

## Appendix 6. Farm Process Version 4 (FMP)

The Farm Process (FMP) underwent substantial changes with this release of MF-OWHM2. Most of the base Fortran code was modernized to FORTRAN 2003 and 2008 to simplify developing land-use simulations, allow for easier development of future input updates, and remove FMP features that were not used. This is the fourth major release of the FMP and is referenced as FMP4 to distinguish it from previous releases; however, in this appendix the acronyms FMP and FMP4 are used interchangeably. The description of numerous changes to FMP4 input initially may seem overwhelming, but this is because all FMP4 input options are presented in this appendix.

Fundamentally, the FMP has four main input parts. The first and most important part, defines the Water Balance Subregions (WBS) that are spatially defined groups of surface model cells over which supply and demand calculations are aggregated. The WBS also acts as a surface IBOUND array—the boundary variable array defined in the Basic Package (BAS)—where the FMP will only perform its calculations in areas defined by a WBS identification (ID) that is specified within the range of one to the maximum number of WBS IDs (**NWBS**). The second part defines the landscape potential consumption from evaporation and transpiration and how excess water is handled on the landscape—where the excess becomes either surface runoff or deep percolation. An overview of this potential consumption, called consumptive use (CU), is described in appendix 4. The third part describes the available supplies to meet the potential consumption—for example, groundwater supply wells or surface-water diversions—and describes the case of irrigation and associated irrigation efficiency. The fourth part applies when climate or soil data are available; it describes how precipitation, reference evapotranspiration, and soil capillary fringe depths can optionally be defined.

This appendix first discusses the block-style input used for all the FMP input. The “Block-Style Input” section provides an overview of the new input structure, an explanation of the bare minimum requirements to run a FMP4 model, and a simple example input. The handling of the FMP4 input is adaptive by utilizing the amount of information given to determine the appropriate assumptions for landscape simulation. Options not specified are set to default values for the users’ convenience. If there is a combination of options that are invalid, then an error is raised explaining why the FMP cannot continue. At the end of this appendix are several example input sets of input keywords based on common FMP model setups.

### Features Removed

The features that were removed from the original input structure and replaced with a simpler block input are the prior appropriation scheme for ranked appropriation by farms that represented a water-rights hierarchy of preferred deliveries; the deficit irrigation options for acreage optimization, conservation pool, water stacking; and the LGR-FMP (Local Grid Refinement-FMP) “P” flag that would initiate an automatic transfer of farm and crop properties from the LGR parent to child model. The fully routed delivery option has been removed, and it is recommended to use semi-routed deliveries (SRDs) in its place. A fully routed delivery provided an automatic search for the uppermost streamflow routing (SFR) diversion segment to remove water from, which can be directly specified as an SRD point as described in the “SURFACE\_WATER Block” section. Additional features removed are the farm well parameters, the daily crop coefficient, and root-depth time series for the entire simulation—formerly set as  $ICUFL=3$  and  $IRTFI=3$ , the efficiency behavior flag (IEBFL) options (efficiency is now held constant until a new efficiency value is loaded), and the option to declare a Non-Irrigation season ( $IROTFL>0$ ). Lastly, the fraction of evaporation (FEP) from precipitation input is no longer required; instead, it is automatically calculated as  $1 - FTR$ , so that  $FEP = 1 - FTR$ .

### Block-Style Input

The FMP uses the new block-style input structure, defined in appendix 1, to group common input properties that are set using keywords. This input redesign is not backward compatible with the previous versions of the FMP (denoted as FMP1, FMP2, FMP3), which relied on a set structure of integer flags that dictated what features were in use, what land-use concepts to employ, and the frequency of data input. In contrast, the FMP version 4 automatically determines features in use and concepts to simulate on the basis of the amount of information provided or keywords supplied. After the keywords, specific input is loaded using the *List Array Input* (LAI) structure, *Universal Loader* (ULOAD), *Generic\_Input* files, and *Generic\_Output* files, which are defined in appendix 1.

Keywords that are not specified—that is, not written in the input block—will not activate the specific feature it represents, be assigned a default value, or FMP will raise an error message (if the keyword is a required input). If the keyword is required for the simulation to continue—such as **REFERENCE\_ET** ( $ET_{ref}$ ), which is required if **CROP\_COEFFICIENT** ( $K_c$ ) is specified ( $K_c \times ET_{ref}$ ; appendix 4)—then an error message is raised explaining why the simulation stopped and how to rectify the error. If an optional keyword is not specified, then it is either ignored or set to a default value. For example, if **PRECIPITATION** is not included, then it is assumed that the model has zero precipitation for the entire simulation. If the keyword pertains to a specific simulation concept, then the appropriate concept is selected depending on the level of input data provided. For example, if crop stress response **ROOT\_PRESSURE** is not included in the input, then the FMP will use the simpler anoxia- or wilting-point groundwater-root concept, called the *linear root response* (appendixes 4 and 5). Conversely, if the **ROOT\_PRESSURE** keyword is specified—indicating that stress-response root pressures are defined—then the crop model automatically uses the *analytical root response* option (appendixes 4 and 5). Previously this was done in MF-OWHM's FMP3 either by setting the input variable ICCFL to 1 or 3 to indicate stress-response root pressures are loaded to simulate the *Analytical root response* option or the ICCFL was set to 2 or 4 to indicate that the *Implicit Stress Assumption* was in use.

For additional flexibility, FMP4 allows for the mixture of some properties. For example, it is possible to have specified crops use the *Implicit Stress Assumption* and the remainder use the *analytical root response* option. This is done by setting to zero the four main inputs (that is, the root pressures) for crops that use the *implicit stress assumption* and by specifying a single non-zero root pressure causes the crop to use the *analytical root response*.

The block input structure supports the block specific keyword **BLOCK\_INCLUDE**. Statements using this keyword function identically to C language `#include "file"` and Fortran `INCLUDE File` statements allowing the user to specify a portion of a block in a separate file that is inserted at the **BLOCK\_INCLUDE** location. Consider a simple example of **BLOCK\_INCLUDE** that loads five keywords (fig. 6.1). At runtime, before any keywords are processed, FMP4 inserts all **BLOCK\_INCLUDE** files, strips out any comments, and adjusts all text to be left justified (fig. 6.1C).

The FMP4 blocks and keywords in the blocks may appear in any order. If a block is not present, or is empty, then it will automatically have all its values set to a default value or disabled. For example, if the **CLIMATE** block is not present in the input, then precipitation is set to zero and reference evapotranspiration is flagged internally as not being available for use within FMP. If a feature defined in another block relies on something in the **CLIMATE** block, then an error is raised explaining what input is necessary. If the block contains a conflicting set of options, either internally or from another block, then an error is raised explaining why the program stopped.

**Figure 6.1.** Block-style input example that uses **BLOCK\_INCLUDE** to insert text located in an external file. *A*, Example GLOBAL DIMENSION block input that contains **BLOCK\_INCLUDE** to load the contents of the file `Global_NVAR.txt`. *B*, The file `Global_NVAR.txt` that is inserted into the GLOBAL DIMENSION block input. *C*, The input that is read by MF-OWHM2.

**A**

```
BEGIN GLOBAL DIMENSION
#
NWBS          5
NCROP         3
#
BLOCK_INCLUDE ./Global_NVAR.txt
#
NRD_TYPES 0
END
```

**B**

```
# Contents of
# Global_NVAR.txt
# that is loaded with BLOCK_INCLUDE

NSOIL          1

NIRRIGATE 0

# note to self - remember this note about...
```

**C**

```
BEGIN GLOBAL DIMENSION
NWBS          5
NCROP         3
NSOIL          1
NIRRIGATE 0
NRD_TYPES 0
END
```

Although there is no requirement for the order of the blocks, it is recommended to follow the figure 6.2 listed order in an FMP input file. The block names were selected to indicate the type of input properties that are nested in them and the common dimension the input properties have. For example, all input that reads a list of numbers in the **LAND\_USE** block always reads **NCROP** numbers, where **NCROP** is the number of land-use types.

## Input Style Options and Explanation of Shorthand Notation

In the FMP4, blocks are the keywords that enable FMP features or load specific input. Keywords that load additional input either specify it as a *Generic\_Input*, **ULOAD**, **LAI**, load a single integer (**INT**), or floating-point number (**FLOAT**). See appendix 1 for a detailed and general description of these input utilities. An example of an **INT** is any number that does not contain a decimal place (–1, 0, 1, or 2), and a **FLOAT** is any number specified with a decimal place or in scientific and engineering notation (–1., 0.0, 1.5, 2E0, or 3.14E1). Please note that scientific and engineering notation implies that the number contains a decimal place, even when it is not specified, so the following are not **INT** numbers because they contain a decimal place: 10.0, 10., 1.E1, and 1E1. If the input expects a **FLOAT** and reads an **INT** number, then it converts it to a **FLOAT**—for example 2, 4, and 6 are read as 2.0, 4.0, and 6.0, respectively. If a keyword expects one of a potential set of additional keywords, then the additional keywords are enclosed in curly braces { } to indicate that one of the keywords within the curly braces must be selected. For example, the keyword **PRORATE\_DEFICIENCY** may only be specified once and must be followed by either the word **ByDEMAND** or **ByAVERAGE**. The shorthand notation would then indicate the input as **PRORATE\_DEFICIENCY { ByDEMAND, ByAVERAGE }** to indicate the input option may only be **PRORATE\_DEFICIENCY ByDEMAND** or **PRORATE\_DEFICIENCY ByAVERAGE**. Unless otherwise specified any input that loads a two-dimensional array with **ULOAD** expects the array to be the same dimension as the model grid (NROW × NCOL). If the input is loaded using **LAI**, then it will include the shorthand notation [S, T, A, L] to indicate the keywords it supports. These are described in detail in the “**LAI** [S, T, A, L] Input Format Meaning” section in appendix 1. The description is briefly reprised here in the context of the FMP with the option keywords (letters) representing the following:

S → <b>STATIC</b>	for single load of input with <b>ULOAD</b>
T → <b>TRANSIENT</b>	for stress period input with the <i>Transient File Reader</i> (TFR)
A → <b>ARRAY</b>	for <i>Array Style</i> input that loads a two-dimensional array
L → <b>LIST</b>	for <i>List Style</i> input that loads a record ID and one value per row of input

Block Name	Description
1) <b>GLOBAL_DIMENSION</b>	Global properties used by other FMP blocks.
2) <b>WATER_BALANCE_SUBREGION</b>	Properties that pertain to defining WBS.
3) <b>OPTIONS</b>	Global modifier options (legacy FMP features).
4) <b>OUTPUT</b>	Ancillary output files (for example, cell-by-cell unit number).
5) <b>SOIL</b>	Soil specific properties.
6) <b>CLIMATE</b>	Climate-related properties.
7) <b>SURFACE_WATER</b>	Surface-water deliveries and runoff properties.
8) <b>SUPPLY_WELL</b>	Groundwater supply well properties.
9) <b>ALLOTMENT</b>	Apply a limit on different water supplies.
10) <b>LAND_USE</b>	Land-use (Crop) specific properties.
11) <b>SALINITY_FLUSH_IRRIGATION</b>	Additional irrigation demand for salinity leaching.

**Figure 6.2.** Farm Process version 4 (FMP) supported Block Style input block names and basic description.

All LAI inputs loaded with LAI will have at least one **TEMPORAL\_KEY** (S and T) and at least one **INPUT\_STYLE** (A and L). If a keyword does not support a specific LAI option, then it is not included in the brackets [ ]. For example, **REFERENCE\_ET** may only be loaded with *Array Style* input, so the input statement is as follows:

```
REFERENCE_ET LAI[S, T, A]
```

This would indicate that the following are potential keyword options when specifying reference ET:

<b>REFERENCE_ET</b>	<b>STATIC</b>	<b>ARRAY</b>	ULOAD
<b>REFERENCE_ET</b>	<b>TRANSIENT</b>	<b>ARRAY</b>	<i>Generic_Input_OptKey</i>
<b>REFERENCE_ET</b>	<b>STATIC</b>		ULOAD
<b>REFERENCE_ET</b>	<b>TRANSIENT</b>		<i>Generic_Input_OptKey</i>
<b>REFERENCE_ET</b>	<b>CONSTANT</b>		VALUE

The *Generic\_Input\_OptKey* specifies the TFR, which would specify what input is loaded for each stress period. A TFR file must be a separate input file and cannot be specified with the **INTERNAL** keyword. The FMP interpreter assumes a **TEMPORAL\_KEY** if there is only one available. For example, because the keyword **PRECIPITATION** only supports *Array Style* input the use of the keyword **ARRAY** is optional. The keyword **CONSTANT** is syntactic sugar to the specifying **REFERENCE\_ET STATIC ARRAY CONSTANT** VALUE (which is one of the ULOAD keywords).

## Multi-Column List Style Input

Some of the FMP4 input requires a multi-column *List Style* input structure. For example, the keyword **ROOT\_PRESSURE** loads a crop ID and four root pressures. Under this situation the L part of the abbreviation is modified to LAI[S, T, A, L-K], where K indicates the number of columns of data that are loaded in addition to the record ID (integer in column 1). If a keyword is associated with multi-column *List Style* input, then it will NOT support *Array Style*. For example, **ROOT\_PRESSURE** may only be loaded with *List Style* input, so the input statement is as follows:

```
ROOT_PRESSURE LAI[S, T, L-4]
```

This indicates that the following are potential keyword options when specifying root pressures:

<b>ROOT_PRESSURE</b>	<b>STATIC</b>	<b>LIST</b>	ULOAD
<b>ROOT_PRESSURE</b>	<b>TRANSIENT</b>	<b>LIST</b>	<i>Generic_Input_OptKey</i>
<b>ROOT_PRESSURE</b>	<b>STATIC</b>		ULOAD
<b>ROOT_PRESSURE</b>	<b>TRANSIENT</b>		<i>Generic_Input_OptKey</i>
<b>ROOT_PRESSURE</b>	<b>CONSTANT</b>		VALUE

The keyword **CONSTANT** is syntactic sugar to the specifying **ROOT\_PRESSURE STATIC LIST CONSTANT** VALUE. The L-4 indicates that the root-pressure input expects four columns of data in addition to the record ID. Figure 6.3 is example input that would load root pressures for five land-use types (**NCROP** = 5). Because the keyword **ROOT\_PRESSURE** only supports *List Style* input the use of the keyword **LIST** is optional. Further, the read utilities interpret the keyword **INTERNAL** to only work with **STATIC**, so specifying **STATIC** with **INTERNAL** is optional (fig. 6.3B).

**A**

```
# Expected input: ROOT_PRESSURE LAI[S, T, L-4]
# TEMPORAL_KEY keywords are TRANSIENT and STATIC
# INPUT_STYLE keyword is LIST
# Generic_Input keyword is "INTERNAL" to specify input location.
#
ROOT_PRESSURE STATIC LIST INTERNAL
# ID    PSI1    PSI2    PSI3    PSI4
  1  -0.15  -0.3    -5.45   -80    # Strawberries
  2  -0.15  -0.3    -7.25   -80    # Vineyards
  3  -0.15  -0.3   -52.1   -160   # Potatoes
  4  10.5    1.13   -1.25   -50    # Phreatophytes
  5  -0.075 -0.2    -8.25  -115   # Native classes
```

**B**

```
# Since input only supports "LIST" INPUT_STYLE, the keyword is optional.
# INTERNAL keyword implies STATIC since it is read only once.
#
ROOT_PRESSURE INTERNAL
# ID    PSI1    PSI2    PSI3    PSI4
  1  -0.15  -0.3    -5.45   -80    # Strawberries
  2  -0.15  -0.3    -7.25   -80    # Vineyards
  3  -0.15  -0.3   -52.1   -160   # Potatoes
  4  10.5    1.13   -1.25   -50    # Phreatophytes
  5  -0.075 -0.2    -8.25  -115   # Native classes
```

**Figure 6.3.** Example use of the FMP keyword `ROOT_PRESSURE` that uses List-Array input. *A*, Example that explicitly specifies the `TEMPORAL_KEY` as “STATIC” and `INPUT_STYLE` as “LIST”; *B*, Example that infers the `TEMPORAL_KEY` from the `Generic_Input` keyword “INTERNAL”; the `INPUT_STYLE` is inferred from the FMP keyword because only LIST input is supported. [LAI, list-array input with the following letters representing the supported keywords: S for STATIC, T for TRANSIENT, A for ARRAY, and L for LIST]

## *IXJ Style* Input as Surrogate to Array-Style Input

Several of the FMP4 keywords support the *IXJ Style* input option described in appendix 1. This is an advanced input style—intentionally not included as part of the LAI[S, T, A, L] shorthand notation—that offers an alternative to the *Array Style* input. The *IXJ Style* input is similar to coordinate compressed array storage and is advantageous when *Array Style* input contains mostly zero values. The *IXJ Style* input also is best suited for models that specify multiple crops per model cell and have a large spatial grid—that is,  $NROW + NCOL \gg 1$ —and large number of land-use types ( $NCROP \gg 1$ ).

The *IXJ Style* input reads a set of integers (I), followed by a set of floating-point numbers (X), and finally by another set of integers (J). The number of integers, floating point numbers, and subsequent integers are specified in the input, which may include zero as the count. For example, there could only be the first set of integers read (I) and no floating-point numbers nor subsequent integers—that is, no X or J read.

If an input block has a keyword that supports the *IXJ Style* input, then an additional section is included that describes the expected *IXJ Style* input structure for the supported keywords. At the time of publication all the keywords that support the *IXJ Style* input read two or three integers followed by a single floating-point number and no subsequent integers—that is, two or three I inputs, one X input, and zero J input. If the keyword expects to read two I inputs, then the first integer represents the model row and the second integer is the model column that will be assigned the one X floating point number loaded—that is, one input record for the **IXJ** is row, column, and non-zero model property. If the keyword expects to read three I inputs, then the first integer represents a global property, such as land use/crop ID, and the second and third integers are the model row and column that will be assigned the one X floating point number loaded. Figure 6.4 contains two examples that use FMP keywords with the *Generic\_Input* keyword **INTERNAL** to load the *IXJ Style* input.

```
# Example that loads 2 I and 1 X
# This input keyword loads REFERENCE_ET LAI[S, T, A]
# This example loads the model row, model column and then reference ET
#
REFERENCE_ET STATIC IXJ INTERNAL
# ROW COL RefET
  2    3    1.1
  5    7    0.8
  1    1    1.2
  4    1    0.9
STOP IXJ # Stop loading IXJ input

# Example that loads 3 I and 1 X
# This input keyword, LAND_USE_AREA_FRACTION LAI[S, T, A],
# is used when specifying the fraction of the model cell
# (ROW, COL) area that contains the land use/crop covers.
#
# When there are multiple crops per model cell allowed the array input
# must specify the area fraction as a NROW by NCOL array for each crop.
#
# IXJ input loads only the Crop ID, the model row, and model column,
# then the area fraction for the non-zero crop area fractions.
# Any crop ID, row, and column not specified is assumed to be zero
#
LAND_USE_AREA_FRACTION STATIC IXJ INTERNAL
# CropID ROW COL Fraction
  1     2     3    0.90
  1     3     2    0.25
  2     2     3    0.10
  2     4     2    0.50
STOP IXJ # Stop loading IXJ input
```

**Figure 6.4.** Example IXJ Style input for the FMP Land\_Use block keywords REFERENCE\_ET and LAND\_USE\_AREA\_FRACTION. [Comments are preceded with the # symbol. Both example keywords use the *Generic\_Input* keyword INTERNAL to indicate that the IXJ style input is loaded on the subsequent lines.]



## Loading Array Style with “INTERNAL” in the Block—Not Recommended

In this appendix, most examples make use of the keyword **INTERNAL**. This use of this keyword is to minimize the number of figures or text boxes necessary to illustrate how to load the input. When the FMP input file is loaded, MF-OWHM2 determines the longest line length in the file—after all the **BLOCK\_INCLUDE** files have been inserted—and pre-allocates enough memory to parse the *Block Style* input. For models with many columns—that is,  $NCOL \gg 1$ —loading *Array Style* input with **INTERNAL** can result in excessive memory allocation due the line length of the input. As a result, it is not recommended to use in a block the keyword **ARRAY** with **INTERNAL** to improve simulation speed. This pre-allocation of memory only applies to input specified directly within a block and does not include any input from external files loaded with **EXTERNAL**, **OPEN/CLOSE**, **DATAFILE**, **DATAUNIT**, or anything loaded from a TFR.

Figures 6.5, 6.6, 6.7, and 6.8 are examples of **CLIMATE** blocks that load **PRECIPITATION** LAI[S, T, A] to specify the amount of precipitation that falls on each model cell. The assumed model grid has NROW equal to 3 and NCOL equal to 10,000. Figure 6.5 and 6.6 are examples of what is not recommended. Because a **BLOCK\_INCLUDE** directly includes the file in the block, figure 6.6.4 produces—within the context of MF-OWHM2—an identical input as figure 6.5.

Figure 6.7 is an example for loading a **STATIC ARRAY** within a block that does not require a larger memory allocation to read the input. By referencing a separate file, the *Block Style* input utility only loads the line “**PRECIPITATION STATIC ARRAY OPEN/CLOSE** ./Precip.txt”, into memory, which requires 50 characters (or 50 bytes of memory). After the *Block Style* input has parsed the keywords, then the contents of the file “./Precip.txt” are efficiently read.

Because a TFR is always read from an external file, it is never part of *Block Style* input’s pre-allocation line. For example, figure 6.8 has the secondary keywords **TRANSIENT ARRAY** to indicate input is read by stress period with the TFR file “./Precip\_TFR.txt”. By referencing a TFR, the *Block Style* input utility only loads the line “**PRECIPITATION TRANSIENT ARRAY OPEN/CLOSE** ./Precip\_TFR.txt” into memory, which requires 57 characters (or 57 bytes of memory). After the *Block Style* input has parsed the keywords, then for each stress period the appropriate array is efficiently read from the file “./Precip\_TFR.txt”.

### BEGIN CLIMATE

```
# Within a Block style input, ARRAY style with INTERNAL is not recommended.
#
# Block style input must allocate enough memory to hold the longest line within the block.
#
# The precipitation array is specified within the block by using the INTERNAL keyword,
# so it has to pre-allocate enough space to the line with 10,000 numbers.
#
# Keyword PRECIPITATION specifies the precipitation flux over model domain
PRECIPITATION STATIC ARRAY INTERNAL # Load 3×10000 array
0.1  0.1  0.2  ...  ...  ...  0.20  0.10
0.1  0.1  0.2  ...  ...  ...  0.20  0.10
0.1  0.1  0.2  ...  ...  ...  0.20  0.10
#
```

### END CLIMATE

**Figure 6.5.** Example loading a 3-by-10000 array with INTERNAL in the FMP Climate block keyword PRECIPITATION. The text within the Block Style input is preloaded into computer memory (RAM), so it is not recommended to specify large arrays with INTERNAL within an input block. An alternative is to change INTERNAL to OPEN/CLOSE and move the 3-by-10000 array to a separate file. [...] is a place holder for the input numbers.]

