1.36	1.82	5.13	5.74	4.35	2.22	0.44	0.51	0.23	23.22

11. This ET value however is an idealized amount. Strictly moving down the production curve. The exogenous forces that are not simulated in CropSim still have not been implemented yet. This is done using the irrigated ET adjustment factor (Equation 49). The difference between the idealized and adjusted ET is called ΔET (Equation 50). The results are shown in Table C-29.

$$ET_{irr,adj} = ET * ADJ_{ET,irr} \tag{49}$$

$ET_{irr,adj}$ The adjusted irrigated ET
ET The idealized irrigated ET
$ADJ_{ET,irr}$ Irrigated ET adjustment factor

$$\Delta ET = ET - ET_{irr,adj} \tag{50}$$

Table C-29. ET base and ET for corn – Cell 159988 (in)

Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
$ET_{irr,adj}$	0.26	0.31	0.78	1.29	1.73	4.87	5.46	4.13	2.11	0.42	0.48	0.22	22.06
ΔET	0.01	0.02	0.04	0.07	0.09	0.26	0.29	0.22	0.11	0.02	0.03	0.01	1.16

12. The ΔET is the divided between runoff and deep percolation using the partitioning factor (Equations 51-52). The results are shown in Table C-30.

$$RO_3 = \Delta ET * RODP_{wt} \tag{51}$$

$$DP_3 = \Delta ET - RO_3 \tag{52}$$

RO_3 Runoff resulting from the ET adjustment

DP_3 Deep Percolation resulting from the ET adjustment

Table C-30. Runoff and deep percolation from the ET adjustment – Cell 159988 (in)

Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
RO_3	0.01	0.01	0.02	0.05	0.07	0.21	0.14	0.17	0.06	0.02	0.01	0.01	0.78
DP_3	0.01	0.01	0.02	0.01	0.02	0.05	0.14	0.04	0.06	0.01	0.01	0.01	0.39

13. The difference between the PSL irrigation and the ET gain is excess irrigation and must be split between deep percolation and runoff (Equation 53-54). The results are shown in Table C-31.

$$RO_2 = \left(PSL - ET_{gain}\right) * RODP_{wt} \tag{53}$$

$$DP_2 = \left(PSL - ET_{gain}\right) * (1 - RODP_{wt}) \tag{54}$$

RO_2 Runoff resulting from irrigation inefficiencies

DP_2 Deep Percolation resulting from irrigation inefficiencies

Table C-31. Runoff and deep percolation from excess irrigation – Cell 159988 (in)

Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
RO_2	0.00	0.00	0.00	0.00	0.00	0.00	0.52	0.42	0.13	0.00	0.00	0.00	1.07
DP_2	0.00	0.00	0.00	0.00	0.00	0.00	0.52	0.10	0.13	0.00	0.00	0.00	0.75

14. The total runoff and the total deep percolation is found by summing the three sub-types (Equation 55-56). This sum in turn is converted from a depth to a volume for the entire crop area. All recharge and all deep percolation with in the cell are then summed to get the cell total (Equation 57-58). The results are summed for the direct runoff from the field. The results can be seen in Table C-32.

$$RO_{dir} = RO_1 + RO_2 + RO_3 \tag{55}$$

$$DP_{dir} = DP_1 + DP_2 + DP_3 \tag{56}$$

RO_{dir} Total direct runoff

DP_{dir} Total direct deep percolation

$$RO_{cell} = \sum_{i=1}^{k} \frac{RO_{dir}}{12} * AC_i \tag{57}$$

$$DP_{cell} = \sum_{i=1}^{k} \frac{DP_{dir}}{12} * AC_i \tag{58}$$

RO_{cell} The total runoff in the cell

DP_{cell} The total deep percolation in the cell

k	Number of crops – irrigation source combinations in the cell
AC	Number of acres for the crop – irrigation source combination

Table C-32. Total cell runoff and deep percolation – Cell 159988 (AF)

Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
RO_{cell}	0.02	0.03	0.07	3.65	2.68	6.72	2.20	2.34	0.63	0.16	0.04	0.02	18.54
DP_{cell}	0.02	0.03	0.07	0.05	0.06	1.47	2.20	0.50	0.63	0.05	0.04	0.02	5.13

The following calculations take place in the in the Make_Well Program.

1. After reading in all sources of pumping for the current year, the well information is retrieved. This information includes the well ID, the number of wells that feed the certificate and the cell each well is located within. Table C-33shows the wells that are the ground water source for certificate 2429.

