Nebraska Surface Water Administration Tool

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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 Nebraska Department of Natural Resources (DNR) and TFG originally dated 9 August 2010.

1.2. Purpose and Scope

This report focuses on the processes and application of estimating the effect of surface water administration on evapotranspiration (ET) in each of the INSIGHT sub-basins within the state of Nebraska. The report discusses the general methodologies and how the model was developed for the multitude of conditions present in the project domain. In the appendix, information is presented to allow a new user to develop estimates of the effect of varying levels of surface water administration (SW Admin) on ET. In addition a copy of the source code is included.

The primary role of the Nebraska Surface Water Administration Tool was to estimate the relative effect of implementing surface water administration on consumptive use.

2. Model Domain

The model was designed for the entire state of Nebraska as a part of the larger INSIGHT project. The influence from SW Admin on ET was designed to be a function of the regional location. As part of the INSIGHT project, 42 Administration areas were developed (Figure 2.1 & Table 2.1).

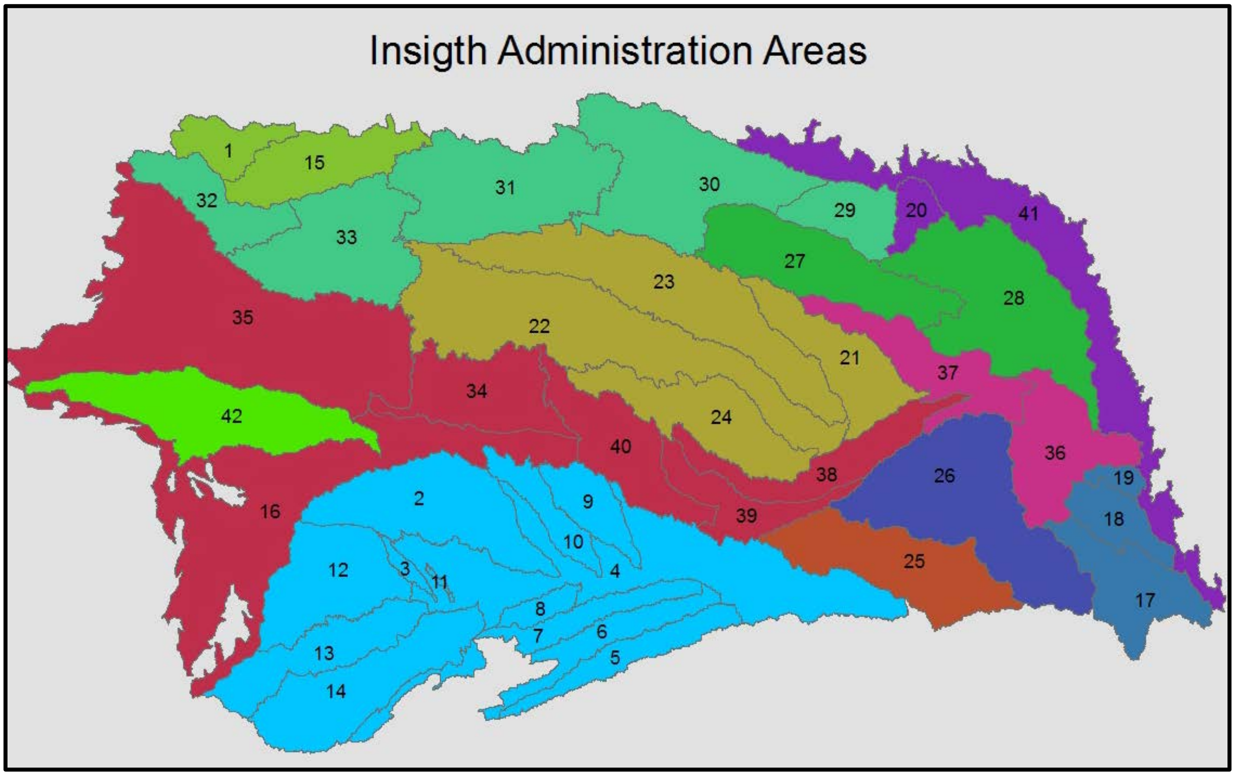

Figure 2.1 INSIGHT model sub-basins used as the as the surface water administration areas.

Table 2.1 Location of the INSIGHT model sub-basins.