**A****BEGIN CLIMATE**

```
# Within a Block style input, ARRAY style with INTERNAL is not recommended.
#
# Block style input must allocate enough memory to hold the longest line within the block.
#
# Since BLOCK_INCLUDE inserts text from Precip_Include.txt into the block and
# the precipitation array is specified using the INTERNAL keyword,
# the read utility has to pre-allocate enough space to the line with 10,000 numbers.
#
# Keyword PRECIPITATION specifies the precipitation flux over model domain
# Array is within block indirectly through BLOCK_INCLUDE.
#
# "BLOCK_INCLUDE ./Precip_Include.txt" is replaced by the
# text stored in the file Precip_Include.txt
#
BLOCK_INCLUDE ./Precip_Include.txt
```

**END CLIMATE****B**

```
# File: Precip_Include.txt
# Precipitation flux for a 3 by 10000 grid
#
PRECIPITATION STATIC ARRAY INTERNAL
0.1 0.1 0.2 ... ... 0.20 0.10
0.1 0.1 0.2 ... ... 0.20 0.10
0.1 0.1 0.2 ... ... 0.20 0.10
```

**Figure 6.6.** Example loading a 3-by-10000 array with INTERNAL in the FMP Climate block keyword PRECIPITATION. The array is indirectly inserted into the Climate block by the BLOCK\_INCLUDE keyword. The text within the Block Style input is preloaded into computer memory (RAM), so it is not recommended to specify large arrays with INTERNAL within an input block. An alternative is to change INTERNAL to OPEN/CLOSE and move the 3-by-10000 array to a separate file. *A*, FMP Climate block that contains a BLOCK\_INCLUDE. *B*, The file, Precip\_Include.txt, that is inserted into the Climate block. [...] is a place holder for the input numbers.]



**A****BEGIN CLIMATE**

```
# Block style input must allocate enough memory to hold the longest line within the block.
#
# This example only has to pre-allocate enough memory to store the text
# "PRECIPITATION STATIC ARRAY OPEN/CLOSE ./Precip.txt"
# which is 50 characters long (or 50 bytes)
#
# Keyword PRECIPITATION specifies the precipitation flux over model domain
#
PRECIPITATION STATIC ARRAY OPEN/CLOSE ./Precip.txt
#
END CLIMATE
```

**B**

```
# File: Precip.txt for
# Precipitation flux for a 3 by 10000 grid
0.1  0.1  0.2  ...  ...  ...  0.20  0.10
0.1  0.1  0.2  ...  ...  ...  0.20  0.10
0.1  0.1  0.2  ...  ...  ...  0.20  0.10
```

**Figure 6.7.** Example loading a 3-by-10000 array with OPEN/CLOSE specified in the FMP Climate block keyword PRECIPITATION. Only 1 line is read by the Block Style input utility, which is 50 characters (50 bytes) long. The precipitation array is stored in a separate file that is read after the Block Style input utility has processed all the keywords. *A*, FMP Climate block. *B*, The file, Precip.txt, that contains the 3-by-10000 precipitation array. [...] is a place holder for the input numbers.]

**A****BEGIN CLIMATE**

```
# Block style input must allocate enough memory to hold the longest line within the block.
#
# This example only has to pre-allocate enough memory to store the text
# "PRECIPITATION TRANSIENT ARRAY OPEN/CLOSE ./Precip_TFR.txt"
# which is 57 characters long (or 57 bytes)
#
# The word "TRANSIENT" indicates that Precip_TFR.txt is a Transient File Reader
# and specifies the precipitation flux for each stress period.
#
# Keyword PRECIPITATION specifies the precipitation flux over model domain
#
PRECIPITATION TRANSIENT ARRAY OPEN/CLOSE ./Precip_TFR.txt
#
```

**END CLIMATE****B**

```
# File: Precip_TFR.txt
#
# File is a Transient File Reader (TFR) that reads a set of precipitation
# fluxes for a 3 by 10000 model grid for each stress period (SP).
#
INTERNAL # SP 1
0.1 0.1 0.2 ... .. 0.20 0.10
0.1 0.1 0.2 ... .. 0.20 0.10
0.1 0.1 0.2 ... .. 0.20 0.10
INTERNAL # SP 2
0.1 0.1 0.2 ... .. 0.20 0.10
0.1 0.1 0.2 ... .. 0.20 0.10
0.1 0.1 0.2 ... .. 0.20 0.10
INTERNAL # SP 3
0.1 0.1 0.2 ... .. 0.20 0.10
0.1 0.1 0.2 ... .. 0.20 0.10
0.1 0.1 0.2 ... .. 0.20 0.10
```

**Figure 6.8.** Example loading a 3-by-10000 array with a *Transient File Reader* (TFR) specified in the FMP Climate block keyword PRECIPITATION. Only 1 line is read by the Block Style input utility, which is 57 characters (57 bytes) long. The precipitation arrays are stored the TFR and read with the keyword INTERNAL. *A*, FMP Climate block. *B*, A TFR file, Precip\_TFR.txt, that specifies the precipitation flux for three stress periods. [...] is a place holder for the input numbers.]

## Advanced Scale Factors and SFAC

**FLOAT** input that loads with **ULOAD** and **LAI** supports scale factors as described in appendix 1. The scale factors can be used as part of calibration, to convert units, or for scenario evaluations. At a minimum all **ULOAD** and **LAI FLOAT** input can apply *Generic\_Input* scale factors, using **SF SCALE** syntax. If the *Generic\_Input* is a TFR, then scale factors can be applied to each input loaded in the TFR. In the “Multi-Column List Style Input” section’s **ROOT\_PRESSURE** example (fig. 6.3B), the data were loaded using the *Generic\_Input* keyword **INTERNAL** to load **FLOAT** data. Figure 6.9A recasts this example to use the *Generic\_Input* post-keyword “**SF SCALE**” to multiply the **ROOT\_PRESSURE**s by 0.3048. This would be the equivalent to the input presented in figure 6.9C.

When **ULOAD** loads **FLOAT** input, it also optionally supports the **SFAC** keyword (appendix 1). All FMP **FLOAT** input keywords support rescaling using a single scale factor, and FMP applies it to all the input—note the similarity to the *Generic\_Input* scale factor **SF SCALE**. Figure 6.9B shows the same 0.3048 scaling as in figure 6.9A but uses the keyword **SFAC** instead.

Advanced **SFAC** scaling can include dimensional keywords (**DIMKEY**s) that indicate the number of scale factors read and how they are applied. The **SFAC DIMKEY**s supported in FMP and their associated dimension (the dimensions are defined in the “Global Dimension Block” section) are presented in figure 6.10.

A

```
# FMP LAND_USE Block keyword that specifies with List-Array Input (LAI)
# four root pressures (PSI1, PSI2, PSI3, PSI4) that represent
# the upper limit pressure head at which the root uptake becomes zero
# as a result of anoxia, then the two pressure heads that represent
# the range of optimal root uptake, and then
# a lower limit pressure head that results in wilting (zero root uptake), respectively.
#
# LAI uses GENERIC_INPUT to specify the input location of the input.
# The GENERIC_INPUT keyword used is INTERNAL to indicate input is on
# subsequent lines. GENERIC_INPUT, also supports the post keyword SF
# to indicate a global scale factor is applied.
#
# Note that the use of INTERNAL with LAI implies the STATIC keyword and
# List-Style input is the only input style supported, so the LIST keyword is optional.
#
ROOT_PRESSURE INTERNAL SF 0.3048 # Convert PSI from feet to meters

# ID    PSI1    PSI2    PSI3    PSI4
1  -0.15  -0.3    -5.45   -80    # Strawberries
2  -0.15  -0.3    -7.25   -80    # Vineyards
3  -0.15  -0.3    -52.1    -160   # Potatoes
4  10.5    1.13    -1.25   -50    # Phreatophytes
5  -0.075 -0.2     -8.25   -115   # Native classes
```

**Figure 6.9.** Examples of A, use of the *Generic\_Input* post-keyword “**SF SCALE**” to apply a scale factor for the FMP keyword **ROOT\_PRESSURE**. B, Equivalent **ROOT\_PRESSURE** input that uses the advanced scale factor keyword **SFAC**. C, Equivalent **ROOT\_PRESSURE** input without a scale factor.

**B**

```
# FMP keywords that load float input check for the SFAC keyword
#   to load advanced scale factors. SFAC is defined before loading the actual input.
#
# This example uses SFAC to indicate the input is multiplied by 0.3048
#   to convert the input from feet to meters.
#
```

**ROOT\_PRESSURE INTERNAL****SFAC 0.3048**

# Convert PSI from feet to meters

# ID	PSI1	PSI2	PSI3	PSI4	
1	-0.15	-0.3	-5.45	-80	# Strawberries
2	-0.15	-0.3	-7.25	-80	# Vineyards
3	-0.15	-0.3	-52.1	-160	# Potatoes
4	10.5	1.13	-1.25	-50	# Phreatophytes
5	-0.075	-0.2	-8.25	-115	# Native classes

**C****ROOT\_PRESSURE INTERNAL**

# ID	PSI1	PSI2	PSI3	PSI4	
1	-0.046	-0.091	-1.661	-24.384	# Strawberries
2	-0.046	-0.091	-2.210	-24.384	# Vineyards
3	-0.046	-0.091	-15.880	-48.768	# Potatoes
4	3.200	0.344	-0.381	-15.240	# Phreatophytes
5	-0.023	-0.061	-2.515	-35.052	# Native classes

**Figure 6.9.** —Continued

<b>DIMKEY</b>	Dimension
<b>ByWBS</b>	<b>NWBS</b>
<b>ByCrop</b>	<b>NCROP</b>
<b>ByIrrigate</b>	<b>NIRRIGATE</b>
<b>BySoil</b>	<b>NSOIL</b>
<b>BySource</b>	4
<b>ByNRD</b>	<b>NRD_TYPES</b>

**Figure 6.10.** FMP supported secondary dimension keyword, **DIMKEY**, for advanced scale factors, **SFAC**, that indicate the number of scale factors that are read and how they are applied. The dimension column references FMP Global Dimension block keywords. [NWBS is the number of water balance subregions; NCROP is the number of land use types simulated; NIRRIGATE is the number of irrigation types; NSOIL is the number of soil types; NRD\_TYPES are the number of non-routed delivery types that are defined.]

The keywords in the figure 6.10 dimension column are defined in the **GLOBAL DIMENSION** block and indicate the number of scale factors loaded. For example, **SFAC ByCrop** would load **NCROP** scale factors with ULOAD. The first of the loaded scale factors would be applied to Crop 1, the second to Crop 2, and so forth until **NCROP**. The **BySoil DIMKEY** is only available in the **SOIL** block keyword **CAPILLARY\_FRINGE** and is applied on the basis of the **SOIL\_ID**, which is from 1 to **NSOIL**. The **ByNRD DIMKEY** is only available in the **SURFACE\_WATER** block keyword **NON\_ROUTED\_DELIVERY** and is only applied to the volume of water delivered for each of the **NRD\_TYPES**. The **BySource DIMKEY** is only used in the **SALINITY\_FLUSH\_IRRIGATION** block keyword **WBS\_SUPPLY\_SALT\_CONCENTRATION**, which loads the salt concentration of non-routed deliveries, SRDs, groundwater pumping, and external water (EXT) sources available for irrigation, which are where the four scale factors are applied, respectively.

Figure 6.11 reuses the previous **ROOT\_PRESSURE** example (fig. 6.9), applying **SFAC** with a **DIMKEY**. Figure 6.11A uses the **DIMKEY “ByCrop”** to read **NCROP** scale factors and apply them to each crop. That is, for crops 1, 3, and 5, root-pressure inputs are multiplied by 3.1, and those for crops 2 and 4 are multiplied by 1.0. Figure 6.11B shows scaling based on the location of the WBS by using the **DIMKEY “ByWBS”** to read **NWBS** scale factors—**NWBS** is the maximum number of the WBS in a simulation. In this example, any land use that is in the WBS 1 has its **ROOT\_PRESSURE**s multiplied by 2.0; those in the WBS 2 are multiplied by 4.0; and lastly, those in the WBS 3 are multiplied by 6.0. In this appendix, there are a set of subsections titled “Supported **SFAC DIMKEY**” that indicate the supported **DIMKEY**s for specific FMP input keywords.

**A**

```

# Example use of the advanced scale factor SFAC that reads the dimension key (DIMKEY) "ByCrop"
#
# ByCrop indicates that NCROP scale factors are read and applied such that
#   the first scale factor is applied to the Crop 1,
#   the second scale factor is applied to the Crop 2, and so forth until Crop NCROP.
#
# This example assumes NCROP = 5 and SFAC uses an Implied Internal to read the 5 scale factors.
# Root pressures of Crops 1, 3, and 5 are multiplied by 3.1 and Crops 2 and 4 are multiplied by 1.
#
ROOT_PRESSURE INTERNAL
SFAC ByCrop 3.1 1.0 3.1 1.0 3.1
# ID    PSI1    PSI2    PSI3    PSI4
1 -0.15 -0.3 -5.45 -80 # Strawberries
2 -0.15 -0.3 -7.25 -80 # Vineyards
3 -0.15 -0.3 -52.1 -160 # Potatoes
4 10.5 1.13 -1.25 -50 # Phreatophytes
5 -0.075 -0.2 -8.25 -115 # Native classes

```

**B**

```

# NWBS is the total number of water balance subregions (WBSs)
#
# ByWBS indicates that NWBS scale factors are read and applied such that
#   the first scale factor is applied to crops that are in WBS 1,
#   the second scale factor is applied to crops that are in WBS 2, and so forth until WBS NWBS.
#
# This example assumes NWBS = 3 and SFAC uses an Implied Internal to read the 3 scale factors.
#
ROOT_PRESSURE INTERNAL
SFAC ByWBS 2.0 4.0 6.0
# ID    PSI1    PSI2    PSI3    PSI4
1 -0.15 -0.3 -5.45 -80 # Strawberries
2 -0.15 -0.3 -7.25 -80 # Vineyards
3 -0.15 -0.3 -52.1 -160 # Potatoes
4 10.5 1.13 -1.25 -50 # Phreatophytes
5 -0.075 -0.2 -8.25 -115 # Native classes

```

**Figure 6.11.** Examples using advanced scale factors (SFAC) with a dimension keyword (DIMKEY). A, Example using the ByCrop DIMKEY to read five scale factors and apply them by crop type. B, Example using the ByWBS DIMKEY to read three scale factors and apply them by Water Balance Subregion (WBS).



## Global Dimension Block

The **GLOBAL DIMENSION** block is always required as part of the FMP input. As the block name implies, it specifies the properties necessary to set dimensions for all the remaining features in the FMP. The only required inputs for the **GLOBAL DIMENSION** are the number of WBSs, land-use types (Crops), soil types, irrigation types, and Non-Routed Deliveries (NRDs) types. Figure 6.12 describes the required keywords for the **GLOBAL DIMENSION** block. These dimensions specify the number of values read during a *List Style* input. For example, the **WATER\_BALANCE\_SUBREGION** block loads **NWBS** records (rows) of input for all keywords that use list style. The dimensions defined here represent a maximum number of input records but not all of them have to be in use at any particular stress period. For example, **NCROP** could be set to 3, indicating that all **LAND\_USE** *List Style* input statements load three records—such as three root depths or three crop coefficients, but it is not required to simulate all crops all the time—for example one stress period could simulate crops 1, 2, and not 3, whereas another stress period could simulate crops 2, 3, and not 1.

The number of soil types, **NSOIL**, is only used to specify the number of capillary fringe lengths and soil coefficients to read. Soil coefficients are only necessary if it is desired to use the analytical pseudo steady-state soil moisture, soil-stress concept called *analytical root response* (appendix 5). It is recommended to specify **NSOIL** as one or more soil types for all FMP simulations and to specify a capillary fringe length—this allows for the calculation of evaporation of groundwater and the potential of groundwater-root uptake from a land use.

Keyword	Input	Description
<b>NWBS</b>	<b>INT</b>	Number of Water Balance Subregions. Alternative keyword— <b>NFARM</b>
<b>NCROP</b>	<b>INT</b>	Number of land-use types (or crops )
<b>NSOIL</b>	<b>INT</b>	Number of soil types. Only used in <b>SOIL</b> block
<b>NIRRIGATE</b>	<b>INT</b>	Number of irrigation types
<b>NRD_TYPES</b>	<b>INT</b>	Number of non-routed deliveries. Only used in <b>SURFACE_WATER</b> block
<b>NSFR_DELIV</b>	<b>INT</b>	Maximum number of SFR surface-water delivery points that are defined. Only used in <b>SURFACE_WATER</b> block
<b>NSFR_RETURN</b>	<b>INT</b>	Maximum number of SFR surface water return-flow points that are defined. Note—return-flow points can be automatically defined with fully routed return flow. Only used in <b>SURFACE_WATER</b> block

**Figure 6.12.** Required keywords for the Global Dimension Block. [After each keyword, a single integer, **INT**, is expected; SFR, streamflow routing package.]

The keyword **NIRRIGATE** specifies the number of irrigation efficiencies (OFE in appendix 4), which are specified in the **WATER\_BALANCE\_SUBREGION** block with the keyword **EFFICIENCY** and loaded with **LAI[S, T, A, L-NIRRIGATE]**. When **EFFICIENCY** uses *List Style* input, then it is loaded with **NWBS** rows and **NIRRIGATE** columns of efficiency values—note the actual number of columns is **NIRRIGATE+1** to include the *List Style* record ID. If a crop is not irrigated, then in the **LAND\_USE** block the keyword **IRRIGATION** **LAI[S, T, A, L]** has an irrigation flag set to 0 for the non-irrigated crop. Conversely, if it is irrigated, then its irrigation flag must be between 1 and **NIRRIGATE** when it is specified with “**L-NIRRIGATE**” to indicate which column to use in the OFE (**EFFICIENCY**). For more details and examples using the keyword **EFFICIENCY**, see the “Water-Balance Subregion (WBS) Block” section.

The keywords **NRD\_TYPES**, **NSFR\_DELIV**, and **NSFR\_RETURN** define the maximum dimensions for properties defined in the **SURFACE\_WATER** block, and if they are not specified, are set to zero. The **NRD\_TYPES** is the number of **NON\_ROUTED\_DELIVERY** triplets that are specified per WBS. Each triplet defines a volume of water that is delivered to a WBS, its priority ranking among the other **NRD\_TYPES**, and what to do with the unused portion of the water. **NSFR\_DELIV** and **NSFR\_RETURN** define the number of records that are read in for the **SURFACE\_WATER** block keywords **SEMI\_ROUTED\_DELIVERY** and **SEMI\_ROUTED\_RETURN**, respectively (see the “**SURFACE\_WATER** Block” section).

If the land-surface elevation is not specified in the Discretization package (DIS; appendix 3), then it must be specified as part of the **GLOBAL\_DIMENSION** block. Figure 6.13 describes the **SURFACE\_ELEVATION** keyword that specifies the land-surface elevation grid that is loaded as **NROW × NCOL** array with **ULOAD**.

The remaining FMP keywords are optional and alter the behavior of the FMP globally. If the Unsaturated-Zone Flow (UZF) package is part of the simulation, then it may optionally be linked to the FMP. This simulates delayed recharge by having water that leaves the root zone, as deep percolation, behave as infiltration to UZF. This linkage is only necessary when there is field evidence that the transient time of deep percolation to the water table is much greater than the time step length. To initiate the FMP-UZF link, the keyword **UZF\_LINK** must be specified in the **GLOBAL\_DIMENSION** block. If the **UZF\_LINK** is enabled, it is important that the UZF package’s ET option is disabled to prevent double accounting from FMP and UZF. All consumptive-use concepts require, at a minimum, specifying the soil capillary fringe in the **SOIL** block. The linear root uptake of groundwater and anoxia concept (formally designated concept 2 with **ICCF** = 2 or 4) requires specifying the root depth (**ROOT**), fraction of transpiration (**FTR**), fraction of evaporation from irrigation (**FEI**), and fractions of delivery losses to surface water from precipitation and irrigation in the **LAND\_USE** block for each crop.

Part of the FMP input requires specifying the SFR package segment and reach (or just the segment). A unique name can be assigned to the SFR segment and reaches, which may be used as a surrogate input in the FMP input that expects a SFR segment and reach. The FMP **GLOBAL\_DIMENSION** block may optionally specify the keyword **SFR\_NAMES**, which loads with **ULOAD** a list of unique SFR stream names and their assigned segment and reach. As many names as necessary may be defined as long as they follow the **ULOAD List Style** input format. Each row loaded with **ULOAD** must specify the record ID, the unique name (**SFRNAME**), the SFR segment identifier (**ISEG**), and the SFR reach identifier (**IRCH**). The **SFRNAME** has a maximum size of 20 characters and the ID, **ISEG**, and **IRCH** are loaded as **INT**. Figure 6.14 is an example that defines three **SFR\_NAMES**, which then allows the use of the words **FARM\_1\_Deliv\_Pnt**, **RES1\_RELEASE**, and **MainRiv** in the place of specifying the SFR segment and reach.

Keyword	Input	Description
<b>SURFACE_ELEVATION</b>	<b>ULOAD</b>	Land-surface elevation of the model. Required if not specified in DIS. Loaded as <b>FLOAT</b> Array [L].

**Figure 6.13.** Keyword that specifies the land-surface elevation. Keyword is not required if land-surface elevation is already specified in the Discretization package (DIS). [FLOAT, floating-point number; [L], length in model units; ULOAD, universal loader]

```
# Example use of the GLOBAL DIMENSION keyword SFR_NAMES.
# Input uses ULOAD List Style input and continues to load input lines
#   if it successfully reads a List Style record ID
#
# The name, SFRNAME, is linked to the specified SFR segment and reach
#
# FMP input that expects an SFR segment and reach identity
#   may use the SFRNAME as a surrogate for the integer identifiers.
#
SFR_NAMES INTERNAL
# ID      SFRNAME          ISEG  IRCH
  1 FARM_1_Deliv_Pnt      22    1
  2 RES1_RELEASE          2     3
  3 MainRiv               5     1
```

**Figure 6.14.** Example use of the FMP Global Dimension Keyword SFR\_NAMES. This keyword associates a unique name with a stream flow routing (SFR) segment and reach.