Table C-33. Well IDs for well feeding certificate 2429.

Well ID	Cell
118610	159991
124064	159467
184839	158945

2. The certificate pumping is then split between the wells. Table C-34 shows the portion of the pumping that is assigned to each well.

Table C-34. The ground water only pumping from certificate 2429 to the specific wells.

Well ID	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
118610	0.00	0.00	0.00	0.00	0.00	3.14	50.31	53.46	28.29	0.00	0.00	0.00	135.20
124064	0.00	0.00	0.00	0.00	0.00	3.14	50.31	53.46	28.29	0.00	0.00	0.00	135.20
184839	0.00	0.00	0.00	0.00	0.00	3.14	50.31	53.46	28.29	0.00	0.00	0.00	135.20
Total	0.00	0.00	0.00	0.00	0.00	9.42	150.93	160.38	84.88	0.00	0.00	0.00	405.61

The following calculations are made in the Make_Rch program.

1. The first process is to read in all sources of runoff. In cell159988, no canal recharge or supplementary recharge is present. So the only source of data for 159988 is limited to the direct runoff and recharge seen in Table C-32.

2. The loss factor and the % to recharge inputs determine the partitioning of the direct runoff between recharge, edge of field ET or non-beneficial ET, and stream flow. The loss factor is determined with Equation 59, and the result is shown in Table C-35.

$$Loss_{factor} = \begin{cases} 0.5 & MiToGauge \leq 0.0 \\ MIN(1 - e^{-LPM*MiToGauge}, 1.0) & MiToGauge > 0.0 \end{cases} \quad (59)$$

$Loss_{factor}$	The portion of the direct runoff that does not become stream flow
LPM	Loss per mile
MiToGauge	Miles to gauge

Table C-35. Loss factor – Cell 159988 (in)

Crop	Total
$Loss_{factor}$	0.17

3. The stream flow, recharge, and non-beneficial ET are computed by Equations 60-62. The results are shown in Table C-36.

$$SF = RO_{cell} * (1 - Loss_{factor}) \quad (60)$$

SF Stream Flow

$$RO2DP = RO_{cell} * Loss_{factor} * Per2rch \quad (61)$$

RO2DP	Runoff transfer to recharge
Per2rch	Partitioning factor of runoff losses between ET and DP

$$RO2ET = RO_{cell} * Loss_{factor} * (1 - Per2rch) \quad (62)$$

RO2ET Runoff transfer to non-beneficial ET

Table C-36. Runoff partitioning – Cell 159988 (AF)

Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
RO_{Cell}	0.02	0.03	0.07	3.65	2.68	6.72	2.20	2.34	0.63	0.16	0.04	0.02	18.54
SF	0.02	0.02	0.06	3.01	2.21	5.55	1.82	1.93	0.52	0.13	0.03	0.02	15.30
RO2DP	0.00	0.00	0.01	0.32	0.23	0.59	0.19	0.20	0.06	0.01	0.00	0.00	1.62
RO2ET	0.00	0.00	0.01	0.32	0.23	0.59	0.19	0.20	0.06	0.01	0.00	0.00	1.62

4. Finally, all sources of recharge are amassed into a single recharge term. The results are converted to the appropriate units (fpd), and written to the .RCH file (Table C-37)

Table C-37. Total Recharge – Cell 159988 (fpd)

Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rch	0.0002	0.00003	0.00006	0.00031	0.00024	0.00171	0.00193	0.00056	0.00057	0.00005	0.00004	0.00002

Conversion technique for converting between Cell ID and Row-Column. This method is based upon a grid that starts in the upper left hand corner and proceeds like a type writer left to right for each row. Equations 63-65 show the conversion method.

$$cell = (row - 1) * ncols + col \quad (63)$$

Cell	The cell ID
Row	The row the cell resides within
Col	The column the cell resides within
Ncols	The total number of columns in the grid (520)

$$col = \begin{cases} MOD(cell, ncols) & MOD(cell, ncols) <> 0 \\ ncols & MOD(cell, ncols) = 0 \end{cases} \quad (64)$$

$$row = \frac{cell - col}{ncols} + 1 \quad (65)$$

Example cell 159988

$$cell = (308 - 1) * 520 + 348 = 159988$$

$$col = MOD(159988{,}520) = 348$$

$$row = \frac{159988 - 348}{520} + 1 = 308$$