Index	Gauge Location
1	Hat Creek near Edgemont, SD
2	Frenchman Creek at Culbertson, NE
3	Buffalo Creek near Haigler, NE
4	Republican River near Hardy, NE
5	Prairie Dog Creek near Woodruff, KS
6	Sappa Creek, 1 mile below gauge, near Stamford, NE
7	Beaver Creek near Beaver City, NE
8	Driftwood Creek near McCook, NE
9	Medicine Creek at Cambridge, NE
10	Red Willow Creek near Red Willow, NE
11	Rock Creek at Parks, NE
12	North Fork Republican River at CO-NE State Line
13	Arikaree River at Haigler, NE
14	South Fork Republican River near Benkelman, NE

Index	Gauge Location
15	White River near NE-SD State Line
16	South Platte River at North Platte, NE
17	Big Nemaha River at Falls City, NE
18	Little Nemaha River at Auburn, NE
19	Weeping Water Creek at Union, NE
20	Bazile Creek near Niobrara, NE
21	Loup River near Genoa, NE
22	Middle Loup River at Saint Paul, NE
23	North Loup River near Saint Paul, NE
24	South Loup River at Saint Michael, NE
25	Little Blue River at Hollenberg, KS
26	Big Blue River at Barneston, NE
27	Elkhorn River at Norfolk, NE
28	Elkhorn River at Waterloo, NE
29	Niobrara River at Niobrara, NE
30	Niobrara River near Spencer, NE
31	Niobrara River near Sparks, NE
32	Niobrara River above Box Butte Reservoir, NE
33	Niobrara River near Gordon, NE
34	North Platte River at North Platte, NE
35	North Platte River near Lewellen, NE
36	Platte River at Louisville, NE
37	Platte River at North Bend, NE
38	Platte River near Duncan, NE
39	Platte River near Grand Island, NE
40	Platte River near Overton, NE
41	Missouri River at Rulo, NE
42	Lodgepole Creek at Ralton, NE

3. Conceptual Model

The administration of surface water involves restricting the diversion of irrigation water from the river for some period of time. If the diversion restriction occurs when the crop is in need of irrigation water, the restrictions on the amount of water applied to the fields have the potential to reduce ET gain[1] which has been shown to be directly linked to yields (citation).

The first step is to determine the portion of the Net Irrigation Requirement (NIR) that the system will not be able to provide to the crop due to the diversion restrictions. The model estimates this deficit in NIR as a function of the ratio between administered days and total days within each month and the number of irrigation grace days[2] (Equation 1).

$$NIR_{Admin} = \begin{cases} \begin{cases} NIR * ADJ_{NIR} * \left(1 - \dfrac{e^{\frac{D_{Admin}-D_g}{DIM-D_g} * f_{shape}} - 1}{e^{f_{shape}} - 1}\right) & f_{shape} \neq 0 \\ NIR * ADJ_{NIR} * \left(1 - \dfrac{D_{Admin} - D_g}{DIM - D_g}\right) & f_{shape} = 0 \end{cases} & D_{Admin} > D_g \\ NIR * ADJ_{NIR} & D_{Admin} \leq D_g \end{cases} \qquad (1)$$

NIR_{Admin}	Net Irrigation Requirement that can be delivered to the field. It is adjusted by surface water administration and for the differences between the idealized CropSim model and field conditions[3]
NIR	CropSim NIR for the basin
ADJ_{NIR}	NIR adjustment factor to account for the differences between the idealized CropSim model and field conditions[3]
D_{Admin}	Number of days of SW Administration for the diversion
D_g	Number of irrigation grace days
DIM	Days in the calendar month
f_{shape}	Factor controlling the shape of the curve

[1] ET gain is the increase in beneficial consumptive use from the application of irrigation water.

[2] Irrigation grace days represent a period of time in which the diversion of surface water is restricted, but the effect on NIR could be negated if the restriction were lifted. During this time period the crop's demand for water could be met by existing available water.

[3] CropSim is idealized in the fact that water is the only limiting factor to production. However, other aspects such: as insects, disease, inclement weather, and management decisions; influence crop production and consumptive use.

The resultant Administered NIR was then converted into a depth of gross irrigation applied by dividing by the application efficiency (Equation 2).

$$AppWat = \frac{NIR_{Admin}}{AE_{SW}} \qquad 2$$

AppWat	Depth of gross irrigation water applied to the field
AE_{SW}	Surface water application efficiency

Simultaneously, the depth of irrigation water that would be applied to the crops under non-administrative conditions is also calculated (Equation 3).

$$AppWat = \frac{NIR}{AE_{SW}} * ADJ_{NIR} \qquad 3$$

With the depth of irrigation water that would be applied under administered and non-administered conditions estimated, the resultant ET gain for amount can be determined. While the relationship between ET and yields is linear, the relationship between applied irrigation and yields has been shown to be subject to diminishing returns. Martin(Cite) proposed the use of a Cobb-Douglas equation to relate applied irrigation to yields. This approach was modified to calculate ET gain as a function of applied irrigation[4] (Equation 4).

$$ET_{gain} = \begin{cases} CIR * (1 - \left(1 - \dfrac{AppWat}{GIR}\right)^{\frac{1}{\beta}} & AppWat < GIR \\ CIR & AppWat \geq GIR \end{cases} \qquad 4$$

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 5

$$CIR = ET_{sea,irr,max} - ET_{sea,base,max} \qquad 5$$

GIR	Gross Irrigation Requirement; the amount of water that needs to be applied in order to meet the net irrigation requirement (Equation 6)

$$GIR = \frac{NIR_{sea}}{AE_{SW}} \qquad 6$$

[4] It should be noted that this equation represents a seasonal curve, as the effects of irrigation in each month have an influence on the subsequent months.