By default, use of the **TRANSIENT** keyword in the **WATER\_BALANCE\_SUBREGION**, **CLIMATE**, and **LAND\_USE** blocks specifies a TFR that loads input every stress period. If it is desired for the TFR to load information every time step, then the optional keyword **BY\_TIMESTEP** followed by the keyword **WATER\_BALANCE\_SUBREGION**, **CLIMATE**, or **LAND\_USE** will alter the TFR operation to load by time step for the respective FMP blocks. The following is an example of such usage for all three keywords:

```
BY_TIMESTEP WATER_BALANCE_SUBREGION
#
BY_TIMESTEP CLIMATE
#
BY_TIMESTEP LAND_USE
```

By default, all land-use types are assumed to have a surface elevation based on the land-surface elevation defined in the DIS package or with the keyword **SURFACE\_ELEVATION**. If a specific crop has a surface elevation different from the default surface elevation, then, if used, the keyword **NCROP\_SPECIFIED\_ELEVATIONS INT** specifies the number of crops for which elevations are defined with the **LAND\_USE** block. This is an advanced feature, and its use is not recommended, unless it is important to represent a land use (crop type) that has a different elevation than the model cell land-surface elevation. Figure 6.15 presents the **GLOBAL DIMENSION** block with all its supported keywords, their expected input structure, and a commented explanation.

```

BEGIN GLOBAL DIMENSION
# Required Keywords -----
NWBS      INT  # Number of water balance subregions (FARMS)
NCROP     INT  # Number of land use types (CROPS)
NSOIL     INT  # Number of soil types that are defined (SOIL)
NIRRIGATE INT  # Number of irrigation types that are defined (EFFICIENCY)
NRD_TYPES INT  # Number of non-routed delivery types defined (NRD)
#
# Required if not specified in DIS package -----
#
SURFACE_ELEVATION  ULOAD  # Read NROW by NCOL array of surface elevations
#
# The rest are optional keywords -----
#
UZF_LINK  # Deep percolation becomes delayed recharge with the UZF Package
#
# Define custom unique names for SFR segments and reaches
SFR_NAMES  ULOAD[ ID, SFRNAME, ISEG, IRCH]  # List Style, as many records as necessary
#
# TFR for specified block is loaded every time step instead of by stress period
BY_TIMESTEP WATER_BALANCE_SUBREGION
BY_TIMESTEP LAND_USE
BY_TIMESTEP CLIMATE
#
NCROP_SPECIFIED_ELEVATIONS INT  # Number of crops that have their elevation specified
using LAND_USE block
#
END GLOBAL DIMENSION

```

**Figure 6.15.** GLOBAL DIMENSION block with all supported keywords and their input format. [FLOAT, floating-point number; INT, integer; WBS, water-balance subregion; ULOAD is the universal loader; LAI, list-array input with the following letters representing the supported keywords: S for STATIC, T for TRANSIENT, A for ARRAY, and L for LIST]

## Water Balance Subregion (WBS) Block

The **WATER\_BALANCE\_SUBREGION** (WBS) block specifies all properties that pertain to defining the supply and demand framework. All *List Style* input in the block expects **NWBS** records. In FMP, the block name can be declared as **WATER\_BALANCE SUBREGION** or **WATER\_BALANCE\_SUBREGION**, but the later version, with underscores, is recommended for clarity. Figure 6.16 describes keywords that may be required depending on the FMP setup.

**LOCATION** LAI[S, T, A], which defines the spatial location of each WBS, is required for all FMP simulations. The **LOCATION** keyword's LAI input is a two-dimensional **INT** array, where **INT** represents the WBS number. If the **LOCATION** input for any model cell is specified with 0, then it is not included in supply and demand calculations and is ignored by the FMP. For example, if a model grid has three rows and four columns (NROW=3 and NCOL=4) and “**NWBS 5**” is in the **GLOBAL DIMENSION** block, then figure 6.17 illustrates acceptable **LOCATION** arrays. The spatial location of each WBS ID identifies the model cells that are included in the FMP—that is, if its WBS ID is greater than zero—and what sets of model cells are aggregated for supply and demand calculations—grouped by the WBS ID. An FMP subprocess—such as crop evapotranspiration, precipitation, evaporation—in a WBS location is aggregated as part of the FMP output—total precipitation over the WBS, total CU over the WBS.

If the land use (crop) receives applied-irrigated water, then there is an associated irrigation efficiency to account for; the excess irrigation required to meet demand after efficient losses becomes either surface runoff or deep percolation to groundwater. The **GLOBAL DIMENSION** block keyword **NIRRIGATE** defines the number of irrigation efficiencies that are specified. The irrigation efficiency (OFE, in appendix 4) is defined with the keyword **EFFICIENCY** and is loaded with LAI[S, T, A, L-**NIRRIGATE**]. It is recommended to use *List Style* input, which would then load **NWBS** records with **NIRRIGATE** columns of input. The OFE values can vary on the basis of agricultural practices and the type and quality of irrigation equipment used. It is recommended to research the efficiency on the basis of the simulated region, but typical values of OFE are 0.8 to 0.95 for drip irrigation, 0.7 to 0.85 for sprinkler irrigation, and 0.55 to 0.7 for flood irrigation. Figure 6.18 contains two examples of how to load the irrigation efficiencies when “**NIRRIGATE 3**” is in the **GLOBAL DIMENSION** block.

**EFFICIENCY** can be thought of as a lookup table for irrigated crops. If a crop is not irrigated, then its irrigation flag (see the “**LAND\_USE** Block” section) is set to 0. If the crop is irrigated and its **EFFICIENCY** is defined with *List Style* input, then the irrigation flag indicates the column in **EFFICIENCY** input to use, and the WBS that the crop resides in indicates the row. For example, given figure 6.18A and a crop has an irrigation flag of 2 and grows in WBS 3, then it would use the sprinkler efficiency for WBS ID 3, which is 0.77. If **EFFICIENCY** is defined as an array, then a crop is irrigated if its irrigation flag is non-zero and uses the efficiency value at the same row and column as the crop's location.

Keyword	Input	Description
<b>LOCATION</b>	LAI[S, T, A]	<b>INT</b> array that specifies the spatial location of the WBS (always required).
<b>EFFICIENCY</b>	LAI[S, T, A, L- <b>NIRRIGATE</b> ]	<b>FLOAT</b> , Irrigation efficiency (OFE) with $0 < \text{OFE} \leq 1$ Required if <b>NIRRIGATE</b> is greater than 0.

**Figure 6.16.** WATER\_BALANCE\_SUBREGION block main keywords. [FLOAT, floating-point number; INT, integer; WBS, water-balance subregion; LAI, list-array input with the following letters representing the supported keywords: S for STATIC, T for TRANSIENT, A for ARRAY, and L for LIST]

**A**

```

# Example use of the WATER_BALANCE_SUBREGION block keyword LOCATION
#
# LOCATION defines the spatial location of each Water Balance Subregion (WBS).
#
# Example assumes NROW = 3, NCOL = 4, NWBS = 5; Input type is LAI[S, T, A]
#
# Input is an INT array of the model grid (NROW by NCOL).
# INT is between 1 and NWBS, max number of WBS, to indicate the location of each WBS.
#
# If a location is <1 or >NWBS, such as 0, then FMP ignores the model cell.
# That is, it's not part of any WBS, so there is no supply and demand calculation.
##
# This following only specifies WBS 1 and 5, so WBS 2, 3, and 4 are not simulated.
#
# Row 3, Column 1 is zero, so it's not associated with a WBS nor simulated in FMP.
LOCATION STATIC ARRAY INTERNAL
1 1 5 5
1 1 5 5
0 5 5 5

```

**B**

```

# Example specifies WBS 1, 2, and 3, so WBS 4 and 5 are not simulated
LOCATION INTERNAL
2 2 3 1
2 2 3 1
3 1 3 2

```

**C**

```

# Example specifies WBS 1, 2, 3, 4 and 5, so all WBS are simulated
LOCATION INTERNAL
5 4 3 2
1 5 4 3
2 1 5 4

```

**Figure 6.17.** Input examples for FMP WATER\_BALANCE\_SUBREGION block keyword LOCATION. Each example assumes that the maximum number of WBS is five. *A*, Example that specifies the location of WBS 1 and 5. *B*, Example that specifies the location of WBS 1, 2, and 5. *C*, Example that specifies the location of WBS 1, 2, 3, 4, and 5. [FLOAT, floating-point number; INT, integer; WBS, water-balance subregion; LAI, list-array input with the following letters representing the supported keywords: S for STATIC, T for TRANSIENT, A for ARRAY, and L for LIST]



**A**

```
# Example use of the WATER_BALANCE_SUBREGION block keyword EFFICIENCY
#
# EFFICIENCY defines the irrigation efficiency for each irrigation type.
#   – List Style input reads NWBS records
#
# Example assumes NROW = 3, NCOL = 4, NWBS = 5; Input is LAI[S, T, A, L-NIRRIGATE]
#
# Input is a FLOAT between 0 and 1.
#
# Chosen NIRRIGATE Types:
# 1 = Drip;   2 = Sprinkler;   3 = Flood
#
EFFICIENCY  STATIC LIST INTERNAL
#      Drip  Sprinkler  Flood
# ID  IRR1    IRR2    IRR3
  1   0.9    0.70    0.6
  2   0.9    0.70    0.6
  3   0.9    0.77    0.6
  4   0.9    0.70    0.6
  5   0.9    0.70    0.6
```

**B**

```
# Example assumes NROW = 3, NCOL = 4, NWBS = 5; Input is LAI[S, T, A, L-NIRRIGATE]
#
EFFICIENCY  STATIC ARRAY INTERNAL
  0.9  0.9  0.7  0.7
  0.9  0.9  0.7  0.7
  0.6  0.6  0.6  0.6
```

**Figure 6.18.** Examples of input for FMP WATER\_BALANCE\_SUBREGION block keyword EFFICIENCY. *A*, List style input example. *B*, Array style input example. [FLOAT, floating-point number; INT, integer; WBS, water-balance subregion; LAI, list-array input with the following letters representing the supported keywords: S for STATIC, T for TRANSIENT, A for ARRAY, and L for LIST]

## Recommended Water-Balance (WBS) Keywords

Keywords may be required depending on the FMP setup and are recommended as part of the normal input. Figure 6.19 lists the keywords, input format, and a description of the functions.

The first recommended keyword (fig. 6.19) is **DEFICIENCY\_SCENARIO** LAI[S, T, L], which defines if a WBS has the capability to obtain external water supplies for irrigated crops when its supply does not meet its demand. A value of 0 indicates that the WBS has access to external water (EXT) sources outside of the simulation domain, called the Zero-Scenario, that ensure demand is always met. A value of 1 indicates that the WBS only uses its available water supplies, called the Deficit Irrigation Scenario. If **DEFICIENCY\_SCENARIO** is not specified, then all WBSs are automatically set to the Deficit Irrigation Scenario and will only apply the water supplies specified in the FMP input—that is, from non-routed deliveries, surface-water deliveries, and groundwater pumping. The following are examples of specifying **DEFICIENCY\_SCENARIO** for five WBSs.

Keyword	Input	Description
<b>DEFICIENCY_SCENARIO</b>	LAI[S, T, L]	<b>INT</b> . Defines whether a WBS has Deficit Irrigation or has access to external water sources to meet a supply shortfall. If not specified, then Deficit Irrigation is the default option.
<b>BARE_RUNOFF_FRACTION</b>	LAI[S, T, A]	<p><b>FLOAT</b> . Defines the fraction of precipitation that becomes runoff when it falls on “bare soil”, for surface area that is not defined with a Land Use (Crop).</p> <p>Bare soil is any model cell that is associated with a WBS <b>LOCATION</b> between 1 and <b>NWBS</b> and has either: a Crop <b>LOCATION</b> number <u>not</u> between 1 and <b>NCROP</b> or the remaining area in a model cell if <b>LAND_USE_AREA_FRACTION</b> is specified and does not sum to 1.</p> <p>If not specified, then the default fraction is set to 0.75</p>
<b>WATERSOURCE</b>	LAI[S, T, L-3]	<p><b>INT</b> . Specifies sources of water, 0 to indicate it is not available/disabled and 1 to indicate it is available.</p> <p>The sources are groundwater pumping, surface water deliveries, and non-routed deliveries.</p> <p>If a source is disabled, then it automatically disables the source, overriding any contrary indication specified in another input.</p> <p>If enabled, then the sources of water are defined by their respective input sections.</p> <p>If not specified, then it is automatically set to a default value, 1, for all sources—all sources are available.</p>

**Figure 6.19.** WATER\_BALANCE\_SUBREGION block recommended keywords. [FLOAT, floating-point number; INT, integer; LAI, list-array input; NCROP, number of land-use types; NWBS, maximum number of water-balance subregions; WBS, water-balance subregion; LAI, list-array input with the following letters representing the supported keywords: S for STATIC, T for TRANSIENT, A for ARRAY, and L for LIST]

```

# NWBS = 5
#
# Recommended Setup, All WBS Deficit Irrigate.
# (This is the also the default when not specified)
#
DEFICIENCY_SCENARIO CONSTANT 1
#
# WBS 2 and 3 can obtain external water supplies
DEFICIENCY_SCENARIO STATIC LIST
INTERNAL
1 1
2 0
3 0
4 1
5 1

```

Another important keyword is **BARE\_RUNOFF\_FRACTION** LAI[S, T, A, L], which accounts for the fraction of effective precipitation that falls on the bare soil area that becomes runoff compared to deep percolation. It should be a value between 0 and 1 and represents the fraction of excess precipitation that becomes runoff compared to infiltration, for example, 0.75 indicates that 75 percent of the precipitation that falls on bare soil becomes surface runoff. The following syntax examples show **BARE\_RUNOFF\_FRACTION** when input with (1) *List Style*, specified by WBS, and (2) *Array Style*, specified by model Row and Column input:

```

# NROW = 3, NCOL = 4, NWBS = 5
#
BARE_RUNOFF_FRACTION STATIC LIST INTERNAL
# ID Fraction of effective precipitation to runoff
1 0.0 # WBS 1 has all become deep
percolation
2 0.9
3 1.0 # WBS 3 has all become runoff
4 0.25
5 0.50 # WBS 5 has half become runoff
#
# This example shows the array style input
BARE_RUNOFF_FRACTION STATIC ARRAY
INTERNAL
0.9 0.9 0.25 0.7
0.9 0.9 0.25 0.7
0.5 0.5 0.50 0.7

```

The **WATERSOURCE** LAI[S, T, L-3] keyword declares the available sources of irrigation water to each WBS. These sources are only used when groundwater-root uptake and precipitation are not enough to meet a WBS's demand. There are three available sources of water: (1) groundwater pumping from the FMP wells and Multi-Node Well Package Version 2 (MNV2), (2) surface-water deliveries, as semi-routed deliveries (SRDs) from SFR, and (3) non-routed deliveries (NRDs). The keyword signals a *List Style* input composed of three columns of values set to 0 or 1. A value of 0 indicates that the source is not available, and 1 indicates it is available. The order of the columns, groundwater pumping, surface-water delivery, and non-routed delivery, are fixed and represent the sources of water. The following are examples of how to set the **WATERSOURCE** keyword:

```
# NROW = 3, NCOL = 4, NWBS = 5
#
WATERSOURCE  STATIC LIST INTERNAL
# ID GW  SW NRD
  1   1   0   0 # WBS 1 only has access to groundwater pumping
  2   0   1   0 # WBS 2 only has access to semi-routed deliveries
  3   1   1   1 # WBS 3 has access to all sources of water
  4   0   0   0 # WBS 4 has no sources of water other than natural ones
  5   0   0   1 # WBS 5 only has access to non-routed deliveries
```

If a source of water is declared as not being available through the **WATERSOURCE** keyword, then this supersedes any contradictory input. However, it also is recommended to ensure that if a WBS does not have access to a specific supply defined it also is designated as not having it as a water source. For example, if a WBS does not have an NRD, its delivery volume should be set to zero, and if another WBS does not have a surface-water delivery, then its SRD segment and reach should be set to zero (ISEG=0 and IRCH=0). The **WATERSOURCE** keyword can be thought of as a simulation speed improvement as it triggers an automatic bypass of the algorithms that check the water sources. For example, without **WATERSOURCE**, the FMP would still check for the total supply of non-routed deliveries even though their total may amount to zero.

## Additional Water-Balance (WBS) Options

Additional keywords can be used depending on the FMP setup for situations such as additional demand, prorating available supplies during irrigation deficiency, and efficiency improvement. Figure 6.20 lists the keywords, input format, and a description of the functions.

If the user wishes to specify additional demand to a WBS, such as pre-wetting a field, the keywords **ADDED\_DEMAND\_RUNOFF\_SPLIT** and **ADDED\_CROP\_DEMAND** allow for this. The **ADDED\_DEMAND\_RUNOFF\_SPLIT** specifies the fraction of the additional demand that becomes runoff and the remainder becomes deep percolation. It is specified for each WBS and Irrigation type (**NIRRIGATE**). If not specified, the **ADDED\_DEMAND\_RUNOFF\_SPLIT** defaults to 0.1 to indicate 10 percent becomes runoff and 90 percent is deep percolation. It also may be specified using *Array Style*, which would apply the split to any additional demanded water that is applied to the specific row and column location. The keyword **ADDED\_CROP\_DEMAND** specifies any additional demands that are applied during a stress period. The second keyword associated with **ADDED\_CROP\_DEMAND** indicates the units in which the additional demand is specified. Both **ADDED\_CROP\_DEMAND FLUX** and **ADDED\_CROP\_DEMAND RATE** may be specified in the **WATER\_BALANCE\_SUBREGION** block, but **FLUX** and **RATE** may only be specified once (fig. 6.20). The keyword **FLUX** indicates that the additional demand is specified as a length per time (L/T) or flux ( $L^3/L^2-T$ ), and the keyword **RATE** indicates that the additional demand is specified as a volume per time or volumetric rate ( $L^3/T$ ). The additional demand is specified for each WBS and for each crop. If the crop has an additional demand, but is not grown within the WBS, then its additional demand is ignored. In the following example input block, **NCROP** is equal to 2:

```

# NROW = 3, NCOL = 4, NWBS = 5, NCROP = 2, NIRRGATE = 3
# Model length units are in meters, and time unit is day
#
ADDED_DEMAND_RUNOFF_SPLIT  STATIC LIST INTERNAL
#      Drip  Sprinkler  Flood
#      IRR1      IRR2      IRR3
1      0.1      0.2      0.1
2      0.1      0.2      0.1
3      0.0      0.1      0.05
4      0.1      0.2      0.1
5      0.1      0.2      0.1
#
ADDED_CROP_DEMAND_FLUX  STATIC LIST INTERNAL
#      CROP1  CROP2
1      0.0254  0.0  # WBS 1, Crop 1 has 1 inch/day of additional demand
2      0.01    0.01 # WBS 2, Crop 1 and 2 have 1 cm/day of additional demand
3      0.0     0.0  # WBSs 3-5 have no additional demand
4      0.0     0.0
5      0.0     0.0
#
ADDED_CROP_DEMAND_RATE  STATIC LIST INTERNAL
#      CROP1  CROP2
1      100.0  0.0  # WBS 1, Crop 1 has 100 m3/day of additional demand
2      1E3    1E3  # WBS 2, Crops 1 and 2 have 1000 m3/day of additional demand
3      0.0    0.0  # WBSs 3-5 have no additional demand
4      0.0    0.0
5      0.0    0.0

```

Note that in this example the additional demand specified from **ADDED\_CROP\_DEMAND\_FLUX** and **ADDED\_CROP\_DEMAND\_RATE** is cumulative—that is, the sum of all additional demands applied to a land use is the final amount specified for the respective WBS.

For the WBSs that have Deficit Irrigation (by setting the **DEFICIENCY\_SCENARIO** to 1), two options are provided to prorate the available supplies to the individual demands within the WBS. This option is set with the keyword **PRORATE\_DEFICIENCY** {**ByDEMAND**, **ByAVERAGE**}, where **ByDEMAND** indicates that the available supply is applied to each individual demand on the basis of the ratio of its demand to the total WBS demand, and **ByAVERAGE** indicates that the supply is applied on the basis of an average demand across the WBS. The options **ByDemand** and **ByAverage** are described in detail in the “New Implementation of Deficit Irrigation” section in the main body of this report. If neither **PRORATE\_DEFICIENCY** option is specified, then the default is to use **ByDemand**.

For the WBSs that have Deficit Irrigation (by setting the **DEFICIENCY\_SCENARIO** to 1), two options determine how the irrigation efficiencies that are defined with **EFFICIENCY** are affected when under deficit irrigation. The two options are to improve irrigation efficiency when under deficit irrigation—a supply shortfall—or hold irrigation efficiencies constant. This selection is set with the keyword **EFFICIENCY\_IMPROVEMENT** LAI[S, T, A, L-**NIRRGATE**], where a 0 indicates that irrigation efficiency remains constant, and a 1 indicates that the irrigation efficiency improves when the WBS is under deficit irrigation. When **EFFICIENCY\_IMPROVEMENT** is not specified, then a value of 0 is set by default and irrigation efficiency remains constant.

Keyword	Input	Description
<b>ADDED_DEMAND_RUNOFF_SPLIT</b>	LAI [ S, T, A, L- <b>NIRRIGATE</b> ]	<b>FLOAT</b> , Fraction of any specified additional demand that becomes runoff as opposed to deep percolation.  If not specified, the default is 0.1
<b>ADDED_CROP_DEMAND_FLUX</b>	LAI [ S, T, L- <b>NCROP</b> ]	<b>FLOAT</b> , Additional demand added to a land use (CROP). Input specified as length [L/T] or flux [ $L^3/L^2-T$ ]
<b>ADDED_CROP_DEMAND_RATE</b>	LAI [ S, T, L- <b>NCROP</b> ]	<b>FLOAT</b> , Additional demand added to a land use (CROP). Input specified as volumetric rate [ $L^3/T$ ]
<b>PRORATE_DEFICIENCY</b>	{ <b>ByDEMAND</b> , <b>ByAVERAGE</b> }	Defines how applied water is spread among different demands when total supply does not meet total demand.  If not specified, then the default is <b>ByDEMAND</b> .
<b>EFFICIENCY_IMPROVEMENT</b>	LAI [ S, T, A, L- <b>NIRRIGATE</b> ]	<b>INT</b> , If Deficit Irrigation occurs allows irrigation efficiency (OFE) to improve in response to supply shortfall.  Set to 0 to hold OFE constant and 1 to indicate OFE improves under deficit irrigation.  If not specified, the default is 0.
<b>WBS_NAME</b>	ULOAD	Specify a name for each WBS. Input expects <b>NWBS</b> records.  Max size is 20 characters.

**Figure 6.20.** WATER\_BALANCE\_SUBREGION block optional, advanced keywords. [FLOAT, floating-point number; INT, integer number; [L/T], length per time in model units; [ $L^3/L^2-T$ ], flux in model units; [ $L^3/T$ ], volumetric rate in model units; NWBS, maximum number of water-balance subregions; ULOAD, universal loader; WBS, water-balance subregion; LAI, list-array input with the following letters representing the supported post-keywords: S for STATIC, T for TRANSIENT, A for ARRAY, and L for LIST]



## Supported **SFAC DIMKEY**

The **WATER\_BALANCE\_SUBREGION** block keywords that support **SFAC DIMKEY**s are presented in figure 6.21. Only the keywords that support **SFAC DIMKEY** are specified, and an X is placed under the respective **DIMKEY** if it is supported by the corresponding keyword. See section “Advanced Scale Factors and **SFAC**” for descriptions of the usage of the **SFAC** keyword and its supported **DIMKEY**s. Figure 6.22 presents the **WATER\_BALANCE\_SUBREGION** block with keyword usages that are relevant to most simulations; the basic definition of each keyword is included as comments.

Keyword	<b>DIMKEY</b>		
	ByWBS	ByCrop	ByIrrigate
<b>EFFICIENCY</b>	X	X	X
<b>BARE_RUNOFF_FRACTION</b>	X		
<b>ADDED_DEMAND_RUNOFF_SPLIT</b>	X	X	X
<b>ADDED_CROP_DEMAND FLUX</b>	X	X	
<b>ADDED_CROP_DEMAND RATE</b>	X	X	

**Figure 6.21.** **WATER\_BALANCE\_SUBREGION** block keywords that support **SFAC DIMKEY**. The supported keywords that can be used for **DIMKEY** are ByWBS, ByCrop, and ByIrrigate. [Supported keyword and **DIMKEY** combinations are marked with an X.]

```

BEGIN WATER_BALANCE_SUBREGION
#
# Required Keywords -----
#
LOCATION    LAI[S, T, A]           # Specify spatial location of the WBS
#
EFFICIENCY LAI[S, T, A, L-NIRRIGATE] # Specify Irrigation Efficiency (OFE) if NIRRIGATE > 0
#
# Recommended Keywords -----
#
DEFICIENCY_SCENARIO LAI[S, T, L] # Set to: 1 for Deficit Irrigation (default); 0 for Zero-Scenario
#
# Fraction of precipitation on bare soil area that becomes runoff. Default is 0.75, if not specified.
BARE_RUNOFF_FRACTION LAI[S, T, A, L]
#
# Additional WBS Options -----
#
WBS_NAME    ULOAD # WBS name used in output. Default name is "WBS_X" where X is the WBS ID.
#
# Fraction of additionally demanded irrigation water that becomes runoff. Default is 0.1, if not
# specified.
ADDED_DEMAND_RUNOFF_SPLIT LAI[S, T, A, L-NIRRIGATE]
#
# Specify additional demand applied to each crop
#
ADDED_CROP_DEMAND_FLUX    LAI[S, T, A, L-NCROP] # Specified in units of length [L/T]
#
ADDED_CROP_DEMAND_RATE    LAI[S, T, A, L-NCROP] # Specified in units of volume [L³/T]
#
# Specify how supply is distributed when deficit irrigation occurs.
# If keyword is not present, then the default is ByDEMAND
PRORATE_DEFICIENCY {ByDEMAND, ByAVERAGE}
#
# Specify if a WBS can improve irrigation efficiency when under deficit irrigation.
# Set to 0, no improvement, or to 1, improve efficiency. Default is 0
EFFICIENCY_IMPROVEMENT LAI[S, T, A, L-NIRRIGATE]
#
# Specify whether WBS has available sources of irrigation or supplemental water for delivery.
# L-3 signifies that values (0 or 1) input as 3 columns refer to each of 3 sources—GW (pumping), SW
# (semi-routed), and NRD (non-routed), respectively.
# Set to 0 to disable source or 1 to indicate source is available. Default is all sources available.
WATERSOURCE LAI[S, T, L-3]
#
END WATER_BALANCE_SUBREGION

```

**Figure 6.22.** WATER\_BALANCE\_SUBREGION block with most of the supported keywords and their input format. [NIRRIGATE, number of irrigation types; NCROP, number of land use types; GW, groundwater; SW, surface water; LAI, list-array input with the following letters representing the supported keywords: S for STATIC, T for TRANSIENT, A for ARRAY, and L for LIST]

## Options Block and Associated Keyword List

The **OPTIONS** block is optional and offers keywords that enact legacy FMP features that did not fit into any other input block. An FMP simulation can run without including the **OPTIONS** block or with specifying the block with nothing in it. It is recommended not to use these features unless necessary to mimic a feature of a previous FMP version. Figure 6.23 presents the **OPTIONS** block supported keywords. Figure 6.24 presents the **OPTIONS** block with the expected input structure and a commented explanation.

Keyword	Description
<b>NOPRINT</b>	Suppress some of the farm well output information from being printed to the LIST file.
<b>WELLFIELD</b>	Allows non-routed deliveries (NRD) to have the well field option, which simulates aquifer storage and recovery.
<b>RECOMP_Q_BD</b>	Forces the FMP to re-run its land-use calculations after model time step has completed. This keyword use is not recommended.
<b>MNWCLOSE</b> QCLOSE HPCT RPCT	Additional multi-node well package (MNW2) closure criteria ( $3 \times \text{FLOAT}$ ). QCLOSE is pumping criterion [L <sup>3</sup> /T] HPCT is head criterion [L] RPCT is residual criterion [L <sup>3</sup> /T] Use of this keyword is not recommended; the FMP automatically handles this.

**Figure 6.23.** Options block keywords list. [FLOAT, floating-point number; [L], length in model units; [L<sup>3</sup>/T], volumetric rate in model units; MNW2, multi-node well package version 2]

```

BEGIN OPTIONS
  # All Keywords are Optional
  NOPRINT
  WELLFIELD
  RECOMP_Q_BD
  MNWCLOSE FLOAT FLOAT FLOAT # Reads 3 floating-point numbers: QCLOSE
  HPCT RPCT
  #
END OPTIONS

```

**Figure 6.24.** Options block with all supported keywords and their input format. [FLOAT, floating-point number.]

## Output Block and Additional Output Keywords

The **OUTPUT** block is optional and contains keywords to output files that are not specifically related to any of the other blocks. Figure 6.25 presents the four keywords that are recommended for specifying output for all the FMP simulations.

**FARM\_WELL\_CBC** and **FARM\_NET\_RECHARGE\_CBC** specify the binary cell-by-cell (CBC) file unit number that all MODFLOW packages write to. Each specified file unit number should match a unit number defined in the MF-OWHM2 NAME file. If they are not specified, then the CBC file unit number is set to 0 to indicate that CBC flows are not written to an external binary file. This CBC output file is then used by post-processing programs, like ZoneBudget, for analysis of all flows in and out of the groundwater system.

The keyword **FARM\_DEMAND\_SUPPLY\_SUMMARY** may be, optionally, followed by a *Generic\_Output\_OptKey* to specify the file. If *Generic\_Output\_OptKey* is not present, then the file created is named “FDS.out”. For every time step the output file contains each WBSs demand for water and corresponding supplies that were used to meet those demands. The output may be text or binary format. If the output file is text format, then it contains a single header line (fig. 6.26A) followed by the output written for each time step. If the output file is binary format, then there is no header and each binary record is formatted as described in figure 6.26B.

Keyword	Input	Description
<b>FARM_WELL_CBC</b>	INT	CBC unit number to write to for farm wells not linked to MNW2. INT is a unit number that is specified in the NAME file. The unit must be declared with the keyword “DATA(BINARY)”.
<b>FARM_NET_RECHARGE_CBC</b>	INT	CBC unit number to write to for the Farm (WBS) Net-Recharge = Deep Percolation – $ET_{gw}$
<b>FARM_DEMAND_SUPPLY_SUMMARY</b>	[ <i>Generic_Output_OptKey</i> ]	Supply and Demand Summary on a WBS basis. Optional to specify file name and location with <i>Generic_Output_OptKey</i> , otherwise the default name is FDS.out
<b>FARM_BUDGET</b>	[ <i>Generic_Output_OptKey</i> ]	Landscape budget; all flows are relative to the landscape—IN to the landscape or OUT of the landscape. Optional to specify file name and location with <i>Generic_Output_OptKey</i> , otherwise the default name is “FB.DETAILS.OUT”

**Figure 6.25.** Output block recommended keyword list. These should be included in all Farm Process (FMP) simulations.  
[CBC, cell-by-cell unit; INT, integer input; MNW2, multi-node well package version 2; WBS, water-balance subregion;  $ET_{gw}$ , evapotranspiration from groundwater]

**A**

PER		is the stress period
STP		is the time step
TIMEUNIT		is elapsed simulation time. Note that the word TIMEUNIT is set to the model time unit T: "SECONDS", "MINUTES", "HOURS", "DAYS", or "YEARS"
FID		is the WBS (Farm) ID number
OFE		is total irrigation efficiency of the WBS
TFDR- INI	[L <sup>3</sup> /T]	is the WBS initial demand for water
NR- SWD- INI	[L <sup>3</sup> /T]	is the WBS initial demand for non-routed deliveries
R- SWD- INI	[L <sup>3</sup> /T]	is the WBS initial demand for semi-routed deliveries.
QREQ- INI	[L <sup>3</sup> /T]	is the WBS initial demand for groundwater pumping
TFDR- FIN	[L <sup>3</sup> /T]	is the WBS amount of demand satisfied with supply
NR- SWD- FIN	[L <sup>3</sup> /T]	is the portion of demand satisfied with non-routed deliveries
R- SWD- FIN	[L <sup>3</sup> /T]	is the portion of demand satisfied with semi-routed deliveries.
QREQ- FIN	[L <sup>3</sup> /T]	is the demanded groundwater pumping
Q- FIN	[L <sup>3</sup> /T]	is the portion of demand satisfied with groundwater pumping
DEF- FLAG		is the WBS <b>DEFICIENCY_SCENARIO</b>
DATE_ START		is the starting calendar date of the time step in the form: yyyy-mm-ddThh:mm:ss
ACTIVE		is set to 1 if the WBS is in use for the stress period and 0 if it is not

**B**

DATE_ START		CHARACTER(19), starting date formatted as 'yyyy-mm-ddThh:mm:ss'
ACTIVE		INTEGER
PER		INTEGER
STP		INTEGER
DELT	[T]	DOUBLE, time step length
TOTIM	[T]	DOUBLE, simulated time at end of time step
FID		INTEGER
DEF- FLAG	[L <sup>3</sup> /T]	INTEGER
TFDR- INI	[L <sup>3</sup> /T]	DOUBLE
NR- SWD- INI	[L <sup>3</sup> /T]	DOUBLE
R- SWD- INI	[L <sup>3</sup> /T]	DOUBLE
QREQ- INI	[L <sup>3</sup> /T]	DOUBLE
TFDR- FIN	[L <sup>3</sup> /T]	DOUBLE
NR- SWD- FIN	[L <sup>3</sup> /T]	DOUBLE
R- SWD- FIN	[L <sup>3</sup> /T]	DOUBLE
QREQ- FIN	[L <sup>3</sup> /T]	DOUBLE
Q- FIN	[L <sup>3</sup> /T]	DOUBLE

**Figure 6.26.** FARM\_DEMAND\_SUPPLY\_SUMMARY (FDS.out) text file header explanation and binary record structure. *A*, Text-header explanation. *B*, Binary-record structure. [[T], unit of time in model units; [L<sup>3</sup>/T], volumetric rate in model units; CHARACTER(19) indicates record is 19 characters long (19 bytes); INTEGER is a 4-byte integer record; DOUBLE is a 8-byte floating-point number record.]

The keyword **FARM\_BUDGET** may be optionally followed by a *Generic\_Output\_OptKey* to specify the file. If *Generic\_Output\_OptKey* is not present, then the file created is named “FB\_DETAILS.out”. The **FARM\_BUDGET** output file may be text or binary format. If the output file is text format, then it contains a single header line (fig. 6.27A) followed by the output written for each time step. If the output file is binary format, then there is no header and each binary record is formatted as described in figure 6.27B. The output file contains for every time step the flow rates in and out of each WBS landscape, where the flow directions are relative to the landscape. That is, an “-in” flow is a flow that enters the landscape—for example precipitation enters the landscape—and an “-out” is a flow that leaves the landscape—the precipitation that enters the landscape may leave as evaporation, transpiration, runoff, or deep percolation. The **FARM\_BUDGET** output file does contain several “-in” headers that are always equal to their corresponding “-out” headers because the flow pass through the landscape—for example, groundwater evaporation passes through the landscape to the atmosphere, so  $Q\text{-egw-in} = Q\text{-egw-out}$ .

Figure 6.28 describes keywords that create output files available in previous versions of the FMP. For exact details on their output see Hanson and others (2014) and Schmid and others (2006, 2009). Each keyword maybe followed with a *Generic\_Output\_OptKey* to specify the file name. If *Generic\_Output\_OptKey* is not specified, then the default filename is used. These output files do not support **BINARY** output.



A

PER	is the stress period	
STP	is the time step	
TIMEUNIT	is elapsed simulation time. Note that the word TIMEUNIT is set to the model time unit T: "SECONDS", "MINUTES", "HOURS", "DAYS", or "YEARS"	
FID	is the WBS (Farm) ID number	
Q-p-in	is precipitation that enters the WBS	[L <sup>3</sup> /T]
Q-nrd-in	is the rate that non-routed delivery flow enters the WBS	[L <sup>3</sup> /T]
Q-srd-in	is the rate that semi-routed delivery flow enters the WBS	[L <sup>3</sup> /T]
Q-wells-in	is the rate that groundwater well water enters the WBS	[L <sup>3</sup> /T]
Q-egw-in	is evaporation from groundwater	[L <sup>3</sup> /T]
Q-tgw-in	is transpiration from groundwater	[L <sup>3</sup> /T]
Q-mar-in	is flood water applied to the WBS as managed aquifer recharge.	[L <sup>3</sup> /T]
Q-drch-in	is <b>DIRECT_RECHARGE</b> applied to WBS—similar to Recharge Package.	[L <sup>3</sup> /T]
Q-ext-in	is the Zero-Scenario external water required to meet demand.	[L <sup>3</sup> /T]
Q-tot-in	is total flows into the WBS	[L <sup>3</sup> /T]
Q-ei-out	is evaporation from irrigation out of the landscape	[L <sup>3</sup> /T]
Q-ep-out	is evaporation from precipitation out of the landscape	[L <sup>3</sup> /T]
Q-egw-out	equals Q-egw-in because it passes through the landscape to the atmosphere	[L <sup>3</sup> /T]
Q-ti-out	is transpiration from irrigation out of the landscape	[L <sup>3</sup> /T]
Q-tp-out	is transpiration from precipitation out of the landscape	[L <sup>3</sup> /T]
Q-tgw-out	equals Q-tgw-in because it passes through the landscape to the atmosphere	[L <sup>3</sup> /T]
Q-run-out	is total overland runoff out of the WBS	[L <sup>3</sup> /T]
Q-dp-out	is deep percolation that leaves the root zone—this includes drch and mar.	[L <sup>3</sup> /T]
Q-nrd-out	is the rate that non-routed delivery flow leaves the WBS	[L <sup>3</sup> /T]
Q-srd-out	is the rate that semi-routed delivery flow leaves the WBS from excess NRD	[L <sup>3</sup> /T]
Q-rd-out	is the rate that fully-routed flow leaves the WBS from excess NRD	[L <sup>3</sup> /T]
Q-wells-out	is the rate that groundwater well water is injected from excess NRD	[L <sup>3</sup> /T]
Q-tot-out	is the total outflow	[L <sup>3</sup> /T]
Q-in-out	is the difference between Q-tot-in and Q-tot-out	[L <sup>3</sup> /T]
Q-Discrepancy[%]	is the percent error between Q-tot-in and Q-tot-out	[%]
DATE_START	is the starting calendar date of the time step in the form: yyyy-mm-ddThh:mm:ss	
ACTIVE	is set to 1 if the WBS is in use for the stress period and 0 if it is not	

**Figure 6.27.** FARM\_BUDGET (FB\_DETAILS.out) text file header explanation and binary record structure. A, Text-header explanation. B, Binary-record structure. [[T], unit of time in model units; [L<sup>3</sup>/T], volumetric rate in model units; CHARACTER(19) indicates record is 19 characters long (19 bytes); INTEGER is a 4-byte integer record; DOUBLE is an 8-byte floating-point number record; %, percent.]

**B**

DATE_START	CHARACTER(19), starting date formatted as 'yyyy-mm-ddThh:mm:ss'
ACTIVE	INTEGER
PER	INTEGER
STP	INTEGER
DELT	DOUBLE, time step length [T]
TOTIM	DOUBLE, simulated time at end of time step [T]
FID	INTEGER
Q-p-in	DOUBLE
Q-nrd-in	DOUBLE
Q-srd-in	DOUBLE
Q-wells-in	DOUBLE
Q-egw-in	DOUBLE
Q-tgw-in	DOUBLE
Q-mar-in	DOUBLE
Q-drch-in	DOUBLE
Q-ext-in	DOUBLE
Q-ei-out	DOUBLE
Q-ep-out	DOUBLE
Q-egw-out	DOUBLE
Q-ti-out	DOUBLE
Q-tp-out	DOUBLE
Q-tgw-out	DOUBLE
Q-run-out	DOUBLE
Q-dp-out	DOUBLE
Q-nrd-out	DOUBLE
Q-srd-out	DOUBLE
Q-rd-out	DOUBLE
Q-wells-out	DOUBLE

**Figure 6.27.** —Continued

**A**

Keyword	Default Filename	Description
<b>FARM_BUDGET_COMPACT</b>	FB_COMPACT.OUT	Same as <b>FARM_BUDGET</b> , but aggregates water by common type [L <sup>3</sup> /T].
<b>FARM_NET_RECHARGE_ARRAY</b>	FNRCH_ARRAY.OUT	Write cell-by-cell WBS (Farm) net recharge (FNR) as an array to a text file [L <sup>3</sup> /T]. FNR is the difference between deep percolation and evaporation from groundwater.
<b>FARM_NET_RECHARGE_LIST</b>	FNRCH_LIST.OUT	Write WBS (Farm) net recharge (FNR) for each WBS to a text file [L <sup>3</sup> /T]. FNR is the difference between deep percolation and evaporation from groundwater.
<b>FARM_WELL_SUMMARY</b>	FWELLS.OUT	Print out layer, row, column, and final rate for all WBS (Farm) wells [L <sup>3</sup> /T].

**B**

Keyword	Default Filename	Description
<b>EVAPOTRANSPIRATION_SUMMARY SUM</b>	ET_ARRAY.OUT	Write cell-by-cell evapotranspiration as an array to a text file [L <sup>3</sup> /T].
<b>EVAPOTRANSPIRATION_SUMMARY SEPARATE</b>	E_n_T_ARRAY.OUT	Write cell-by-cell evaporation and transpiration as two separate arrays in a text file [L <sup>3</sup> /T].
<b>EVAPOTRANSPIRATION_LIST</b>	ET_LIST.OUT	Write to a text file the evaporation, transpiration, and evapotranspiration for each WBS [L <sup>3</sup> /T].

**Figure 6.28.** Output block additional keywords that provide specific output information. The resulting file created has the default file name or, optionally, the output file name and location can be specified with *Generic\_Output\_OptKey*. *A*, WBS (farm) specific output options. *B*, Evapotranspiration specific output options. *C*, Runoff and deep percolation output options. [[L<sup>3</sup>/T], volumetric rate in model units; NCOL and NROW, number of columns and rows, respectively, in the model grid; WBS, water-balance subregion]

c

Keyword	Default Filename	Description
<b>LANDSCAPE_RUNOFF</b>	RUNOFF.out	Write the cell-by-cell surface runoff [ $L^3/T$ ]. An optional keyword, <b>COMPACT</b> , can be placed after the keyword to indicate that output should only write model cells whose runoff is greater than zero as a compact list of row, column, runoff. If not specified, then output is a NROW by NCOL array.
<b>DEEP_PERCOLATION</b>	DPERC.out	Write the cell-by-cell deep percolation [ $L^3/T$ ]. An optional keyword, <b>COMPACT</b> , can be placed after the keyword to indicate that output should only write model cells whose runoff is greater than zero as a compact list of row, column, runoff. If not specified, then output is a NROW by NCOL array.

Figure 6.28. —Continued

## Climate Block

The **CLIMATE** block is conditionally optional and specifies reference evapotranspiration, potential evaporation, precipitation, potential consumption of precipitation, and any additional recharge passed as deep percolation—this is like the Recharge Package (RCH). Figure 6.29 presents all the keywords that the **CLIMATE** block can load.

The **CLIMATE** block becomes required if a land use/crop is defined using crop coefficients or if a model cell that is in a WBS does not have a defined land use. If crop coefficients are defined in the **LAND\_USE** block, then it is necessary to specify **REFERENCE\_ET** (fig. 6.29A) to calculate the land use potential consumptive use (CU). The second situation that requires the **CLIMATE** block is a model cell that resides in a WBS but has no defined land use, which is assumed to be bare soil. This situation requires a user to specify a **POTENTIAL\_EVAPORATION\_BARE** (fig. 6.29B) to use as a potential evaporation rate for groundwater and precipitation. If **REFERENCE\_ET** is specified, but the **POTENTIAL\_EVAPORATION\_BARE** is not specified, the FMP will automatically use the **REFERENCE\_ET** as the potential evaporation rate over bare soil. Any remaining precipitation after evaporation becomes either runoff or deep percolation based on the **WATER\_BALANCE\_SUBREGION** block keyword **BARE\_RUNOFF\_FRACTION**.

The **PRECIPITATION** keyword (fig. 6.29A) is optional and specifies the precipitation rate ( $L/T$ ) that falls over the WBSs. It is specified as an array that has the same dimension as the model grid ( $NROW \times NCOL$ ). The scale of the precipitation must be an equivalent rate for the entire stress period—or equivalent for the time step if the **WATER\_BALANCE\_SUBREGION** block has the keyword **BY\_TIMESTEP CLIMATE**. Precipitation is automatically set to zero if it is specified on a model cell that is not associated with a WBS—specifically, any model cells with a **WATER\_BALANCE\_SUBREGION LOCATION** that is less than 1 or greater than **NWBS** have no defined WBS and thus are assigned no precipitation. If **PRECIPITATION** is not specified, the FMP assumes there is no precipitation for the simulation.

The **PRECIPITATION\_POTENTIAL\_CONSUMPTION** keyword (fig. 6.29C) is optional and limits how much precipitation can be consumed as evaporation and transpiration (consumptive use). The use of the **PRECIPITATION\_POTENTIAL\_CONSUMPTION** keyword is not recommended unless FMP simulation results indicate an overconsumption of precipitation. This could occur when a stress period has a long-time span compared to the total time precipitation occurred during the stress period. Instead of using this option, it may be better to specify precipitation by time step to get a more accurate representation of precipitation events—this is done with the keyword **BY\_TIMESTEP CLIMATE** in the **GLOBAL DIMENSION** block. Using **PRECIPITATION\_POTENTIAL\_CONSUMPTION** keyword is only advantageous when a stress period has high intensity, short-duration precipitation events relative to the stress period length or as a correction factor for sporadic precipitation events during a stress period.

The limit on precipitation consumption can be viewed as defining a potential effective precipitation, which represents the quantity of rainfall that is not runoff nor deep percolation. The reason it is considered a potential effective precipitation is because there can be additional runoff and deep percolation if the landscape's CU is less than the potential consumption of precipitation—that is, the simulated actual evapotranspiration does not consume all the available precipitation. If not specified, then the potential consumption of precipitation is the full amount of precipitation. The limit can be defined as a length—**PRECIPITATION\_POTENTIAL\_CONSUMPTION BY\_LENGTH**—or as a fraction—**PRECIPITATION\_POTENTIAL\_CONSUMPTION BY\_FRACTION**. If defined as a length, then only precipitation up to the specified length (L/T) is available for consumption. If defined as a fraction, then it is multiplied by the precipitation to get the effective precipitation length. To disable limiting the effective precipitation, set the length to 1E30 or any value larger than the actual precipitation.