β Water use efficiency term defined by Equation 7

$$\beta = \frac{CIR}{GIR} \quad 7$$

AppWat	Depth of gross irrigation water applied to the field
$ET_{sea,irr,max}$	ET needed to meet the max yield potential for an irrigated crop during the growing season
$ET_{sea,base,max}$	Expected ET for an irrigated crop grown under rain-fed conditions (no irrigation water is applied) during the growing season.

Equation 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 gross irrigation requirement, the marginal increase in ET goes to zero, with any additional increases in irrigation resulting in no increase in beneficial consumptive use.

The ET gain for the administrated and non-administrated scenarios is then divided from the seasonal value to monthly values. This apportionment was weighted based upon the relative monthly Administrated NIR and NIR respectively (Equations 8-9).

$$ET_{gain,Admin,i} = ET_{gain,Admin} * \frac{NIR_{Admin,i}}{NIR_{Admin,sea}} \quad 8$$

$$ET_{gain,NA,i} = ET_{gain,NA} * \frac{NIR_i}{NIR_{sea}} \quad 9$$

$ET_{gain,Admin,i}$	Monthly ET gain from administered conditions
$ET_{gain,Admin}$	Growing season ET gain from administered conditions
$NIR_{Admin,i}$	Administrated NIR in month i
$NIR_{Admin,i}$	Growing season Administrated NIR
$ET_{gain,NA,i}$	Monthly ET gain from non-administered conditions
$ET_{gain,NA}$	Growing season ET gain from non-administered conditions
NIR_i	Monthly NIR
NIR_{sea}	Seasonal NIR
i	month

Each ET gain was then combined with the base ET to determine the total monthly ET. An adjustment to the ET was applied to account for the idealization of CropSim. Finally the monthly ratio of Administrated ET to Non-Administrated ET was computed (Equation 10-12).

$$ET_{Admin,i} = \left(ET_{gain,Admin,i} + ET_{base,i}\right) * ADJ_{ET} \quad 10$$

$$ET_{NA,i} = \left(ET_{gain,NA,i} + ET_{base,i}\right) * ADJ_{ET} \quad 11$$

$$R_{ET} = \frac{ET_{Admin,i}}{ET_{NA,i}} \quad 12$$

$ET_{Admin,i}$	Monthly ET under administered conditions
$ET_{base,I}$	Monthly ET expected under rainfed conditions
ADJ_{ET}	ET adjustment to account for the difference between the idealized CropSim and field conditions
$ET_{NA,I}$	Monthly ET under non-administered conditions
$ET_{gain,NA,I}$	Monthly ET gain under non-administered conditions
R_{ET}	Monthly ratio of Administered ET to Non-Administered ET

4. Model Construction

4.1. Statewide NIR

As part of the INSIGHT project, water balance parameter values were developed on a mile grid for the entire state of Nebraska. Further information on the development of the statewide NIR is available in the Draft statewide NIR document.

4.2. Potential Surface Water Irrigation Area

Due to the unknown location of many of the small surface water diverters, ambiguity arises in which water balance parameters to utilize in the model. The distributed water balance parameters already have the soils information incorporated into their values. While a simple average of the cells within each basin was considered, many of the large basins had the possibility to be overwhelmed by the soils that were not subject to surface water irrigation. Rather, the assumption was made that the majority of the surface water irrigated fields would be located near the irrigation source. Therefore, the basin water balance parameters were developed utilizing the cells that were within a mile of the major rivers within each basin (Figure 4.1).