Note that the keyword **EFFECTIVE\_PRECIPITATION\_TABLE** in the **SOIL** block functions identically to **PRECIPITATION\_POTENTIAL\_CONSUMPTION**. The difference is that the **SOIL** block specifies the potential consumption of precipitation as a lookup table of precipitation to effective precipitation by soil type. See the “Soil Block” section for more details and examples of transforming precipitation to effective precipitation.

A

Keyword	Description
<b>REFERENCE_ET</b>	Reference Evapotranspiration ( $ET_{ref}$ ), as a length or flux, that occurs over model cell. Required if land use defined with crop coefficients ( $K_c$ ). Zero is an acceptable value for $ET_{ref}$ , but this will disable all evapotranspiration. Loaded as <b>FLOAT</b> Array [L/T].
<b>PRECIPITATION</b>	Precipitation, as a length or flux, that falls over model cell. Precipitation that is for model cells that are not associated with a WBS is ignored—that is a <b>WATER_BALANCE_SUBREGION LOCATION</b> that is less than 1 or greater than <b>NWBS</b> . Loaded as <b>FLOAT</b> Array [L/T].

**Figure 6.29.** CLIMATE block keyword list. All keywords are followed by input loaded with LAI[ S, T, A ]. Secondary keywords enclosed in curly braces, {}, indicate that only one of the keywords may be selected and used during a simulation. *A*, Recommended CLIMATE block keywords. *B*, Optional CLIMATE block keywords. *C*, Advanced CLIMATE block keywords. [FLOAT, floating-point number; L/T, length per time in model units; L<sup>3</sup>/T, volumetric rate in model units; NWBS, number of water-balance subregions; UZF, unsaturated-zone flow package; WBS, water-balance subregion; LAI, list-array input with the following letters representing the supported keywords: S for STATIC, T for TRANSIENT, A for ARRAY]

**B**

Keyword	Description
<b>DIRECT_RECHARGE</b> { <b>FLUX</b> , <b>RATE</b> }	<p>Recharge that is added to deep percolation and not available for consumption as evaporation or transpiration.</p> <p>The model cell that has <b>DIRECT_RECHARGE</b> must be associated with a WBS.</p> <p>Mimics the Recharge package (RCH), except if <b>UZF_LINK</b> is enabled then deep percolation is received as infiltration to UZF.</p> <p><b>DIRECT_RECHARGE</b> must be followed by either <b>FLUX</b> or <b>RATE</b>.</p> <p><b>FLUX</b> keyword indicates input is read as [L/T] and the <b>RATE</b> keyword indicates input is [L<sup>3</sup>/T]</p> <p>Read as a <b>FLOAT</b> array.</p>
<b>POTENTIAL_EVAPORATION_BARE</b>	<p>Potential Evaporation rate of groundwater and precipitation over any model cell located in a WBS that does not have a land use defined (Bare Soil).</p> <p>If not specified and <b>REFERENCE_ET</b> is, then it is set to half of <b>REFERENCE_ET</b>.</p> <p>It is required, either specified directly or via <b>REFERENCE_ET</b>, if there are model cells within a WBS that do not have a defined land use (Bare Soil).</p> <p>Loaded as <b>FLOAT</b> Array [L/T].</p>

**C**

Keyword	<b>PRECIPITATION_POTENTIAL_CONSUMPTION</b> { <b>BY_LENGTH</b> , <b>BY_FRACTION</b> }
Description	<p>Places a limitation on the consumption of precipitation by the landscape as evaporation and transpiration. Precipitation that is beyond limit becomes runoff or deep percolation.</p> <p>If not specified, then there is no limit and actual evapotranspiration can potentially consume all the precipitation.</p> <p>The <b>BY_LENGTH</b> keyword indicates that input is in units of length per time [L/T] and any precipitation in excess of this length is not available for consumption.</p> <p>The <b>BY_FRACTION</b> keyword indicates that input is a fraction between 0 and 1 to indicate the fraction of the precipitation that is available for consumption.</p> <p>Loaded as <b>FLOAT</b> Array.</p>

Figure 6.29. —Continued

**DIRECT\_RECHARGE** (fig. 6.29B) is a source of water not available for consumption by a land use/crop. **DIRECT\_RECHARGE** is applied directly to deep percolation that either recharges the water table or becomes an inflow to the unsaturated zone—through the **UZF\_LINK**—for delayed recharge. It can be viewed as a surrogate for the Recharge (RCH) package but is included in the FMP landscape budgets and optionally linked to UZF.

## Supported **SFAC DIMKEY**

The **CLIMATE** block keywords that support **SFAC DIMKEY**s are presented in Figure 6.30. Only the keywords that support **SFAC DIMKEY** are specified and an “X” placed under the respective **DIMKEY**. The only **SFAC DIMKEY** that is supported by the **CLIMATE** block is **ByWBS**.

## *IXJ Style* Input Support

At the time of this report’s publication, all the supported keywords for the **CLIMATE** block allow for the use of the *IXJ Style* input that serves as an alternative input to the *Array Style* input. If *IXJ Style* input is used, then the FMP expects to load two integers (I) and one floating-point number (X) and does not read any subsequent integers (J). The floating-point number is the keyword property—such as the precipitation rate—and the two integers are the model row and column that the property is applied to. Figure 6.31 illustrates the use of *IXJ Style* input in the **CLIMATE** block.

## Keyword List

Figure 6.32 presents the **CLIMATE** block with all its supported keywords, their expected input structure, and a commented explanation.

Keyword	<b>DIMKEY</b>		
	ByWBS	ByCrop	ByIrrigate
<b>REFERENCE_ET</b>	X		
<b>POTENTIAL_EVAPORATION_BARE</b>	X		
<b>PRECIPITATION</b>	X		
<b>DIRECT_RECHARGE</b>	X		

**Figure 6.30.** **CLIMATE** block keywords that support **SFAC DIMKEY**. The only supported word for **DIMKEY** is **ByWBS**. [Supported keyword and **DIMKEY** combinations are marked with an X.]

```

# Example CLIMATE block for a model grid with NROW = 3, NCOL = 4
# [L] Model length units are in meters
# [T] Model time units are in days
#
BEGIN CLIMATE
#
# PRECIPITATION keyword with INTERNAL automatically implies STATIC
# and, because the only INPUT_STYLE supported is Array style (ARRAY or IXJ),
# so if not specified implies that the input follows ARRAY as an input.
# To use IXJ style, then the keyword IXJ must be specified.
#
PRECIPITATION INTERNAL
0.50 0.68 0.81 0.75
0.55 0.72 0.82 0.77
0.52 0.73 0.83 0.79
#
#
# DIRECT_RECHARGE keyword uses IXJ Style input to specify recharge
# as deep percolation at three model cell locations.
#
# Note that IXJ Style is a surrogate for Array Style input.
# That is, the array is specified by row and column reference rather than as a full array.
#
DIRECT_RECHARGE STATIC IXJ INTERNAL
# ROW COL Recharge Rate
2 4 1.E3
3 4 50.5
3 3 75.0
STOP IXJ # Stop loading IXJ input
#
END CLIMATE

```

**Figure 6.31.** CLIMATE block example with Array Style and IXJ Style inputs for a 3-by-4 model grid. [NROW is the number of model rows; NCOL is the number of model columns; COL is shorthand for model column.]



```

BEGIN CLIMATE
#
# Recommended Keyword -----
#
PRECIPITATION LAI[S, T, A] # Specify precipitation flux over model domain
#
# Conditionally Required Keywords -----
#
REFERENCE_ET LAI[S, T, A] # Specify reference evapotranspiration flux over model domain
#
# Specify potential evaporation flux for model cells with undefined land use (bare soil area)
# If not specified, then set to REFERENCE_ET × REFERENCE_ET_TO_BARE
POTENTIAL_EVAPORATION_BARE LAI[S, T, A]
#
# Advanced Keywords -----
#
DIRECT_RECHARGE {FLUX, RATE} LAI[S, T, A, L] # Additional recharge added to deep percolation
#
# Multiplier to convert REFERENCE_ET to POTENTIAL_EVAPORATION_BARE, if not specified default is 0.5
REFERENCE_ET_TO_BARE FLOAT
#
# Specify potential consumption limit for precipitation (converts precip to effective precip).
PRECIPITATION_POTENTIAL_CONSUMPTION {BY_LENGTH, BY_FRACTION} LAI[S, T, A]
#
END CLIMATE

```

**Figure 6.32.** CLIMATE block with all supported keywords and their input format. [FLOAT, floating-point number; LAI, list-array input with the following letters representing the supported keywords: S for STATIC, T for TRANSIENT, and A for ARRAY]

## Soil Block

The **SOIL** block is conditionally optional and specifies the Soil ID location, soil capillary fringe, and soil coefficients. The number of soil types is defined external to the **SOIL** block by the Global Dimension block variable, **NSOIL**, and is the number of records read with *List Style*. Figure 6.33 presents the four keywords that are available in the **SOIL** block.

The **SOIL\_ID** array is only required if **NSOIL** is greater than 1. If **SOIL\_ID** is not specified and **NSOIL** is equal to 0 or 1, then it is automatically set to 1 for the entire model grid. The **CAPILLARY\_FRINGE** specifies the distance above the water table that the capillary fringe extends to. The water table elevation plus the capillary fringe defines a threshold elevation used to determine whether there is (1) the potential for groundwater evaporation when the threshold is above the **SURFACE\_ELEVATION** and (2) the potential for a land use to have groundwater-root uptake—groundwater consumption—when the threshold is above the bottom of the root zone. Appendixes 4 and 5 describe in detail the determination of groundwater evaporation when the water table is between ground surface and the extinction depth and of crop root uptake under variably saturated conditions. The **CAPILLARY\_FRINGE** may be specified with *Array Style*—in which case it does not require nor use **SOIL\_ID**—to specify the capillary fringe for the surface layer of the model grid or FMP may use *List Style* to read **NSOIL** records that apply the capillary fringe on the basis of the **SOIL\_ID** array—for example, record 1 is applied to every cell containing a 1 in the **SOIL\_ID** array. Figure 6.34 illustrates the relationship between **SOIL\_ID** and **CAPILLARY\_FRINGE** when using *List Style* input and *Array Style* input.

A

Keyword	Input	Description
<b>SOIL_ID</b>	ULOAD	<p><b>INT</b> Array whose value is between 0 and <b>NSOIL</b> to indicate the location of each soil type. A Soil ID of 0 is ignored.</p> <p>If <b>NSOIL</b>=1, then <b>SOIL_ID</b> is optional; if not specified, then the entire model grid is automatically set to a <b>SOIL_ID</b> of 1.</p>
<b>CAPILLARY_FRINGE</b>	LAI [ S, A, L ]	<p><b>FLOAT</b> Array or List (length = <b>NSOIL</b>) that specifies the capillary fringe length above the water table [L].</p> <p>The capillary fringe in the FMP is the length above saturated groundwater in which water is held by surface tension and can evaporate if near the land surface or be transpired if near a crop's roots.</p> <p>For groundwater evaporation to occur, the groundwater head must be greater than the land-surface elevation minus the capillary length.</p> <p>For groundwater transpiration—direct uptake of groundwater by a crop— to occur, the groundwater head must be greater than the land-surface elevation minus the crop's root length minus the capillary length.</p> <p><i>Array Style</i> specifies each model cell's capillary fringe and <i>List Style</i> uses the <b>SOIL_ID</b> array to assign the <b>NSOIL</b> capillary fringes.</p>

**Figure 6.33.** SOIL block keyword list. Keywords enclosed in curly braces, {}, indicate that only one of the keywords may be used during a simulation. *A*, Required keywords. *B*, Advanced keywords. [Input that is not separated by an or is specified on the same line. Abbreviations: FMP, farm process; ID, water balance subregion identification number; WBS, water-balance subregion; INT, integer; [L], length in model units; [L/T], length per time in model units.]

**B**

Keyword	Input	Description
<b>COEFFICIENT</b>	LAI[S, L]  or  LAI[S, L-5]	Soil coefficients used in the analytical, pseudo steady-state soil-moisture, soil-stress concept ( <i>analytical root response</i> ) land-use calculation. Required if <b>LAND_USE</b> block specifies <b>ROOT_PRESSURE</b> .  <i>List Style</i> reads for each record one of the following secondary keywords: <b>SILT</b> , <b>SILTYCLAY</b> , <b>SANDYLOAM</b> , and <b>SAND</b>  or five <b>FLOAT</b> numbers that represent the coefficients A, B, C, D, and E defined in appendix 6.
<b>EFFECTIVE_PRECIPITATION_TABLE</b>	{ <b>BY_LENGTH</b> , <b>BY_FRACTION</b> }  LAI[S, L]	Reads <b>NSOIL</b> Lookup Tables that specify the relationship between <b>PRECIPITATION</b> and effective precipitation.  This is applied as a limitation on the potential consumption of precipitation by the landscape to satisfy evaporation and transpiration. Precipitation that is beyond limit becomes runoff or deep percolation.  If not specified, then there is no limit and actual evapotranspiration can potentially consume all the precipitation.  Each table is loaded with <i>Lookup</i> -Style Input. The “lookup values” are precipitation rates in [L/T]. Effective precipitation is the “return value” of the table.  The <b>BY_LENGTH</b> keyword indicates that the return value is [L/T] and any precipitation in excess of this is not available for consumption.  The <b>BY_FRACTION</b> keyword indicates that the return value is a fraction between 0 and 1 and is the fraction of the precipitation that is effective.

**Figure 6.33.** —Continued

A

```
# Example use of the SOIL block keyword SOIL_ID
#
# NROW = 3, NCOL = 4, NSOIL = 3; [L] has model length units in meters
#
# SOIL_ID defines the spatial location of each soil type.
# SOIL_ID is read with ULOAD to read a 3 by 4 array, INTERNAL indicates it is on subsequent lines.
SOIL_ID  INTERNAL
1  1  2  2
1  1  2  2
1  1  3  3
```

B

```
# CAPILLARY_FRINGE defines the capillary fringe length above the water table [L]. Input is LAI[S, A, L]
# The keyword STATIC is optional because it is the only TERMPORAL_KEY
# ARRAY or LIST must be specified to indicate the input structure.
#
# This example illustrates the use of LIST-style input to load NSOIL=3 records
#
CAPILLARY_FRINGE  STATIC LIST INTERNAL
# ID      Capillary Fringe Length      ↓ Resulting Model Grid ↓
1      1.2                                # 1.2  1.2  1.8  1.8
2      1.8                                # 1.2  1.2  1.8  1.8
3      1.5                                # 1.2  1.2  1.5  1.5
#
```

C

```
# This example illustrates the use of ARRAY-style input to load a 3 by 4 array of capillary fringe
lengths
#
# This example also includes the advanced scale factor, SFAC BySoil, to scale the array by soil type
# SFAC BySoil indicates that soil 1 is scaled by 1.1, soil 2 by 1.2, soil 3 by 1.3
# Note that if SFAC BySoil was not present, the capillary fringe is identical to the LIST version in (B)
#
CAPILLARY_FRINGE  STATIC ARRAY INTERNAL
SFAC BySOIL  1.1  1.2  1.3      # ↓      SFAC result      ↓
1.2  1.2  1.8  1.8      # 1.32  1.32  2.16  2.16
1.2  1.2  1.8  1.8      # 1.32  1.32  2.16  2.16
1.2  1.2  1.5  1.5      # 1.32  1.32  1.95  1.95
```

**Figure 6.34.** The relationship between the SOIL block keywords SOIL\_ID and CAPILLARY\_FRINGE. *A*, Define the soil type location. *B*, Define the capillary fringe with List Style input. *C*, Define the capillary fringe with Array Style input with an advanced scale factor, **SFAC**, using the BySoil **DIMKEY**. [**DIMKEY**, Dimensional keyword; BySoil, indicates NSOIL scale factors are read; NSOIL is the number of soil types; NROW is the number of model rows; NCOL is the number of model columns; LAI, list-array input with the following letters representing the supported keywords: S for STATIC, T for TRANSIENT, A for ARRAY, and L for LIST]

The **EFFECTIVE\_PRECIPITATION\_TABLE** keyword is optional and limits how much precipitation can be consumed as evaporation and transpiration (Consumptive Use). The only supported input is *List Style*, which reads **NSOIL** record IDs followed by *Lookup Style* input. The return value for **EFFECTIVE\_PRECIPITATION\_TABLE** is analogous to effective precipitation, which represents the quantity of rainfall that becomes neither runoff nor deep percolation. It is different from effective precipitation because there can be additional runoff and deep percolation if the landscape's consumptive use is less than the potential consumption of precipitation—that is, the simulated actual evapotranspiration does not consume all the available precipitation. If not specified, then the potential effective precipitation—potential consumption—is the same as the precipitation. The actual consumption of precipitation is either the effective precipitation or the actual evapotranspiration less any groundwater-root uptake for transpiration, whichever is smaller. The limit can be defined as a length—**EFFECTIVE\_PRECIPITATION\_TABLE BY\_LENGTH**—or as a fraction—**EFFECTIVE\_PRECIPITATION\_TABLE BY\_FRACTION**. If defined as a length, then only precipitation up to the specified length (L/T) is available for consumption. If defined as a fraction, then it is multiplied by the precipitation to get the effective precipitation length. If the lookup table returns an effective precipitation that is negative, then it is set to zero. Conversely, if the lookup table returns an effective precipitation larger than the actual precipitation, then it is reset to the actual precipitation. To disable limiting the effective precipitation, set the length to 1E30—or any value larger than the actual precipitation. Figure 6.35 is an example that specifies lookup tables of effective precipitation for two soil types and uses a constant for a third soil type.

A

```
# Example use of the SOIL block keyword EFFECTIVE_PRECIPITATION_TABLE
#
# NSOIL = 3; [L/T] has model length units in centimeters and time units in days
# Soil 1 and 2 refer to lookup tables in external files
# Soil 3 contains a large number so the effective precipitation is equal to precipitation.
#
# EFFECTIVE_PRECIPITATION_TABLE specify lookup tables that define the
#   relationship between precipitation and effective precipitation as a lookup table.
#   BY_LENGTH indicates input is expected to be in units of [L/T]
# ULOAD reads NSOIL Lookup Style input, INTERNAL indicates it is on subsequent lines.
#
EFFECTIVE_PRECIPITATION_TABLE BY_LENGTH INTERNAL
#ID METHOD          NTERM  GENERIC_INPUT
 1 INTERPOLATE    0      TAB1.txt    # Load table in TAB1.txt; 0 indicates to auto-count rows
 2 INTERPOLATE    5      TAB2.txt    # Load table in TAB2.txt; Table has 5 rows
 3 CONSTANT  1E30                      # Table set to a large constant value
```

B

```
# File: TAB1.txt
# Values chosen are for illustrative purposes
# and should not be used in practice
# LookUp      ReturnValue
 5.0          1.0
10.0          5.0
15.0         10.0
20.0         15.0
25.0         20.0
# End of file; auto-count sets NTERM = 5
```

C

```
# File: TAB2.txt
# Values chosen are for illustrative purposes
# and should not be used in practice
# LookUp      ReturnValue
 5.0          10.0
10.0          10.0
15.0          10.0
20.0          15.0
20.1          1E30
```

**Figure 6.35.** SOIL block **EFFECTIVE\_PRECIPITATION\_TABLE** keyword example that reads using Lookup Style two lookup tables. A, Setup required to define **EFFECTIVE\_PRECIPITATION\_TABLE**. B, File TAB1.txt that contains a lookup table. C, File TAB2.txt that contains a lookup table. [[L/T] length per time in model units; NSOIL is the number of soil types; ULOAD is the universal loader]

In figure 6.35, the lookup table defined in TAB2.txt (fig. 6.35C) has precipitation lookup values 5, 10, and 20.1, which are less than or equal to their associated effective precipitation (for example,  $5 < 10$ ). For these three rows the consumption of precipitation is not limited (effective precipitation cannot be larger than actual). For example, a precipitation value of 6 has an effective precipitation of 10, which is greater than the actual precipitation, so the available precipitation is 6. Any precipitation greater than 20 has the effective precipitation greater than the actual, so the effective precipitation is always set equal to the actual. For example, precipitation of 20.001 returns an effective precipitation of 1E28, which is greater than 20.001, so the available precipitation for consumption is 20.001.

It should be noted that the effective precipitation only serves as a potential consumption. The effective precipitation may not fully be consumed by the land use. This can occur when the consumptive use is less than the effective precipitation or the consumptive use is satisfied by direct groundwater uptake. Figure 6.36 presents three example cases to illustrate how the **EFFECTIVE\_PRECIPITATION\_TABLE** can limit the consumption. In figure 6.36, the *Potential-Actual Consumptive Use* represents the actual consumptive use [L/T] if there is enough water supply. The *FMP Calculated Transpiration from Groundwater* is determined on the basis of the water-table location, the soil properties, and the root depth. The *FMP Calculated Potential Consumption of Precipitation* is the consumption of precipitation from evaporation and transpiration if there is no limit imposed. The *Potential-Actual Consumption of Precipitation by Evaporation and Transpiration* is the actual maximum consumption of precipitation by evaporation and transpiration given enough precipitation. Each test case shows, in bold, which input becomes the limiting factor for the consumption of precipitation.

The use of the **EFFECTIVE\_PRECIPITATION\_TABLE** keyword is not recommended, unless FMP simulation results present concerns with overconsumption of precipitation. This could occur when a stress period has a long time span compared to the total time that precipitation fell during the stress period. For example, a 30-day stress period that has 1 day with 0.3 meter (m) of precipitation and no precipitation for the rest of the period would have an input of 0.01 meter per day (m/d). The precipitation from a single event is spread out across the month resulting in overconsumption. An example limit on the consumption could be specified by including one of the post-keywords—**BY\_LENGTH** of 0.002 m or equivalently as **BY\_FRACTION** of 0.1. If there is a lack of data about a simulation area and the model tends to overconsume precipitation, then figure 6.37 (Brouwer and Heibloem, 1986) provides rough effective precipitation estimates for a given precipitation per month. Additional empirical methods, including the U.S. Department of Agriculture Soil Conservation Service (USDA SCS) method, for determining effective precipitation are described in Dastane (1978).

If it is desired to use the analytical pseudo steady-state soil moisture, soil-stress concept called *analytical root response* (appendixes 4 and 5), then the soil **COEFFICIENT** and the **LAND\_USE** block keyword **ROOT\_PRESSURE** must be specified. The soil **COEFFICIENT** may be specified using keywords that have predefined soil coefficients or by directly specifying the five soil coefficients (A, B, C, D, and E). Figure 6.38 presents the soil **COEFFICIENT** keywords and their coefficients. Figure 6.39 is an example that specifies the **SOIL\_ID** and **COEFFICIENT** for three soil types.

	Case 1	Case 2	Case 3
<i>FMP Calculated Potential-Actual Consumptive Use [L/T]</i>	1.0	1.0	1.0
<i>FMP Calculated Transpiration from Groundwater [L/T]</i>	0.8	0.3	0.0
<i>FMP Calculated Potential Consumption of Precipitation [L/T]</i>	$1.0 - 0.8 =$ <b>0.2</b>	$1.0 - 0.3 =$ 0.7	$1.0 - 0.0 =$ 1.0
<i>FMP Input Precipitation [L/T]</i>	0.4	<b>0.4</b>	0.6
<i>Effective Precipitation Returned from the Lookup Table [L/T]</i>	0.5	0.5	<b>0.5</b>
<i>Potential-Actual Consumption of Precipitation by Evaporation and Transpiration [L/T]</i>	<b>0.2</b>	<b>0.4</b>	<b>0.5</b>

**Figure 6.36.** Three example cases that illustrate the effect of the effective precipitation. [Effective precipitation is determined from either the SOIL block EFFECTIVE\_PRECIPITATION\_TABLE or CLIMATE block PRECIPITATION\_POTENTIAL\_CONSUMPTION keywords. The use of these keywords is not recommended unless simulation results present concerns with overconsumption of precipitation. This may occur when the number of days of precipitation is small compared to the duration of a stress period and the potential consumptive use is large for the stress period. Abbreviations: FMP, farm process; [L/T], length per time in model units]

Precipitation (mm/month)	Effective Precipitation (mm/month)	Effective Fraction
10	0	0.00
20	2	0.10
30	8	0.27
40	14	0.35
50	20	0.40
60	26	0.43
70	32	0.46
80	39	0.49
90	47	0.52
100	55	0.55
110	63	0.57
120	71	0.59
130	79	0.61
140	87	0.62
150	95	0.63
160	103	0.64
170	111	0.65
180	119	0.66
190	127	0.67
200	135	0.68
210	143	0.68
220	151	0.69
230	159	0.69
240	167	0.70
250	175	0.70

**Figure 6.37.** Estimated relation of precipitation to effective precipitation from Brouwer and Heibloem (1986). [These values may be used as an estimate for the SOIL block keyword EFFECTIVE\_PRECIPITATION\_TABLE. The effective precipitation may be used as the BY\_LENGTH option and effective fraction may be used as the BY\_FRACTION option. The expected units for this are in millimeter per month (mm/month), whereas units in the farm process (FMP) are [L/T], which is length per time in model units].

COEFFICIENT Keyword	Soil Coefficients
<b>SILT</b>	A = 0.3201 B = -0.3286 C = 2.8519 D = 1.3027 E = -2.0416
<b>SANDYLOAM</b>	A = 0.2007 B = -0.1955 C = 3.0831 D = 3.2012 E = -3.9025
<b>SILTYCLAY</b>	A = 0.3481 B = -0.3274 C = 1.7308 D = 0.5298 E = -3.9025
<b>SAND</b>	A = 0.1100 B = -0.0590 C = 3.0900 D = 4.3260 E = -4.0990

**Figure 6.38.** Analytical, pseudo steady-state soil-moisture, soil-stress concept soil coefficients A, B, C, D, and E for the predefined COEFFICIENT keywords.



```

# Example use of the SOIL block keywords SOIL_ID and COEFFICIENT
#
# NSOIL = 3
# SOIL_ID indicates the location that the soil coefficients are applied to
#
SOIL_ID  INTERNAL
1  1  2  2
1  1  2  2
1  1  3  3
#
# COEFFICIENT uses ULOAD to read NSOIL List Style records that
# either specify a soil type keyword: SILT, SANDYLOAM, SILTYCLAY, or SAND
# or directly specify the soil type coefficients A, B, C, D, and E.
# ULOAD uses INTERNAL to indicate input is on subsequent lines
#
COEFFICIENT  INTERNAL
1  SANDYLOAM
2  0.3201  -0.3286  2.8519  1.3027  -2.0416  # coefficients are equivalent to "SILT"
3  SILTYCLAY

```

**Figure 6.39.** SOIL block COEFFICIENT keyword example. [NSOIL is the number of soil types; ULOAD is the universal loader]

## Supported SFAC DIMKEY

The **SOIL** block keywords that support **SFAC DIMKEY**s are presented in figure 6.40. Only the keywords that support **SFAC DIMKEY** are specified, and an “X” is placed under the respective **DIMKEY**. The only keyword that supports a **SFAC** keyword is **CAPILLARY\_FRINGE**, and it only supports the keyword “**BySoil**” that loads **NSOIL** scale factors.

## Keyword List

Figure 6.41 presents the **SOIL** block with all its supported keywords, their expected input structure, and a commented explanation.

## Supply Well Block

The **SUPPLY\_WELL** block is an optional block that specifies the properties of groundwater wells that extract or inject water into the groundwater flow process. Supply wells do not specify a pumping rate, but instead specify a maximum pumping capacity (QCAP) of the well, and the pumping rate is dynamically assigned on the basis of satisfying water demand up to the maximum rate, QCAP. The **SUPPLY\_WELL** block can be superseded by the **WATER\_BALANCE\_SUBREGION** block keyword **WATERSOURCE**, which can disable all the supply wells for a WBS during a stress period. In FMP, the block name can be declared as **SUPPLY WELL** or **SUPPLY\_WELL**, but the later version, with an underscore, is recommended for clarity.

Supply wells can either be specified as a single model cell—defined by a layer, row, and column—or linked to wells defined in the MNW2 package, which can represent multiple cells. The FMP supply wells that are linked to MNW2 rely on the MNW2 package to perform the simulated pumping, and the FMP determines the desired pumping rate. The FMP-MNW2 linked wells must have their construction information—such as well radius, screen interval, and location—specified in MNW2 input, but the desired pumping rate is assigned by the FMP on the basis of water demand (up to a user specified maximum capacity). The advantage of using MNW2 linked wells is that their desired pumping rate is dynamically set on the basis of water demand, but the simulated pumping rate is constrained by the well construction and antecedent aquifer conditions.

Keyword	DIMKEY			
	ByWBS	ByCrop	ByIrrigate	BySoil
<b>CAPILLARY_FRINGE</b>				X

**Figure 6.40.** SOIL block keywords that support **SFAC DIMKEY**. Only one keyword provides support, and only for one **DIMKEY**—BySoil. [Supported keyword and **DIMKEY** combinations are marked with an X.]

#### BEGIN SOIL

```
#
# Specifies NSOIL soil types' (integer soil IDs) grid locations.
# Input is read with ULOAD to load NROW × NCOL array of INT values.
#   Optional if NSOIL = 1
SOIL_ID   ULOAD
#
# Specifies capillary fringe length for the soil. If not specified, then set to zero.
# List Style input uses SOIL_ID list to assign the spatial location for the capillary fringe values
CAPILLARY_FRINGE   LAI[S, A, L]
#
#
DIRECT_RECHARGE {FLUX, RATE} LAI[S, T, A, L] # Additional recharge added to deep percolation
#
# Only required if LAND_USE Block specifies ROOT_PRESSURES.
# In place of specifying the five coefficients for a soil type,
#   input may use one the predefined keywords SILT, SILTYCLAY, SANDYLOAM, and SAND
COEFFICIENT LAI[S, L-5]
#
# Define for each soil type a precipitation-to-effective precipitation lookup table.
EFFECTIVE_PRECIPITATION_TABLE {BY_LENGTH, BY_FRACTION} LAI[S, L]
#
END SOIL
```

**Figure 6.41.** SOIL block with all supported keywords and their input format. [INT, integer number; NROW is the number of model rows; NCOL is the number of model columns; ULOAD, universal loader; LAI, list-array input with the following letters representing the supported keywords: S for STATIC, T for TRANSIENT, and A for ARRAY]

The **SUPPLY\_WELL** block includes three possible input formats (fig. 6.42) to define the spatial location, maximum capacity, and construction of the supply wells. Only one of the three input formats may be used during a simulation. They have the same basic input properties (fig. 6.43), but they differ in how they define the transient (stress period) information. The **SUPPLY\_WELL** block must include one of the three input format keywords (fig. 6.42), then on subsequent input lines contain a *Generic\_Input* file, one per line, and continues until the next **SUPPLY\_WELL** keyword is found or **END SUPPLY\_WELL** is reached. This allows for **TIME FRAME** or **LINEFEED** input to be split into multiple files (see appendix 2 for how multiple LineFeed files are handled).

Input Format Keyword	Description
<b>TIME FRAME</b>	<p>Supply well spatial and temporal description are read as one well per line—same well may be repeated multiple times for different time intervals.</p> <p>Each row of input specifies a starting and ending stress period—or date—for when the well is continuously available to provide groundwater supply.</p> <p>This is the most flexible and recommended input style.</p>
<b>LINEFEED WBS</b>	<p>Supply well specified with LineFeed format (appendix 2). The LineFeed temporal section (input read every stress period) specifies the water balance subregion (WBS) that the supply well is associated with.</p> <p>Set the WBS to 0 to disable the well from providing supply for that stress period.</p> <p>This option is best suited when supply wells frequently change the WBS that they provide supply to.</p>
<b>LINEFEED CAPACITY</b>	<p>Supply well specified with LineFeed format (appendix 2). The LineFeed temporal section (input read every stress period) specifies the maximum capacity (QCAP) of the well.</p> <p>Set the QCAP to NaN or 0 to disable the well from providing supply for that stress period.</p> <p>This option is best suited when supply wells have frequently changing maximum capacities.</p>

**Figure 6.42.** SUPPLY\_WELL block keywords that initiate the main supply-well input. [Only one of these keywords may be present during a simulation. Abbreviation: WBS, water-balance subregion]

Supply Well Property	Data type and Description
Well_Name	<p>Name that identifies supply well.</p> <p>It may be any alpha-numeric character with a max length of 20 characters.</p> <p>If supply well is linked to MNW2, then this name must match a MNW2 WELLID, which is the MNW2 well that it is linked to.</p> <p>The name does not have to be unique, but it must be unique among the supply wells in use during a stress period.</p>
WBS	<p><b>INT</b> is the WBS ID that the supply well provides water to.</p> <p>(Desired well pumpage is determined by the WBS demand.)</p>
LAY	<p><b>INT</b> is the layer number of the supply well.</p> <p>If set to "MNW" or 0, then well is linked to MNW2 and Well_Name must match a MNW2 WELLID.</p> <p>(Desired pumping rate is assigned to MNW2 based on the WBS demand.)</p> <p><b>INPUT_OPTION</b> keyword may change LAY to be specified as a <b>FLOAT</b>, and to represent either a depth from land surface or elevation.</p>
ROW	<p><b>INT</b> is the row number of the supply well.</p> <p>If well is linked to MNW2, this number is read, but ignored.</p> <p>If the keyword "<b>INPUT_OPTION XY</b>" is present, then instead of reading the row number, ROW is read as a <b>FLOAT</b> and represents the well's X-Coordinate in the MF-OWHM2 coordinate space.</p>
COL	<p><b>INT</b> is the column number of the supply well.</p> <p>If well is linked to MNW2, this number is read, but ignored.</p> <p>If the keyword "<b>INPUT_OPTION XY</b>" is present, then instead of reading the column number, COL is read as a <b>FLOAT</b> and represents the well's Y-Coordinate in the MF-OWHM2 coordinate space.</p>
QCAP	<p><b>FLOAT</b> is the maximum pumping capacity of the well [<math>L^3/T</math>].</p> <p>(Based on the WBS demand, the FMP assigns a desired pumping rate between 0 and QCAP.)</p>

**Figure 6.43.** SUPPLY\_WELL block required base-input properties necessary to define a supply well. [ID, water balance subregion identification number; WBS, water-balance subregion; INT, integer number; FLOAT, floating-point number; [ $L^3/T$ ], volumetric rate in model units; MNW2, multi-node well package version 2; WELLID is a well name defined in MNW2]

## Multi-Node Well Package Version 2 (MNW2) Supply-Well Linkage

To set up an FMP-MNW2 supply-well link it is required to have the MNW2 package enabled and its input set up. At a minimum the MNW2 input (Konikow and others, 2009) must specify all data items defined in the “For Each Simulation” input group—that is, any input that appears before the stress-period data input item ITMP, which begins the “For Each Stress Period” datasets. The “For Each Simulation” input identifies each MNW2 with a unique alphanumeric identification label called WELLID, which is used by the FMP for locating linked wells. The FMP-MNW2 linkage happens when the FMP supply well has LAY set to 0 or “MNW” and the FMP input Well\_Name is identical to a MNW2 WELLID.

Additionally, the FMP-MNW2 link requires that the MNW2 well be “active” during the stress periods that the FMP uses it as a supply well. The MNW2 documentation (Konikow and others, 2009) defines a MNW2 as being “active” if it is specified as part of the “For Each Stress Period” ITMP well list. An “active” well may extract water, inject water, or remain idle with no pumping. An idle “active” well is still simulated, and if the well extends across multiple layers can include intraborehole flow. The FMP-MNW2 linked wells should always specify the desired pumping (QDES) in MNW2 input as zero—because QDES is automatically set by the FMP. It also is recommended to have the FMP-MNW2 linked wells made “active” when they are drilled and then “not active”—removed from the simulation—when a well is destroyed. This is not necessarily the same as the period that the well provided supply and allowing it to be idle when not in use. The supply period is defined in the FMP input part (fig. 6.42), which defines when the FMP is allowed to dynamically set the value of QDES.

An alternative to directly specifying when MNW2 wells are “active” is to include in the **SUPPLY\_WELL** block the keyword **MNW\_AUTOMATIC\_ON**. This keyword enables the FMP to automatically set to “active” any MNW2 wells that are not already declared “active” during stress periods that the FMP inputs had defined for using it as a supply. For example, if an FMP supply well is defined as being active and available to provide a supply in stress period 3, then on the third stress period, the FMP checks if the corresponding WELLID is “active,” and, if not, the **MNW\_AUTOMATIC\_ON** keyword enables it. The MNW2 wells that are made “active” through **MNW\_AUTOMATIC\_ON** remain “active” for the remainder of the simulation and have QDES set to zero for stress periods when the FMP does not use them. Conversely, the **SUPPLY\_WELL** block keyword **MNW\_AUTOMATIC\_OFF** allows the FMP to automatically deactivate, that is, remove from the simulation, an “active” MNW2 well when the FMP supply well is no longer needed to provide supply. The **MNW\_AUTOMATIC\_OFF** option is not suitable for simulating areas where wells are typically abandoned rather than destroyed.

If **MNW\_AUTOMATIC\_ON** is not specified, then the FMP-MNW2 linked wells must be included in the MNW2 “For Each Stress Period” input or specified with LineFeed for the stress periods that they are in use. This is done by including the FMP Well\_Name as the WELLID in the FMP input for the appropriate stress period corresponding to ITMP in the MNW2 package input and setting QDES to zero. This method is advantageous if the supply well’s drilled and destroyed dates are different than the period that they provide supply. Figure 6.44 is an example MNW2 input file used for a simulation of four stress periods (SP) that defines four wells: (1) Industrial1, (2) Industrial2, (3) FMP\_MNW\_1, and (4) FMP\_MNW\_2. The wells Industrial1 and Industrial2 start on stress period 1 and have their pumping rate specified by MNW2. The wells FMP\_MNW\_1 and FMP\_MNW\_2 are linked in the FMP input and are first “active” in stress periods 2 and 3, respectively. Industrial2 and FMP\_MNW\_2 are assumed to be destroyed by stress period 4—they are not specified in the list following ITMP. Note that in figure 6.44 the corresponding FMP input is not shown.

## Time Frame Input Structure

The **TIME FRAME** input structure is the recommended method for specifying supply wells in the FMP. The supply-well input specifies the base properties on each line defined in figure 6.43 and then provides starting and ending stress periods—or calendar dates—for when the well is available for pumping. Figure 6.45 is the **TIME FRAME** input structure where the supply well is continuously available to supply pumpage between Date\_Start and Date\_End. During this interval, a supply well can be disabled at any stress period that has the **WATER\_BALANCE\_SUBREGION** block keyword **WATERSOURCE** set to disable groundwater pumping. If a change is needed in the association between a supply well and the WBS that it supplies, then it must be specified twice, and the two input statements will have different values for Date\_Start and for Date\_End.

The next line after the keyword **TIME FRAME** is *Generic\_Input* that specifies where the supply-well input is. Multiple *Generic\_Input* files may be specified with one *Generic\_Input* file per line. Only one *Generic\_Input* is allowed if it is specified with keyword **INTERNAL**, which indicates that the subsequent lines contain the supply-well input. The FMP auto-counts the number of supply wells that are defined in the *Generic\_Input* file. If the input is directly within the block (*Generic\_Input* is defined as **INTERNAL**), then the auto-counting determines the number of wells on the basis of the number of lines (excluding those that are blank or commented with a “#” symbol) between the keyword **TIME FRAME** and either the next **SUPPLY\_WELL** keyword or **END SUPPLY\_WELL**, whichever is first. If the input is in a separate file (*Generic\_Input* is not defined as **INTERNAL**), then the number of wells is the number of lines in the file that are non-blank and not commented with a “#” symbol.

```

# For FMP to link to an MNW2 well, the FMP Well_Name must match the MNW2 WELLID.
# FMP_MNW_1 and FMP_MNW_2 are assumed to be linked to the FMP SUPPLY_WELL block input.
# Note that the FMP-MNW WELLID can be a 20-character string, but FMP_MNW_ is chosen for clarity.
# In this example, FMP can only use for supply FMP_MNW_1 during stress periods (SP) 2, 3, and 4.
# FMP can only use for supply FMP_MNW_2 during SP 3
# If the FMP SUPPLY_WELL block has the keywords MNW_AUTOMATIC_ON and MNW_AUTOMATIC_OFF,
# then the FMP-MNW linked wells are automatically changed to "active" or "inactive"
# when the FMP input indicates they are available for supply.
# This negates the need to define the wells as part of the ITMP portion of this input.
#
# MNW Construction Part – For Each Simulation
4 0 2 # MNWMAX IWL2CB MNWPRNT
Industrial1 -1 # WELLID NNODES
SKIN 0 0 0 0 # LOSSTYPE PUMPLOC Qlimi PPFLAG PUMPCAP
0.1 0.35 1.6683 # Rw Rskin Kskin
-75 -50 6 2 # Ztop Zbot ROW COL
Industrial2 -1
SKIN 0 0 0 0
0.1 0.35 1.6683
-70 -55 8 2
FMP_MNW_1 -1
SKIN 0 0 0 0
0.1 0.35 1.6683
-70 -55 10 2
FMP_MNW_2 -1
SKIN 0 0 0 0
0.1 0.35 1.6683
-70 -55 3 3
# For Each Stress Period
2 # ITMP - SP 1
Industrial1 50.0 # WELLID QDES – Industrial wells "active"
Industrial2 250.0 # WELLID QDES
3 # ITMP - SP 2
Industrial1 50.0
Industrial2 250.0
FMP_MNW_1 0.0 # FMP linked well now "active", FMP may use it for supply.
4 # ITMP - SP 3
Industrial1 50.0
Industrial2 250.0
FMP_MNW_1 0.0
FMP_MNW_2 0.0 # FMP linked well now "active", FMP may use it for supply.
2 # ITMP - SP 4
Industrial1 50.0 #
FMP_MNW_1 0.0 # FMP_MNW_2 isn't specified, making it "inactive", FMP may not use it for supply

```

**Figure 6.44.** Example MNW2 input file that contains two wells that are linked to FMP for use as supply wells. These wells can provide supply only if, they are “active” in MNW2 and the FMP SUPPLY\_WELL block indicates they are available to provide supply. [MNW2, multi-node well package version 2; FMP, farm process]

**A**

Well_Name	WBS	LAY	ROW	COL	QCAP	Date_Start	Date_End	[xyz]
-----------	-----	-----	-----	-----	------	------------	----------	-------

**B**

Input Format Keyword	Description
Date_Start	<p>Is the starting stress period or date that a supply well is available to provide water to its water-balance subregion (WBS). A date is converted to a stress period by selecting the one that either contains the date or is closest to the date.</p> <p>Dates may be formatted using International Standard Organization (ISO) standard (year-month-day, yyyy-mm-dd) or American style (mm/dd/yyyy) as defined in the appendix 3, "Calendar Dates" section.</p>
Date_End	<p>Is the ending stress period or date that a supply well is available to provide water to its WBS. A date is converted to a stress period by selecting the one that either contains the date or is closest to the date.</p> <p>If set to the word "NPER", then it is automatically set to the end of the simulation—that is, stress period NPER.</p> <p>Dates may be formatted using ISO standard (yyyy-mm-dd) or American style (mm/dd/yyyy) as defined in the appendix 3, "Calendar Dates" section.</p>
XYZ	<p>Represents auxiliary integer (<b>INT</b>) flags if an auxiliary option is specified.</p> <p>By default, there are no auxiliary flags read.</p> <p>They are only present when an auxiliary option is set. Multiple auxiliary flags may be required if multiple auxiliary options are in use.</p>

**Figure 6.45.** SUPPLY\_WELL block TIME FRAME general input structure and partial explanation of input variables. A, TIME FRAME general input structure. B, Explanation of select input variables. [INT, integer number]

Figure 6.46 is a set of simple examples of supply-well inputs using the **TIME FRAME** keyword. In figure 6.46A, FMP reads **INTERNAL** input to load the spatiotemporal data for three supply wells. It is a limitation of the **TIME FRAME** input structure that wells must be specified multiple times if either its WBS association or its maximum capacity changes though time. Figure 6.46B and figure 6.46F illustrate pros and cons of using the **TIME FRAME** option. For example, figure 6.46B specifies four lines of well inputs, but only three unique wells are simulated (that is, **Well\_2** is repeated), and in figure 6.46F, **WELLA** is repeated three times. Figure 6.46C is an example that defines the well input in a separate file (fig. 6.46E). Figure 6.46D defines the input as contained in three separate files and uses the FMP-MNW2 linked wells defined in figure 6.44 (that is, in fig. 6.46F the **Well\_Names** "FMP\_MNW\_1" and "FMP\_MNW\_2"). In figure 6.46F, FMP will determine the starting and ending stress period of the **FMP\_WEL\_1** on the basis of the provided calendar dates. Also in figure 6.46F, **WELLA** undergoes changes in its WBS association over time, so it must be repeated in the input table. In this example **WELLA** provides pumpage to WBS 1 from stress period 15 to 25, then to WBS 2 from stress period 36 to 45, and then to WBS 3 from stress period 50 to 55.