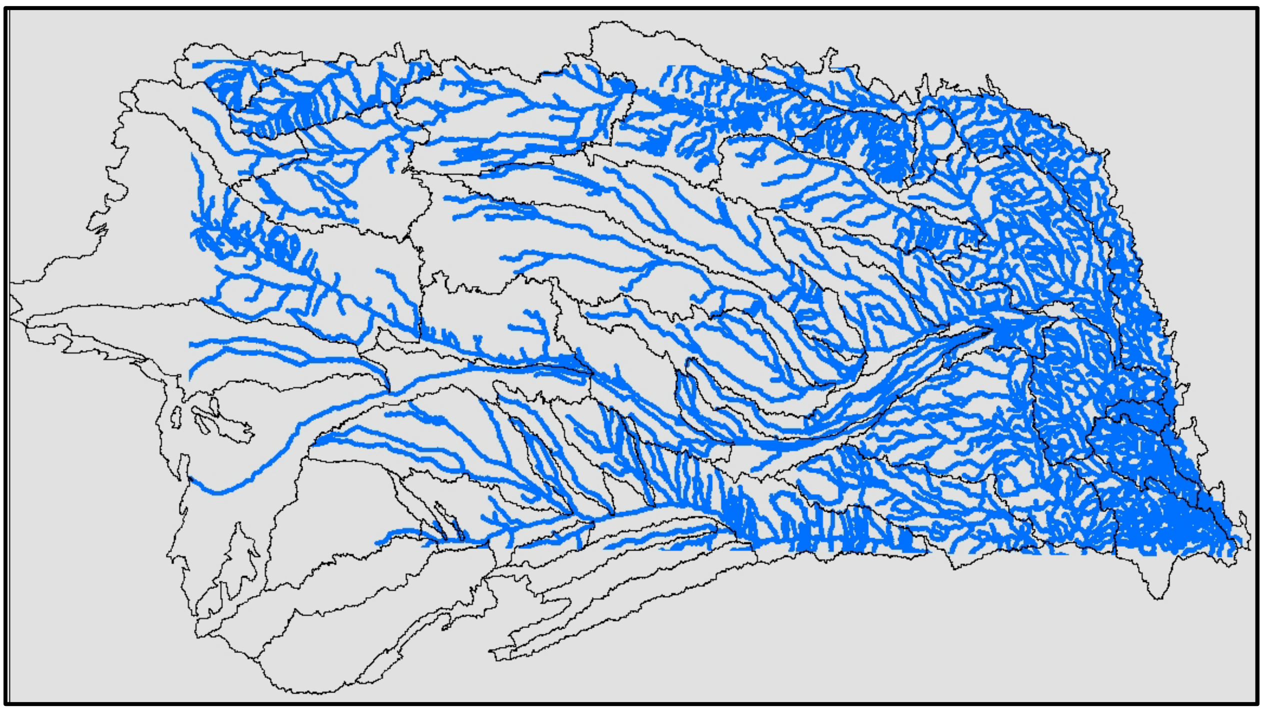

Figure 4.1. Model area used to identify the basin water balance parameters.

4.3. Application Efficiency – Surface Water

Surface water application efficiency is the ratio of net irrigation to gross irrigation. This parameter is necessary in determining the depth of gross irrigation needed to provide the appropriate amount of net irrigation to the field. The prevailing assumption of the model is that these surface water diversions are applied to the field using flood irrigation; therefore, an application efficiency of 0.65 was used.

4.4. Adjustment Factor

The adjustment factor were used to adjust the idealized conditions in CropSim to field conditions. The adjustment factors were extracted from the Regionalized Soil Water Balance Models for the Upper Niobrara White Model, Western Water Use Model, Blue Basin Model, Central Nebraska Model, and Lower Platte and Missouri Tributaries Assessment Model. The modeling process used to determine the adjustment factors is not currently being employed in the COHYST or Republican River areas. Insight sub-basins in this area were assigned default adjustment factors.

A NIR adjustment factor of 0.95 was used for all basins. While the dryland and irrigated ET adjustment factors were 0.95 for all basins. The only exceptions were for the Little Blue River Basin (index 25) and the Big Blue River Basin (index 26). In these two basins the calibrated ET adjustment factor was found to be more nearly 0.99.

4.5. Grace Days and f shape

The administration of a surface water diversion can influence the ability of an irrigator to meet a crop's demand for water. However, the exact timing of when restricting the diversion will start to exhibit this influence depends on several factors. An irrigation event which occurs the day before the administration begins will have a different influence than if the last irrigation was 5 day before. Precipitation occurring during the administration can mitigate the lack of irrigation. The presence of sufficient plant available soil water potentially provides a reserve from which the crop can draw. Lower potential ET can reduce the rate at which water is demanded. Furthermore, the timing of the administration and the need to apply irrigation water may not overlap. At the scope in which the model is being run much of this information is not available.

Therefore some allowances are made to try to account for this lack of information. The grace days and f shape parameter in Equation 1 are used to adjust the influence of timing and available water to the plant. Grace days would reduce the number of administration days that influence would reduce the portion of NIR the irrigator would be able to apply. The current model setting for grace days is 0. The f shape parameter adjusts the rate at which administration days influence the portion of the NIR that the irrigator can provide to the crop. The model utilizes an f shape parameter of 1.5 which reduces the marginal change in NIR that the irrigator can apply for fewer administrated days and increases that marginal change as the number of administrated days increases.

5. Model Inputs

5.1. Basin Water Balance Parameters

The model uses three water balance parameters to estimate the Administrated ET ratio: dryland ET, irrigated ET, and NIR. Employing the potential surface water irrigation area in each basin, basin values were created by averaging the active cell values. The result was twelve monthly values for each basin year combination. These input values can be found in the worksheets *Dry ET, Irrigated ET,* and *NIR* respectively.

5.2. Administered Diversion

The administered diversions are the user input into the model. The required values are the diversion name, year, basin index, and the monthly administered days. The diversion name indicates the diversion identification. The year identifies which set of water balance parameters will be used to calculate the administered ET ratio. The basin index identifies the general location of the surface water diverter. The monthly administered days defines how many days each month the irrigator is subject to surface water administration.

5.3. Model Output

The model returns a list of all of the administered diversions. Each line consists of the diversion name, the year, the basin index number, and the administered ET Ratio for each month.

6. Model Operations

6.1. Getting Started

The model is completely contained with a Microsoft Excel® macro-enabled workbook. Begin by opening the file. The program may prompt you to allow macros; this is necessary to run the model.

6.2. Input Administration Data

Click on the "Days of Administration" tab. This is where the monthly days of administration are inputted into the model. The top two rows of the worksheet are inert. The first diversion-year to be simulated should be placed in row three. Each new diversion-year combination should be placed in in the first blank row.

Each input line needs the following information:

Location	Item	Description
Column A	Diversion name	Diversion Identification
Column B	Year	Year to be simulated; needs to be between 1950 and 2012
Column C	Basin Index	Location of the surface water diversion. A map and the list of the basins is located in Figure 2.1 & Table 2.1 of this document and the "Basin ID" tab in the workbook.
Columns D-O 12 columns	Administration Days	Number of days in that month that the diverter was restricted

6.3. Running the Program

After all of the administration data has been inputted into the program, press the "Run Surface Water Administration Tool" button (Figure 6.3) located near cell "Q1". The program will cycle through each diversion-year to be simulated and output the results to the "Adjustment Factor" tab.

Figure 6.1 Start button for Surface Water Administration Tool

6.4. Model Output

The results of the model are written to the "Adjustment Factor" tab. Each line in the output directly corresponds to the same line in the "Days of Administration" tab. The results starting in row 3 are:

Location	Item	Description
Column B	Year	Year to be simulated; needs to be between 1950 and 2012
Column C	Basin Index	Location of the surface water diversion. A map and the list of the basins is located in Figure 2.1 & Table 2.1 of this document and the "Basin ID" tab in the workbook.

Columns D-O 12 columns	Administered ET Ratio	Ratio of the administered adjusted ET to the adjusted fully irrigated ET

The results can be saved or exported in the same fashion as any Microsoft Excel® workbook.

7. Model Operations: Advanced Settings

7.1. Locked Worksheets

Several worksheets within the model are locked to user manipulation; NIR, Irrigated ET, Dry ET. While it is not suggested, these sheets can be unlocked (unprotect workbook; review ribbon) with the password: *TFG*. It should be noted that the functionality of the model is indirectly tied to these sheets; alterations will not take effect until the hidden worksheet is updated. However, once updated alterations to these sheets will cause the program to function differently or crash.

7.2. Hidden Worksheets

The model contains one hidden worksheet: Pivots. This sheets is used to sort through the basin water balance parameter sheets making the appropriate value readily accessible. It consists of three pivot tables. The sheet can be viewed by un-hiding the hidden sheets. This is accomplished by right-clicking on worksheet tabs at the bottom of your screen, choosing *Unhide*, and then selecting the Pivots sheet. It should be noted that the functionality of the model is directly tied to these sheets; alterations will cause the program to function differently or crash.

7.3. Altering the Model Code

The application efficiency, adjustment factors, grace days, and f shape are all hard coded into the model. To adjust these parameters, the model code must be adjusted. To view the code click on the *Developer* tab on the Ribbon and select *Visual Basic*. If the *Developer* tab is not visible; select the *File* tab, choose *options*, then chose *Customize Ribbon.* Select the *Developer* box.

The model code can be adjusted from in the visual basic window. The code is shown in Section 7.4.