**A**

```

# Example use of the SUPPLY_WELL block that only specifies the input option TIME FRAME
# Example assumes NROW = 3, NCOL = 4, NWBS = 5; NPER = 100
#
# The general input is
#           TIME FRAME
#           GENERIC_INPUT
#           [GENERIC_INPUT]  <-- as many GENERIC_INPUTs as necessary
#
# where GENERIC_INPUT indicates the location of the TIME FRAME input.
#           [GENERIC_INPUT], if present, indicates that multiple sets of input can be specified.
# For example:
#           TIME FRAME
#           OPEN/CLOSE  WEL_SET1.txt
#           OPEN/CLOSE  WEL_SET2.txt
#
# This example specifies one set of input with the INTERNAL keyword (input on subsequent lines).
BEGIN SUPPLY_WELL
#
TIME FRAME
#
INTERNAL
# Well_Name WBS LAY ROW COL  QCAP Date_Start Date_End
  Wel_1      3   2   3   2  1000.         1  NPER # Entire Simulation
  Wel_2      2   1   2   1  1000.         5  NPER # Stress period 5 to the end
  Wel_3      2   2   2   1  1000.         1  NPER # Entire Simulation

# Well count determined by the number of non-blank, uncommented lines between
# TIME FRAME and END SUPPLY_WELL
#
END SUPPLY_WELL

```

**B**

```

BEGIN SUPPLY_WELL
# Wel_2 supplies water to WBS 3 from stress period 1 to 4, then it supplies water to WBS 2.
# Wel_3 is linked to MNW2, which must have defined a WELLID "Wel_3" in the MNW2 input
TIME FRAME
#
INTERNAL
# Well_Name WBS LAY ROW COL  QCAP Date_Start Date_End
  Wel_1      3   2   3   2  1000.         1  NPER
  Wel_2      3   1   2   1  1000.         1    4 # Supplies WBS 3
  Wel_2      2   1   2   1  1000.         5  NPER # Supplies WBS 2
  Wel_3      2  MNW   0   0  1000.         1  NPER # MNW2 Link
#
END SUPPLY_WELL

```

**Figure 6.46.** Supply Well block TIME FRAME input examples. *A*, Example input from a single INTERNAL. *B*, Example input from a single INTERNAL that contains wells linked to MNW2. *C*, Example that specifies input in the file "FMP\_SUPPLY\_WELL.txt". *D*, Example that specifies input in three separate files. *E*, The file "FMP\_SUPPLY\_WELL.txt". *F*, The file "FMP\_SUPPLY\_WELL\_Group2.txt". [Note that contents of file FMP\_SUPPLY\_WELL\_Group3.txt are not included in this figure. Abbreviations: MNW2, multi-node well package version 2; WBS, water-balance subregion; NPER is the number of stress periods]



**C**

```
# This example specifies the TIME FRAME input in a separate file.
# GENERIC_INPUT specified as "OPEN/CLOSE ./FMP_SUPPLY_WELL.txt"
BEGIN SUPPLY_WELL
#
  TIME FRAME
#
  OPEN/CLOSE  ./FMP_SUPPLY_WELL.txt
#
END SUPPLY_WELL
```

**D**

```
# Example specifies the TIME FRAME input in three separate files.
BEGIN SUPPLY_WELL
#
  TIME FRAME
#
  OPEN/CLOSE  ./FMP_SUPPLY_WELL.txt           # First  GENERIC_INPUT
  OPEN/CLOSE  ./FMP_SUPPLY_WELL_Group2.txt    # Second GENERIC_INPUT
  OPEN/CLOSE  ./FMP_SUPPLY_WELL_Group3.txt    # Third  GENERIC_INPUT
END SUPPLY_WELL
```

**E**

```
# File: FMP_SUPPLY_WELL.txt
#
# WBS 2 and 3 have wells, all wells linked to MNW2,
# MNW2 must have defined WELLIDs of "Wel_1", "Wel_2", and "Wel_3"
# Specifying ROW and COL is required but not used—any INT can be set there

# Well_Name WBS  LAY ROW COL  QCAP Date_Start Date_End
  Wel_1      3  MNW  3    2  1000.      1  NPER
  Wel_2      2  MNW  2    1  1000.      5  NPER
  Wel_3      2  MNW  2    1  1000.      1  NPER
```

**F**

```
# File: FMP_SUPPLY_WELL_Group2.txt
# Well_Name  WBS  LAYER ROW  COL  QCAP  Date_Start  Date_End
  FMP_WEL_1  3    2    5    25  1000.  3/15/1992  1/31/2015
  FMP_MNW_1  2    MNW  2    5    1000.  2          4
  FMP_MNW_2  2    MNW  2    5    1000.  3          3
  WELLA      1    2    5    25  1000.  15         25
  WELLA      2    2    5    25  1000.  36         45
  WELLA      3    2    5    25  1000.  50         55
```

**Figure 6.46.** —Continued

### LineFeed Water-Balance Subregion (WBS) Input Structure

The **LINEFEED WBS** input structure is beneficial if supply wells either undergo change frequently in their WBS association or are frequently enabled and disabled in a manner that is not well handled by the **WATER\_BALANCE\_SUBREGION** block keyword **WATERSOURCE** or the **TIME FRAME** keyword. This input relies on LineFeed, described in appendix 2, to load the WBS of the supply wells every stress period—that is, the FeedFiles’ temporal input corresponds with the WBS. Any number of FeedFiles, specified with *Generic\_Input*, may be specified on the lines after the keyword **LINEFEED WBS**; however, only one *Generic\_Input* is allowed per line, and the keyword **INTERNAL** is not allowed. Figure 6.47 is an example that loads three LineFeed files, called FeedFiles.

The LineFeed’s FeedFile structure has a “Spatial Input Section” and a “Temporal Input Section” (appendix 2). From the Spatial Input Section, the FMP reads the time invariant information pertaining the **LINEFEED WBS**. Figure 6.48 presents general input structure for the Spatial Input Section. The Spatial Input Section specifies as many wells as necessary until the keyword **TEMPORAL INPUT** is encountered to indicate that the Temporal Input Section (stress-period input) is on the subsequent lines. The temporal input specifies each supply well’s WBS. If a supply well is not in use for a stress period, then its WBS must be set to either 0 or NaN. Figure 6.49 illustrates how to set up a **LINEFEED WBS** input FeedFiles.

```
BEGIN SUPPLY_WELL

  LINEFEED WBS
  #
  OPEN/CLOSE ./FWEL_FEEDFILE1.txt
  OPEN/CLOSE ./FWEL_FEEDFILE2.txt
  OPEN/CLOSE ./FWEL_FEEDFILE3.txt
  #
END SUPPLY_WELL
```

**Figure 6.47.** SUPPLY\_WELL block LINEFEED WBS example that specifies three FeedFiles.

Well_Name	LAY	ROW	COL	QCAP	[xyz]
-----------	-----	-----	-----	------	-------

**Figure 6.48.** SUPPLY\_WELL block LINEFEED WBS general input structure for the LineFeed’s Spatial Input Section (time invariant input information).

**A**

```
# Supply Well block LINEFEED WBS example FeedFile
# Example assumes NROW = 3, NCOL = 4, NWBS = 5; NPER = 6
#
# The FeedFile example is equivalent to the following TIME FRAME input:
#   Wel_1    3  2  3  2 1000.    1 NPER
#   Wel_2    2  1  2  1 1000.    5 NPER
#   Wel_3    2  2  2  1 1000.    1 NPER
#
# Spatial Input Section
#       LAY ROW COL   QCAP
Wel_1   2   3   2   1000.
Wel_2   1   2   1   1000.
Wel_3   2   2   1   1000.
#
TEMPORAL INPUT
#
# Wel_1 Wel_2 Wel_3
    3     0     2 # SP 1 – WBS assigned to each supply well
    3     0     2 # SP 2 – WEL_2 not available for supply
    3     0     2 # SP 3
    3     0     2 # SP 4
    3     2     2 # SP 5 – WEL_2 is available for supply
    3     2     2 # SP 6
```

**B**

```
# The FeedFile example is equivalent to the following TIME FRAME input:
# Wel_1    3    2  3  2 1000.    1 NPER
# Wel_2    3    1  2  1 1000.    1  4
# Wel_2    2    1  2  1 1000.    5 NPER
# Wel_3    2 MNW 0   0 1000.    1 NPER
#
# Spatial Input Section
#       LAY ROW COL   QCAP
Wel_1   2   3   2   1000.
Wel_2   1   2   1   1000.
Wel_3  MNW   0   0   1000. # Wel_3 is linked to MNW2
#
TEMPORAL INPUT
#
# Wel_1 Wel_2 Wel_3
    3     3     2 # SP 1 – WBS assigned to each supply well
    3     3     2 # SP 2 – Wel_3 can provide supply only if “active” in MNW2
    3     3     2 # SP 3
    3     3     2 # SP 4
    3     2     0 # SP 5 – No supply from Wel_3 irrelevant of MNW2 status
    3     2     0 # SP 6
```

**Figure 6.49.** FeedFile examples for the SUPPLY\_WELL block LINEFEED WBS. *A*, FeedFile that defines three FMP Supply wells. *B*, FeedFile that defines three FMP supply wells and indicates that one well is linked to MNW2. [MNW2, multi-node well package version 2; WBS, water-balance subregion; NPER, is the number of stress periods]

### LineFeed Capacity Input Structure

The **LINEFEED CAPACITY** input structure is beneficial if supply well maximum capacity changes frequently. This input relies on LineFeed, described in appendix 2, to load the maximum capacity, **QCAP**, of the supply wells every stress period. The input is similar to that described in the “LineFeed WBS Input Structure” section, except that a FeedFile may only be associated with one WBS, and its “Temporal Input Section” specifies the supply wells’ **QCAP**. Each line after the keyword **LINEFEED CAPACITY** specifies a **WBS** followed by its associated FeedFile, which is loaded with *Generic Input*. This input is analogous to *List Style* input that reads **WBS** number as the record ID and the FeedFile location as the input. This input automatically continues to read the input as long as it correctly identifies a record ID. However, there is a limitation of one FeedFile per **WBS**—that is, a **WBS** number may only be used as a record ID once. Any **WBS** not defined as a record ID is assumed to have no supply wells associated. If it is desired to explicitly specify a **WBS** that does not have any supply wells, then the keyword **NOWELL** is written in the place of the *Generic Input*.

Figure 6.50 is an example that reads two LineFeed files, with the first one specifying the supply-well capacities for **WBS 2**, the second is for **WBS 3**. In this example, any **WBS** that is not associated with a FeedFile is assumed to not have any supply wells. Additionally, any **WBS** that has the keyword **NOWELL** in the second column does not have any supply wells.

Figure 6.51 presents general input structure for the Spatial Input Section. The Spatial Input Section specifies data for as many wells as necessary until the keyword **TEMPORAL INPUT** is encountered to indicate that the stress-period input is on the subsequent lines. The Temporal input specifies the **QCAP** for each supply well. If a supply well does not exist for a stress period, then its **QCAP** must be set to **NaN**; however, if instead its **QCAP** is set to **0.0**, then its capacity is reduced to zero, but its existence is still simulated, allowing intraborehole flow for **MNW2** linked wells.

```
BEGIN SUPPLY_WELL
#
LINEFEED CAPACITY
#
# WBS   FeedFile
 2   OPEN/CLOSE  ./FWEL_FEEDFILE2.txt
 3   OPEN/CLOSE  ./FWEL_FEEDFILE3.txt
 5   NOWELL      # Explicitly state WBS 5 does not have supply wells
#
END SUPPLY_WELL
```

**Figure 6.50.** Supply Well block **LINEFEED CAPACITY** example that specifies input for three water balance subregions (**WBS**). This example only specifies FeedFiles for **WBS 2** and **3**, so all the other **WBS** do not have supply wells.

Well_Name	LAY	ROW	COL	[xyz]
-----------	-----	-----	-----	-------

**Figure 6.51.** **SUPPLY\_WELL** block **LINEFEED WBS** general input structure for the LineFeed FeedFile’s Spatial Input Section (time invariant input information).

## Optional Keywords

The **SUPPLY\_WELL** block includes a set of optional keywords that modify the global behavior of the FMP supply wells. The optional keywords and their descriptions are presented in figure 6.52.

**A**

Keyword	Argument	Description
<b>SFAC</b>	{ <b>FLOAT</b> , <b>ByWBS</b> <b>ULOAD</b> }	<b>FLOAT</b> is a scale factor that is multiplied by all the supply-wells' maximum capacity (QCAP). If followed by the keyword <b>ByWBS</b> , then <b>NWBS</b> scale factors are read with <b>ULOAD</b> and applied to the respective wells associated with each WBS.
<b>MNW_AUTOMATIC_ON</b>		Automatically enables, makes "active", a MNW2 well that is linked to an FMP supply well. The MNW2 well is made active when the corresponding FMP well is first available to provide supply. If the supply well is no longer available, then the MNW2 well remains "active" with a desired pumping rate of zero until the simulation ends. This serves as a short cut to double specifying the MNW2 well name in its stress period input to mimic the time periods of use by the FMP.
<b>MNW_AUTOMATIC_OFF</b>		Automatically disables, removes from simulation, a MNW2 well that is linked to an FMP supply well. The MNW2 well is removed when the corresponding FMP well is defined to no longer provide supply. This feature should be used when the FMP supply well is considered "destroyed" rather than no longer providing supply to a WBS.

**Figure 6.52.** SUPPLY\_WELL block optional keywords that modify its behavior. Secondary keywords enclosed in curly braces, {}, indicate that only one of the keywords may be selected and used during a simulation. *A*, Recommended keywords. *B*, Advanced keywords. *C*, Advanced keywords. *D*, Advanced keywords. [DIS, discretization package; FMP, farm process; MNW2, multi-node well package version 2; ULOAD, universal loader; WBS, water-balance subregion]

B

Keyword	Argument	Description
<b>QMAXRESET</b>	[ <b>ByWBS</b> ULOAD ]	<p>MNW2 linked supply wells use the FMP QCAP as an initial estimate of the well capacity. This capacity is then reduced by MNW2 for the given aquifer conditions and then reset to the original QCAP at the start of the next stress period. This keyword tells FMP that QCAP should be reset every time step.</p> <p>If followed by the keyword <b>ByWBS</b>, then a list of <b>NWBS</b> 0s or 1s are read with ULOAD to indicate which WBS should use (1) QMAXRESET or not (0). By default, this setting is True (1), so specifying it is unnecessary unless a user desires to disable the feature for specific WBS's.</p>
<b>NOQMAXRESET</b>		<p>Disables <b>QMAXRESET</b> for all MNW2 linked supply wells so their QCAP is only reset at the start of each stress period rather than each time step. This may improve speed of the simulation but at the potential expense of under-estimating pumpage.</p>
<b>NOCIRNOQ</b>	[ <b>ByWBS</b> ULOAD ]	<p>Specifies that supply wells will only provide supply if there is irrigation demand within the row and column where the well is located. That is, if there is zero irrigation demand for a specific row and column, then all wells that have the same row and column will not provide any supply to the WBS. This works best for wells that only supply water to the land surface they are underneath.</p> <p>If followed by the keyword <b>ByWBS</b>, then <b>NWBS</b> 0 or 1s are read with ULOAD to indicate which WBS should use (1) NOCIRNOQ or not (0).</p>

Figure 6.52. —Continued

C

Keyword	Argument	Description
<b>INPUT_OPTION XY</b>		<p>Indicates that all supply-well input will use the X- and Y-coordinate in the place of the row and column input.</p> <p>The coordinates must be a location within the Cartesian coordinate system defined by the DIS package.</p> <p>The row and column are determined based on what model cell contains the given X- and Y-coordinate.</p>
<b>INPUT_OPTION</b>	{ <b>ELEVATION</b> , <b>DEPTH</b> }	<p>Indicates that all supply-well input will use either the <b>ELEVATION</b> or <b>DEPTH</b> from land surface in the place of the Layer input.</p> <p>If <b>ELEVATION</b> is specified, then the layer number is determined based on the DIS TOP and BOTM input for the supply-well's location.</p> <p>If <b>DEPTH</b> is specified, then it is converted to an elevation by subtracting the depth from the <b>GLOBAL DIMENSION</b> block's <b>SURFACE_ELEVATION</b> for the supply-well's location.</p>
<b>MNW_PUMP_SPREAD</b>	{ <b>BY_COND</b> , <b>BY_COUNT</b> , <b>BY_TOP</b> }	<p>This option may improve convergence speed and will not affect the final pumping rate.</p> <p>Wells linked to MNW2 that contain more than one node must assign the desired pumping to all of the well's nodes.</p> <p>MNW2 will then allocate the desired pumpage among the nodes to meet the total desired pumping rate. This option offers different methods for initially applying the desired pumping rate to MNW2 when there is more than one node.</p> <p><b>BY_COND</b> is the default and applies the desired pumpage based on each node's conductance relative to the total.</p> <p><b>BY_COUNT</b> divides the desired pumpage by the total node count and applies that rate to all nodes.</p> <p><b>BY_TOP</b> applies the desired pumpage to the uppermost, top node. This was how FMP3 originally assigned MNW2 linked pumpage.</p>

Figure 6.52. —Continued

D

Keyword	Argument	Description
<b>PRORATE</b>	{ <b>ByAverage</b> , <b>ByCapacity</b> }	<p>When the demanded water for a WBS is less than its total pumpage capacity (QMAX) the assigned pumpage is prorated across all the supply wells.</p> <p><b>ByCapacity</b> is the default, indicates that the total demand for pumpage is spread across supply wells based on the ratio of each well's capacity, QCAP, to the total capacity of the WBS, QMAX. This has the effect of having higher capacity wells supply more pumpage than lower capacity wells.</p> <p><b>ByAverage</b> calculates an average demand per well and then wells with capacity below this average are set to their QCAP and wells with capacity above the average have an even split of the remaining demand. This has the effect of having lower capacity wells use their full capacity before the larger capacity wells. This was the method used by FMP3.</p>
<b>SMOOTH</b>	{ <b>ByFRACTION</b> , <b>ByTHICK</b> }	<p><b>FLOAT</b>, Smoothing allows reduction of pumping from non-MWN2 linked wells when the water table approaches the bottom of the model cell.</p> <p>Modifier <b>ByTHICK</b> specifies a minimum thickness in model units before smoothing occurs,</p> <p>while <b>ByFRACTION</b> specifies a minimum fraction of cell thickness before smoothing occurs.</p>

Figure 6.52. —Continued



## Output Keywords

The **SUPPLY\_WELL** block has a set of optional, additional output keywords to improve the understanding and analysis of the demand based pumpage. To initiate the output options, write in the **SUPPLY\_WELL** block the keyword **PRINT**, followed by the output type, and then the output file, specified with *Generic\_Output\_OptKey*. The output types available are **LIST**, **INPUT**, **SMOOTHING**, **ByWBS**, **ByWell**, and **ByMnw**. The **LIST** and **INPUT** options print a transcript of the input loaded to either the Listing File or an external file, respectively. If the **SUPPLY\_WELL** block input includes the keyword **SMOOTH** and the well undergoes capacity smoothing, the **SMOOTHING** file records the smoothing values applied to the well. The **ByWBS**, **ByWell**, and **ByMnw** output provide detailed information on the requested pumpage and any reductions in pumpage that may result from allotments, smoothing, and MNW. The three output types differ in how the well information is aggregated. **ByWBS**, **ByWell**, and **ByMnw** aggregate the information at the WBS level, for each well, and only for wells linked to MNW2, respectively. The recommended output type is the **ByWBS**, which indicates the groundwater production capacity of each WBS and what resulted in reduction of the capacity. Figure 6.53 presents the output keywords and gives a basic description of each.

Keyword	Argument	Description
<b>PRINT LIST</b>	—	Write to the LIST file a transcript of the supply wells that are in use.
<b>PRINT INPUT</b>	<i>Generic_Output_OptKey</i>	Write a transcript of the well input to a separate file.
<b>PRINT SMOOTHING</b>	<i>Generic_Output_OptKey</i>	If <b>SMOOTH</b> is enabled, then writes any non-MNW2 linked wells that had their capacity reduced because of smoothing. If not enabled, then file will be empty.
<b>PRINT ByWBS</b>	<i>Generic_Output_OptKey</i>	Writes to a file at every time step a summary of well information for each WBS.
<b>PRINT ByWELL</b>	<i>Generic_Output_OptKey</i>	Writes to a file at every time step a summary of well information for each well in use.
<b>PRINT ByMnw</b>	<i>Generic_Output_OptKey</i>	Writes to a file at every time step a summary of well information for each supply well that is linked to MNW2.

**Figure 6.53.** SUPPLY\_WELL block output file keywords. [MNW2, multi-node well package version 2; WBS, water-balance subregion; —, no input values apply]

## PRINT ByWBS Header

The keyword **PRINT ByWBS** writes the aggregated pumpage information for each WBS to the *Generic\_Output\_OptKey* file every time step. The output may be text or binary format and has the header defined in figure 6.54.

**A**

PER	is the stress period number	
STP	is the time step number	
WBS	is the Water Balance Subregion (Farm) ID number	
Q-CAP-INIT	is the initial farm well's pumping capacity as specified by the input	[L <sup>3</sup> /T]
Q-CAP-ALLOT	is the farm well's capacity after any allotment constraints are applied	[L <sup>3</sup> /T]
Q-CAP-FIN	is the farm well's final pumping capacity	[L <sup>3</sup> /T]
Q-FIN	is the final volumetric discharge rate of well during current time step	[L <sup>3</sup> /T]
TFDR-INIT	is the initial demand for water supply	[L <sup>3</sup> /T]
TFDR-FIN	is the demand that was satisfied with water supply	[L <sup>3</sup> /T]
DELT	is the time step length	[T]
DYEAR	is the date at the end of the time step as a decimal year	
DATE_START	is the calendar date at the start of the time step (yyyy-mm-ddThh:mm:ss)	

**B**

DATE_START	CHARACTER(19), starting date formatted as 'yyyy-mm-ddThh:mm:ss'
DYEAR	DOUBLE
DELT	DOUBLE
PER	INTEGER
STP	INTEGER
WBS	INTEGER
Q-CAP-INIT	DOUBLE
Q-CAP-FIN	DOUBLE
Q-FIN	DOUBLE
TFDR-INIT	DOUBLE
TFDR-FIN	DOUBLE

**Figure 6.54.** Supply Well block keyword PRINT ByWBS text file header explanation and binary record structure. *A*, Text-header explanation. *B*, Binary-record structure. [[T], unit of time in model units; [L<sup>3</sup>/T], volumetric rate in model units; CHARACTER(19) indicates record is 19 characters long (19 bytes); INTEGER is a 4-byte integer record; DOUBLE is a 8-byte floating-point number record.]

## PRINT ByWELL Header

The keyword **PRINT ByWELL** writes the pumpage information for each supply well in use for that time step to the *Generic\_Output\_OptKey* file every time step. The output may be text or binary format and has the header defined in figure 6.55.