7.4. Model Code

The model code was written as a sub-routine in VBA. The sub-routine was then assigned to the start button (Figure 6.1). The following includes the code and a description of the functions and variables within it.

```
Sub Admin()

    'ADJET         ET adjustment factor
    'ADJNIR        NIR adjustment factor
    'Adminday(12)  Number of days that the diverter is restricted from diverting each month - monthly
    'AdminET(12)   Total ET (base + gain) under adminstered conditions = monthly
    'AdminNIR(12)  Portion of NIR that can be met by an irrigator under administered conditions
    'AdminNIRsea   Total growing season NIR that can be met by an irrigator under administered conditions
    'AESW          Application Efficiency - surface water
    'AppWat        Total applied water during the growing season - Administered
    'AppWatMax     Total applied water during the growing season - No Administration
    'Beta          Water use efficiency
    'CIR           Consumptive Irrigation Requirement, Full ET gain
    'DaysInMon(12) Number of calendar days in the month - monthly
    'ET            Evapotranspiration
    'ETb(12)       Base ET, ET under rainfed conditions
    'ETbsea        Total growing season base ET
    'ETd(12)       Dry ET, ET under dryland conditions - monthly
    'ETg(12)       ET gain, Increase in ET from the application of irrigation water - Administrated - monthly
    'ETgmax(12)    ET gain, Increase in ET from the application of irrigation water - No Admininstration - monthly
    'ETi(12)       Irrigated ET, ET under fully irrigated conditions - monthly
    'ETisea        Total growing season fully irrigated ET
    'fshape        Function parameter to control the reduction of NIR caused by administration
    'GIR           Gross irrigation requirement
    'gracedays     Period of time (days) which during adminsitration do not effect NIR
    'ibasin        Basin within which the current diversion is located
    'imon          Month counter
    'irow          Current row itteration
    'istruct       Identification of current diversion
    'iyear         Simulated year
    'MaxET(12)     Total ET (base + gain) under non-administered conditions - monthly
    'NIR(12)       Net Irrigation Requirement - monthly
    'NIRsea        Total growing season NIR
    'nrows         Number of diversion-year combinations needed to be simulated
    'OUT1          Name of the sheet where the results are written
    'sAdmin        Name of the sheet containing the Administration data
    'WBPS          Name of the sheet containing the water balance parameter pivot tables
```

```
'initialize variable that are arrays
Dim adminday(12)
Dim NIR(12)
Dim ETi(12), ETd(12), ETb(12), ETg(12), ETgmax(12)
Dim AdminNIR(12), AdminET(12), MaxET(12)
Dim DaysInMon(12)

'identify the location of inputs and outputs
sAdmin = "Days of Administration"
WBPs = "Pivots"
OUT1 = "Adjustment Factor"

'Initialize the number of days each month
DaysInMon(1) = 31
DaysInMon(2) = 28
DaysInMon(3) = 31
DaysInMon(4) = 30
DaysInMon(5) = 31
DaysInMon(6) = 30
DaysInMon(7) = 31
DaysInMon(8) = 31
DaysInMon(9) = 30
DaysInMon(10) = 31
DaysInMon(11) = 30
DaysInMon(12) = 31

'Count the number of diversion-year combinations to be simulated
nrows = WorksheetFunction.CountIf(Sheets(sAdmin).Range("B:B"), ">0")

'Initialize model parameters
ADJNIR = 0.95
AESW = 0.65

'Added to change the NIR reduction function shape
fshape = 1.5
gracedays = 0

'Begin diversion-year combination (DYC) loop
For irow = 1 To nrows

  'Identify DYC characteristics
  istruct = Sheets(sAdmin).Range("A2").Offset(irow, 0).Value
  ibasin = Sheets(sAdmin).Range("C2").Offset(irow, 0).Value
  iyear = Sheets(sAdmin).Range("B2").Offset(irow, 0).Value
```

```
'Write DYC characteristics to output
Sheets(OUT1).Range("A2").Offset(irow, 0).Value = istruct
Sheets(OUT1).Range("B2").Offset(irow, 0).Value = iyear
Sheets(OUT1).Range("C2").Offset(irow, 0).Value = ibasin

'Ensure simulation year is within the model domain
If iyear < 1950 Or iyear > 2012 Then
   Sheets(OUT1).Rage("D2").Offset(irow, 0).Value = "Year Outside Range of data"
   GoTo 1
End If

'Update Pivot tables to the appropriate year
Sheets(WBPs).Range("C2").Value = iyear
Sheets(WBPs).Range("C51").Value = iyear
Sheets(WBPs).Range("C100").Value = iyear

'Adjust February days for leap years
If iyear Mod 4 = 0 Then
   DaysInMon(2) = 29
Else
   DaysInMon(2) = 28
End If

'Initialize the ET adjustment
If ibasin = 26 Or ibasin = 25 Then
   ADJET = 0.99
Else
   ADJET = 0.95
End If

'Zero Growing season totals
ETbsea = 0#
ETisea = 0#
NIRsea = 0#
AdminNIRsea = 0#

For imon = 1 To 12

   'Retrieve information: Administration Days
   adminday(imon) = Sheets(sAdmin).Range("C2").Offset(irow, imon).Value

   'Retrieve Information: Basin Water Balance Parameters
   NIR(imon) = Sheets(WBPs).Range("B4").Offset(ibasin, imon).Value
   ETi(imon) = Sheets(WBPs).Range("B53").Offset(ibasin, imon).Value
   ETd(imon) = Sheets(WBPs).Range("B102").Offset(ibasin, imon).Value
```

```
    'Identify the rainfed ET
    If NIR(imon) > 0 Then
      If ETi(imon) >= ETd(imon) Then
        ETb(imon) = ETd(imon)
      Else
        ETb(imon) = ETi(imon)
      End If
    Else
      ETb(imon) = ETi(imon)
    End If

    'Make adjustment to NIR for idealization and administration
    If adminday(imon) <= gracedays Then
      'No administration effect
      AdminNIR(imon) = NIR(imon) * ADJNIR
    Else
      If fshape = 0 Then
        'Linear model
         AdminNIR(imon) = NIR(imon) * ADJNIR * (1 - (adminday(imon) - gracedays) / (DaysInMon(imon) -
         gracedays))
      Else
        'Non-Linear model
         AdminNIR(imon) = NIR(imon) * ADJNIR * (1 - (Exp((adminday(imon) - gracedays) / (DaysInMon(imon) -
         gracedays) * fshape) - 1) / (Exp(fshape) - 1))
      End If
    End If

    'Compute growing season totals
    If NIR(imon) > 0# Then
      AdminNIRsea = AdminNIRsea + AdminNIR(imon)
      NIRsea = NIRsea + NIR(imon)
      ETisea = ETisea + ETi(imon)
      ETbsea = ETbsea + ETb(imon)
    End If
  Next

  'Calculate the seasonal Cobb-Dougals parameters
  CIR = WorksheetFunction.Max(ETisea - ETbsea, 0.0001)
  GIR = NIRsea / AESW
  Beta = CIR / GIR

  'Determine the depth of water applied to the field - Administered
  AppWat = AdminNIRsea / AESW
```

```
        'Determine the Administered seasonal ET gain
        If GIR > AppWat Then
           'Deficit irrigation
           ETgain = WorksheetFunction.Max(CIR * (1 - (1 - AppWat / GIR) ^ (1 / Beta)), 0#)
        Else
           'Sufficient irrigation
           ETgain = WorksheetFunction.Max(ETisea - ETbsea, 0#)
        End If

        'Determine the non-adminstered water applied to the field
        AppWatMax = NIRsea / AESW * ADJNIR

        'Determine the non-adminsterd seasonal ET gain
        If GIR > AppWatMax Then
           'Deficit irrigation
           ETGainMax = WorksheetFunction.Max(CIR * (1 - (1 - AppWatMax / GIR) ^ (1 / Beta)), 0#)
        Else
           'Sufficient irrigation
           ETGainMax = WorksheetFunction.Max(ETisea - ETbsea, 0#)
        End If

        For imon = 1 To 12
           'Distribute Seasonal ET gain to the months
           ETg(imon) = ETgain * AdminNIR(imon) / AdminNIRsea
           ETgmax(imon) = ETGainMax * NIR(imon) / NIRsea

           'Compute total monthly ET
           AdminET(imon) = (ETb(imon) + ETg(imon)) * ADJET
           MaxET(imon) = (ETb(imon) + ETgmax(imon)) * ADJET

           'Determine and output the ratio of Administered to Non-Administered ET
           Sheets(OUT1).Range("C2").Offset(irow, imon).Value = AdminET(imon) / MaxET(imon)

        Next
1   Next
End Sub
```

8. Sample Calculations

A sample calculation will be performed to show the methodology used in the model. The test data has the following information:

Structure ID:	aSFD	
Basin ID:	9	
Gauge:	Medicine Creek at Cambridge, NE	
Year:	2002	
Administration Days:	June	15
	July	28
	August	21

Furthermore, the following model parameter are used:

NIR adjustment:	ADJ_{NIR} =	0.95
ET adjustment:	ADJ_{ET} =	0.95
Application Efficiency:	AE_{SW} =	0.65
Grace days:		0
f shape:		1.5

Using the administered diversion information, the water balance parameters for Basin 9 are identified (Table 8.1).

Table 8.1 Basin Water Balance Parameters

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
NIR	-	-	-	-	-	0.95	9.44	5.83	0.19	-	-	-	16.40
ET irr	0.41	0.30	0.40	0.52	1.73	5.99	9.71	7.47	2.03	0.78	0.84	0.02	30.19
ET dry	0.04	0.32	0.36	0.57	1.69	4.59	1.07	1.85	0.92	0.97	0.86	-	13.23

The first step is to determine the base ET. The base ET represents the ET that would occur if the irrigated crop received no irrigation water. It is calculated using Equation xx and the results can be found in Table 8.2.

$$ET_{base} = \begin{cases} \begin{cases} ET_{dry} & ET_{irr} \geq ET_{dry} \\ ET_{irr} & ET_{irr} < ET_{dry} \end{cases} & NIR > 0 \\ \qquad\quad ET_{irr} & NIR \leq 0 \end{cases} \tag{13}$$

Table 8.2 Rainfed ET

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
ET base	0.41	0.30	0.40	0.52	1.73	4.59	1.07	1.85	0.92	0.78	0.84	0.02	13.42

Next the portion of NIR that can be met by the irrigator after administration is calculated using equation xx. The results are shown in Table 8.3.

$$NIR_{Admin} = NIR * ADJ_{NIR} * \left(1 - \frac{e^{\frac{D_{Admin}-D_g}{DIM-D_g} * f_{shape}} - 1}{e^{f_{shape}} - 1}\right) \quad \mathbf{14}$$

Table 8.3 Portion of NIR an irrigator can apply to a field under administration.

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Admin NIR	-	-	-	-	-	0.61	1.56	2.74	0.18	-	-	-	5.08

With the monthly Administered NIR calculated, the growing season totals are computed. The growing season is defined as months where NIR > 0. Table 8.4 shows the growing season totals for NIR, Administrated NIR, Irrigated ET, and Base ET.

Table 8.4 Growing season totals

Parameter	Total
NIR	16.40
Admin NIR	5.08
ET irr	25.20
ET base	8.42

Using the information in Table 8.3 and Table 8.4, The depth of gross irrigation applied under administration (Equation 15) and non-administration (Equation 16) conditions can be calculated. Furthermore, the Consumptive Irrigation Requirement (CIR, Equation 17), Gross Irrigation Requirement (GIR, Equation 18), and Water Use Efficiency (β, Equation 19) can be calculated. The results are shown in Table 8.5.

$$AppWat = \frac{NIR_{Admin}}{AE_{SW}} \quad 15$$

$$AppWat = \frac{NIR}{AE_{SW}} * ADJ_{NIR} \quad 16$$

$$CIR = ET_{sea,irr,max} - ET_{sea,base,max} \quad 17$$

$$GIR = \frac{NIR_{sea}}{AE_{SW}} \quad 18$$

$$\beta = \frac{CIR}{GIR} \quad 19$$

Table 8.5 Cobb-Douglas Equation Parameters

Parameter	Value
Applied Water Administered	7.82
Applied Water	23.97
CIR	16.77
GIR	25.23
β	0.66

With the Cobb-Douglas parameters, the seasonal ET gain for both the administered and non-administered scenarios by using Equation 20. The results can be seen in Table 8.6.

$$ET_{gain} = \begin{cases} CIR * (1 - \left(1 - \frac{AppWat}{GIR}\right)^{\frac{1}{\beta}} & AppWat < GIR \\ CIR & AppWat \geq GIR \end{cases} \quad 20$$

Table 8.6 Seasonal ET gain totals under administered and non-administered conditions.

Scenario	ET gain
Administered	7.17
Non-Administered	16.59

The seasonal ET gain is then distributed to the months for each the administered (Equation 21) and non-administered (Equation 22) conditions. Next the monthly total ET for each condition is calculated by adding the monthly ET gain to the ET base (Equations 23-24). Results are shown in Table 8.7.

$$ET_{gain,Admin,i} = ET_{gain,Admin} * \frac{NIR_{Admin,i}}{NIR_{Admin,sea}} \quad 21$$

$$ET_{gain,NA,i} = ET_{gain,NA} * \frac{NIR_i}{NIR_{sea}} \quad 22$$

$$ET_{Admin,i} = \left(ET_{gain,Admin,i} + ET_{base,i}\right) * ADJ_{ET} \quad 23$$

$$ET_{NA,i} = \left(ET_{gain,NA,i} + ET_{base,i}\right) * ADJ_{ET} \quad 24$$

Table 8.7 Monthly ET gain and total ET values for the administrated and non-administrated conditions.

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
ET gain Admin	-	-	-	-	-	0.86	2.20	3.86	0.25	-	-	-	7.17
ET Admin	0.39	0.29	0.38	0.49	1.64	5.17	3.10	5.42	1.12	0.74	0.80	0.02	19.56
ET gain Non-Admin	-	-	-	-	-	0.96	9.54	5.90	0.19	-	-	-	16.59
ET Non-Admin	0.39	0.29	0.38	0.49	1.64	5.26	10.08	7.36	1.06	0.74	0.80	0.02	28.50

Finally the ratio of Administered ET to Non-Administered ET is computed using Equation 25. The results are shown in Table 8.8.

$$R_{ET} = \frac{ET_{Admin,i}}{ET_{NA,i}} \quad 25$$

Table 8.8 Ratio of administered ET to non-administered ET.

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ET Ratio	1.00	1.00	1.00	1.00	1.00	0.98	0.31	0.74	1.06	1.00	1.00	1.00