**A**

PER	is the stress period number	
STP	is the time step number	
WBS	is the Water Balance Subregion (Farm) ID number	
WELLID	is the name (WELL_ID) of the specific supply well	
Q-CAP-INIT	is the initial well's pumping capacity as specified by the input	[L <sup>3</sup> /T]
Q-CAP-FIN	is the well's final pumping capacity	[L <sup>3</sup> /T]
Q-ACT	is the final volumetric discharge rate of the well during current time step	[L <sup>3</sup> /T]
Q-DES-DMD	is an estimate of the well's initial demand for pumping	[L <sup>3</sup> /T]
LAY	is the well's model layer; it is set to zero if linked to MNW2	
ROW	is the well's model row	
COL	is the well's model column	
DELT	is the time step length	[T]
DYEAR	is the date at the end of the time step as a decimal year	
DATE_START	is the calendar date at the start of the time step (yyyy-mm-ddThh:mm:ss)	

**B**

WELLID	CHARACTER(20)
LAY	INTEGER
ROW	INTEGER
COL	INTEGER
DATE_START	CHARACTER(19), starting date formatted as 'yyyy-mm-ddThh:mm:ss'
DYEAR	DOUBLE
DELT	DOUBLE
PER	INTEGER
STP	INTEGER
WBS	INTEGER
Q-CAP-INIT	DOUBLE
Q-CAP-FIN	DOUBLE
Q-FIN	DOUBLE
TFDR-INIT	DOUBLE
TFDR-FIN	DOUBLE

**Figure 6.55.** Supply Well block keyword PRINT ByWELL text file header explanation and binary record structure. *A*, Text-header explanation. *B*, Binary-record structure. [T], unit of time in model units; [L<sup>3</sup>/T], volumetric rate in model units; CHARACTER(20) indicates record is 20 characters long (20 bytes); CHARACTER(19) indicates record is 19 characters long (19 bytes); INTEGER is a 4-byte integer record; DOUBLE is a 8-byte floating-point number record.]

## PRINT ByMNW Header

The keyword **PRINT ByMNW** writes the pumpage information for each FMP-MNW2 linked supply well in use for that time step to the *Generic\_Output\_OptKey* file every time step. The output may be text or binary format and has the header defined in figure 6.56.

**A**

PER	is the stress period number	
STP	is the time step number	
WBS	is the Water Balance Subregion (Farm) ID number	
WELLID	is the name (WELL_ID) of the specific supply well	
Q-CAP-INIT	is the initial well's pumping capacity as specified by the input	[L <sup>3</sup> /T]
Q-CAP-FIN	is the well's final pumping capacity	[L <sup>3</sup> /T]
Q-ACT	is the final volumetric discharge rate of the well during current time step	[L <sup>3</sup> /T]
Q-DES-DMD	is an estimate of the well's initial demand for pumping	[L <sup>3</sup> /T]
H-WEL	is the MNW2 calculated well head ( $h_{\text{well}}$ )	[L]
H-CEL-AVE	is MNW2 well's aquifer head (conductance weighted by node)	[L]
DELT	is the time step length	[T]
DYEAR	is the date at the end of the time step as a decimal year	
DATE_START	is the calendar date at the start of the time step (yyyy-mm-ddThh:mm:ss)	

**B**

WELLID	CHARACTER(20)
DATE_START	CHARACTER(19), starting date formatted as 'yyyy-mm-ddThh:mm:ss'
DYEAR	DOUBLE
DELT	DOUBLE
PER	INTEGER
STP	INTEGER
WBS	INTEGER
Q-CAP-INIT	DOUBLE
Q-CAP-FIN	DOUBLE
Q-ACT	DOUBLE
Q-DES-DMD	DOUBLE
H-WEL	DOUBLE
H-CEL-AVE	DOUBLE

**Figure 6.56.** Supply Well block keyword PRINT ByMNW text file header explanation and binary record structure. *A*, Text-header explanation. *B*, Binary-record structure. [[T], unit of time in model units; [L<sup>3</sup>/T], volumetric rate in model units; CHARACTER(20) indicates record is 20 characters long (20 bytes); CHARACTER(19) indicates record is 19 characters long (19 bytes); INTEGER is a 4-byte integer record; DOUBLE is a 8-byte floating-point number record.]

## Surface-Water Block

The **SURFACE\_WATER** block is an optional block that specifies surface-water related deliveries to a WBS and the destination of aggregated surface runoff. In this release of MF-OWHM2, there are two surface-water delivery options: semi-routed deliveries (SRD) and non-routed deliveries (NRD). The surface runoff may either be aggregated by a WBS and then applied to the streamflow routing package (SFR) as return flow or re-infiltrated as deep percolation. There are two return flow choices, which are semi-routed return flow (SRR) and fully routed return flow (FRR). This sub-section gives an overview of the types of deliveries and return flow. This input block differs from other blocks in that the *List Style* input varies depending on the keyword. In FMP, the block name can be declared as **SURFACE WATER** or **SURFACE\_WATER**, but the later version, with an underscore, is recommended for clarity. Figure 6.57 presents the supported keywords for the **SURFACE\_WATER** block.

### Non-Routed Delivery (NRD)

A non-routed delivery (NRD) is a user-specified amount of water that is available to the WBS as supply. To have an NRD the **GLOBAL DIMENSION** block must specify the keyword **NRD\_TYPES**, which indicates the number of NRDs per WBS that will be defined. The NRD itself is defined with the keyword **NON\_ROUTED\_DELIVERY**. An NRD may be specified as a **VOLUME** ( $L^3$ ) or **RATE** ( $L^3/T$ ) per stress period. If the WBS demand is less than the NRD, then the unused portion of the NRD may be directed to one or more of the following: left in the SFR reach at the point of diversion (not be delivered to the WBS), released as runoff to the SFR network, injected into groundwater from the WBS supply wells, or added as deep percolation—groundwater recharge—to specific model locations. If the unused portion is added to deep percolation, then the keyword **NRD\_INFILTRATION\_LOCATION** LAI[S, T, A] must be included to define where the surplus water is added to deep percolation. It is important to note that an NRD that is specified using keyword **VOLUME** is specified as a volume per stress period and not as a rate nor volume per time step.

The NRD expects three input values per **NRD\_TYPES**, called the NRD triplet, which are read for each WBS. The NRD triplet is composed of the quantity of water delivered, its order of consumption amongst the other **NRD\_TYPES**, and how the excess water is treated (fig. 6.58). The formal NRD input definition is **NON\_ROUTED\_DELIVERY** [**VOLUME**, **RATE**] LAI[S, T, L-(3×**NRD\_TYPES**)], where the keywords **VOLUME** and **RATE** are optional. The keyword **VOLUME** indicates that the NRD is specified as a volume ( $L^3$ ) per stress period and the keyword **RATE** indicates that the NRD is specified as a rate ( $L^3/T$ ) per stress period. If neither **VOLUME** nor **RATE** are specified, then the NRD defaults to volume per stress period—this is the method that previous versions of the FMP processed NRDs.

**Figure 6.57.** SURFACE\_WATER block keyword list. Secondary keywords enclosed in brackets, [ ], indicate that they are optional and at most one may be selected and used during a simulation. Input enclosed in curly braces, { }, indicate that it is optional. A, Non-Routed Delivery keywords. B, Return flow keywords. C, SFR surface water delivery keywords. [Some of the keywords are specified over two lines because of their length, but should be a single, contiguous word in the input. The proper set up is to have on one line the keyword, secondary keyword, and input. SEG and RCH may be specified with using a name defined with the keyword SFR\_NAMES in the GLOBAL DIMENSION block. Abbreviations: FLOAT, floating-point number; INT, integer number, ID, water balance subregion identification number; WBS, water-balance subregion; [L], length in model units; [ $L^3$ ], volume in model units; [ $L^3/T$ ], volumetric rate in model units; SFR, streamflow routing package; LAI, list-array input with the following letters representing the supported keywords: S for STATIC, T for TRANSIENT, A for ARRAY, and L for LIST]

A

Keyword Secondary Keyword Input	Description
<b>NON_ROUTED_DELIVERY</b> [VOLUME, RATE] LAI[S, T, L-(3×NRD_TYPES)]	<p>Non-Routed Delivery (NRD) is water supply that is delivered to a WBS for a stress period.</p> <p>Use of the secondary “input” keyword (<b>RATE</b> or <b>VOLUME</b>) is optional, but only one may be specified per simulation.</p> <p>if no “input” keyword is present or specified as <b>VOLUME</b>, then the input for NRD volume (NRD_VOL) is a volume [L<sup>3</sup>].</p> <p>The <b>VOLUME</b> [L<sup>3</sup>] is divided by the stress period length to obtain a rate of water that is available during the stress period.</p> <p>If <b>RATE</b> is specified, then NRD_VOL is specified as a volumetric rate [L<sup>3</sup>/T].</p> <p><i>List Style</i> reads <b>NWBS</b> records with each record containing an <b>NRD_TYPES</b> set of three values, called a “NRD Triplet”.</p> <p>The NRD Triplet is:</p> <p>(NRD_VOL, NRD_RANK, NRD_USE)            ( FLOAT, INT, INT)</p> <p>where</p> <p>NRD_VOL is the quantity of water delivered to the WBS</p> <p>NRD_RANK is the order that water is consumed by the WBS demand.</p> <p>NRD_USE is what to do when delivered water exceeds demand.</p> <p>Accepted values are:</p> <p>0 indicates only water necessary to meet demand is delivered.</p> <p>1 indicates excess water is discharged to the WBS semi-routed delivery location.</p> <p>2 indicates excess water is injected to the WBS supply wells.</p> <p>≥10 indicates excess water is infiltrated as deep percolation wherever the integer, NRD_USE, is in the array defined in <b>NRD_INFILTRATION_LOCATION</b>.</p>
<b>NRD_INFILTRATION_LOCATION</b> LAI[S, T, A]	<p>Identifies location to infiltrate excess water from a <b>NON_ROUTED_DELIVERY</b> (NRD).</p> <p>Input is an <b>INT</b> array that specifies infiltration locations as either 0 (not used location) or ≥10.</p> <p>An NRD with NRD_USE ≥10 has its unused delivered (excess) water infiltrated at the corresponding ≥10 location in array.</p>

Figure 6.57. —Continued

**B**

Keyword and Input	Description
<b>NO_RETURN_FLOW</b> { LAI[S, T, L] }	Keyword indicates all surface runoff re-infiltrates as deep percolation. Optionally, the flag can be specified by the WBS with LAI[S, T, L] input reads either a value of 1 —to indicate no return flow— or 0 —to allow return flow.
<b>SEMI_ROUTED_RETURN</b> LAI[S, T, L-3] or LAI[S, T, L-4]	Reads <b>NSFR_RETURN</b> records that specify the location in SFR that a WBS's return flow (aggregated surface runoff) flows into. Input expects for each record: ISRR, WBS, SEG, RCH, [FRAC] that is read as INT, INT, INT, INT, [FLOAT] where ISRR is the record ID, WBS is either 0 to indicate the return flow point is skipped or the WBS that the return flow is coming from, SEG and RCH are the SFR segment and reach that return flow is sent to, and FRAC is the fraction of the WBS return flow that is applied to SEG and RCH. If FRAC is not specified, the return flow is prorated across all specified SEG and RCH based on their length compared to the total length. If the same WBS is defined multiple times, then the return flow is either length prorated or applied based on the specified FRAC. If a WBS has SEG set to 0, then the WBS return flow is removed from the model domain. If RCH is set to 0, then all reaches in SEG receive the return flow. SEG and RCH maybe be specified with a name defined from <b>SFR_NAMES</b> in the <b>GLOBAL DIMENSION</b> block. If WBS set to 0, then SEG, RCH, [FRAC] are not read.
<b>ROUTED_RETURN_ANY_NON_DIVERSION_REACH</b>	Fully routed return flow is enabled for all WBSs not defined with a <b>SEMI_ROUTED_RETURN</b> location. A WBS surface runoff is prorated by the length of all “non-diversion” SFR reaches within the WBS. This keyword is recommended whenever a simulation includes SFR.
<b>ROUTED_RETURN_ANY_REACH</b>	Fully routed return flow is enabled for all WBSs not defined with a <b>SEMI_ROUTED_RETURN</b> location. A WBS surface runoff is prorated by the length of all SFR reaches within the WBS.

**Figure 6.57.** —Continued

c

Keyword and Input	Description
<b>SEMI_ROUTED_DELIVERY</b> LAI[S, T, L-3] or LAI[S, T, L-4]	<p>Reads <b>NSFR_DELIV</b> records that each define where a specific WBS has access to SFR surface water deliveries—where a WBS can remove water from SFR to satisfy demand.</p> <p>Input expects for each record:</p> <p style="text-align: center;">ISR D, WBS, SEG, RCH, [FRAC]</p> <p>that is read as</p> <p style="text-align: center;">INT, INT, INT, INT, [FLOAT]</p> <p>where ISR D is the record ID, WBS is either 0 to indicate the delivery is not used or the WBS that can use the delivery point, SEG and RCH are the SFR segment and reach that water is removed from, and FRAC is optional and is the fraction of the WBS demand that the delivery point attempts to satisfy.</p> <p>If FRAC is not specified, then delivery points attempt to satisfy the demand in the order they are specified.</p> <p>If WBS set to 0, then SEG, RCH, [FRAC] are not read.</p>
<b>SEMI_ROUTED_DELIVERY_LOWER_LIMIT</b> LAI[S, T, L]	<p>Optional, reads <b>NSFR_DELIV</b> records that define the lower limit for each <b>SEMI_ROUTED_DELIVERY</b> in <math>[L^3/T]</math>.</p> <p>Only flow greater than the lower limit is available for delivery.</p> <p>Analogous to an SFR flood-control type diversion (IPRIOR = -3).</p> <p>If this keyword is not specified, then the default value is a lower limit of 0.0—that is any flow present is available for delivery.</p>
<b>SEMI_ROUTED_DELIVERY_UPPER_LIMIT</b> LAI[S, T, L]	<p>Optional, reads <b>NSFR_DELIV</b> records that define the upper limit for each <b>SEMI_ROUTED_DELIVERY</b> in <math>[L^3/T]</math>.</p> <p>The delivery only has access to water flow up to this upper limit.</p> <p>Analogous to an SFR specified-diversion flow (IPRIOR = 0).</p> <p>If this keyword is not specified, then the default value is an upper limit of 1E100.</p>
<b>SEMI_ROUTED_DELIVERY_CLOSURE_TOLERANCE</b> FLOAT	<p>Optional, and specifies a tolerance for delivery rate changes between solver iterations before convergence is allowed.</p> <p>If not specified it has a default value of 0.02 <math>[L^3/T]</math>.</p>

Figure 6.57. —Continued



## NRD Triplet Definition

$(\text{NRD\_VOL}, \text{NRD\_RANK}, \text{NRD\_USE}) \times \text{NRD\_TYPES}$

where:

**NRD\_TYPES** is the number of Non-Routed Delivery (NRD) defined in the Global Dimension Block.

**NRD\_VOL** is the volume [ $L^3$ ] or rate [ $L^3/T$ ] of water delivered to the WBS for the stress period. If the **OPTIONS** Block has the keyword **WELLFIELD**, then this value is ignored.

**NRD\_RANK** is order of consumption of the NRDs, it must be between 1 and **NRD\_TYPES**. This only has an effect when a WBS demand is less than the volume of water delivered from all the NRDs.

**NRD\_USE** defines how the unused portion of the NRD is handled.

The following are the accepted options:

<0: is only allowed with **WELLFIELD** option. Its absolute value is the WBS that represents the well field.

0: indicates that only the amount necessary to satisfy demand is delivered. No excess water occurs or is brought into the WBS.

1: the unused portion of water delivered is discharged back into the WBS's semi-routed delivery locations. If there are more than one location, the excess is divided evening across them.

2: the unused portion of water delivered is injected into groundwater using the WBS Supply Wells.

≥10: is an integer located within the **NRD\_INFILTRATION\_LOCATION** array. Any surplus water is added to deep percolation at that integer location. If the integer is located at multiple spots in the array, then the surplus is divided evenly among the locations. If the integer is not located in the array, then an error is raised.

**Figure 6.58.** Non-Routed Delivery (NRD) triplet input structure and explanation. [ $L^3$ ], volume in model units; [ $L^3/T$ ], volumetric rate in model units]

Figure 6.59 illustrates the structure of the NRD input with an example **GLOBAL DIMENSION** and **SURFACE\_WATER** blocks. Figure 6.59A has five WBSs and four **NRD\_TYPES** defined where the NRD triplets, (4×**NRD\_TYPES**), represent water available from a recycled water facility, an imported water pipeline, and two water sources that can be purchased from an external market—Purchase1 and Purchase2. The recycled water facility and imported water pipeline always deliver their water, irrelevant of their consumption, so they have **NRD\_USE** set to 1—to allow the excess to runoff. The recycled water facility provides water to WBS 1, 2, 3, and 4, whereas the imported water pipeline only provides water to WBS 1, 2, and 3. Purchase1 and Purchase2 are available to WBS 1 and 2, but WBS 1 prefers Purchase1 over Purchase2—say they have a contract to pay less for Purchase1, whereas WBS 2 has the opposite preference—preferring Purchase2 over Purchase1. Because the WBS will pay for supplies from Purchase1 and Purchase2 the **NRD\_USE** is set to 0 to only use what is needed. WBS 5 does not have access to any NRD sources. Note that the use of the **STATIC** keyword indicates that these volumes are delivered for every stress period. If **TRANSIENT** is specified, then the TFR file would specify the volumes delivered for each month.

Figure 6.59B is an example demonstrating how to use **NRD\_INFILTRATION\_LOCATION** to have the unused NRD passed to infiltration ponds. This example assumes a model grid of **NROW=3** and **NCOL=4**. For simplicity, **NRD\_TYPES** is reduced to 2, with the first source being the recycled water the second source the pipeline water, but the unused portion is passed to deep percolation.

A

```

BEGIN GLOBAL DIMENSION
  NWBS      5  # Number of water balance subregions (FARMS)
  NRD_TYPES  4  # Number of non-routed delivery types defined (NRD)
  NCROP      5  # Assume the following are defined elsewhere
  NSOIL      1
  NIRRIATE   1
END GLOBAL DIMENSION

BEGIN SURFACE_WATER
  #
  NON_ROUTED_DELIVERY VOLUME STATIC LIST INTERNAL
  #
  # WBS (NRD_VOL, NRD_RANK, NRD_USE) × NRD_TYPES
  #
  #   Recycled Water  Pipeline      Purchase1      Purchase2
  1  100.  1  1  50.  2  1  500.  3  0  100.  4  0 # Preference for Purchase1
  2  100.  1  1  50.  2  1  200.  4  0  400.  3  0 # Preference for Purchase2
  3  100.  1  1  50.  2  1   0.  3  0   0.  4  0 # Recycled + Pipeline
  4  100.  1  0   0.  2  0   0.  3  0   0.  4  0 # Only has recycled water
  5   0.  1  0   0.  2  0   0.  3  0   0.  4  0 # No NRD
  #
END SURFACE_WATER

```

**Figure 6.59.** Non-Routed Delivery input example consisting of the FMP Global Dimension and Surface\_Water blocks. A, Example defining 4 **NRD\_TYPES**. B, Example defining 2 **NRD\_TYPES** and defines infiltration locations with **NRD\_INFILTRATION\_LOCATION**.

B

```

BEGIN GLOBAL DIMENSION
  NWBS      5  # Number of water balance subregions (WBS)
  NRD_TYPES 2  # Number of non-routed delivery types defined (NRD)
  NCROP     5  # Assume the following are defined elsewhere
  NSOIL     1
  NIRRIATE  1
END GLOBAL DIMENSION

BEGIN SURFACE_WATER
#
  NRD_INFILTRATION_LOCATION STATIC ARRAY INTERNAL
    0  0  10  10
    0  0  10  10
  11 11  0  0
#
  NON_ROUTED_DELIVERY VOLUME STATIC LIST INTERNAL
#
#   Recycled Water  Pipeline
1  100.  1  1  50.  2  1  # Pipeline water discharged to SFR
2  100.  1  1  50.  2  10 # Unused Pipeline is infiltrated at location 10
3  100.  1  1  50.  2  11 # Unused Pipeline is infiltrated at location 11
4  100.  1  0   0.  2  0  # Only has recycled water
5   0.  1  0   0.  2  0  # No NRD
#
END SURFACE_WATER

```

Figure 6.59. —Continued

## Semi-Routed Delivery (SRD)

A semi-routed delivery (SRD) is a user specified SFR segment and reach that a WBS can remove water from to meet its demand. An SRD differs from the NRD in that the conveyance, through the SFR package, to the WBS is simulated—that is, the SRD quantity of water is limited and determined by the amount of flow through the SFR network. The keyword **SEMI\_ROUTED\_DELIVERY** in the **SURFACE\_WATER** block enables SRDs and uses *List Style* input. The **SEMI\_ROUTED\_DELIVERY** *List Style* input that expects **NSFR\_DELIV** records (fig. 6.60).

Figure 6.61 illustrates how to set up an input with **SEMI\_ROUTED\_DELIVERY** by defines six SRD locations. The simulation has a total of five WBSs, but only WBS 1, 2 and 4 have access to a surface-water delivery to meet their demand. WBS 4 has three delivery locations, and because **FRAC** is not specified the first delivery location (**ISR**D=3), attempts to fully meet the WBS demand. If it does not meet the demand, then the second delivery location (**ISR**D=4) attempts to meet the demand. If the first two SRDs have not met the demand, then the final potential surface-water source (**ISR**D=5) attempts to meet the WBS demand.

The amount of water that the WBS can remove from the SRD is either equal to its demand or the available flow in the SFR diversion segment and reach, whichever is smaller. There are three methods to impose control over the quantity of water that a WBS can remove from stream flow. The first is to use a “dummy” diversion segment that serves as the SRD. This dummy segment is a small segment that is a diversion from the main SFR flow and immediately connects back to the same segment it diverts water from. Figure 6.62 presents a simple SFR network that has the dummy segment, Segment 3, deliver water to a WBS. This method relies on the SFR diversion options to control the dummy segment’s flow, and consequently, the water delivered to the WBS. Any water that flows into the dummy segment that is not consumed by the WBS returns to the main SFR flow at Segment 4.

**A**

ISRD	WBS	SEG	RCH	[FRAC]
------	-----	-----	-----	--------

**B**

Input Format Keyword	Description
ISRD	<i>List Style</i> input record ID, <b>INT</b> , for the Semi-Routed Delivery (SRD) location. Its value is read, but not used. It must be sequential from 1 to <b>NSFR_DELIV</b> .
WBS	The WBS ID, <b>INT</b> , that can remove water from the specified SEG and RCH. A WBS may be specified in multiple ISRD records allowing for the WBS to have multiple SRD locations. If WBS is set to 0, then the ISRD is not available to deliver water. This allows for fewer than <b>NSFR_DELIV</b> to be in use during a stress period. If the WBS is set to 0, then the rest of the input line is ignored.
SEG	The semi-routed delivery's SFR segment, <b>INT</b> , that the WBS can remove water from at the SRD location to meet its demand.
RCH	The semi-routed delivery's SFR reach, <b>INT</b> , that the WBS can remove water from at the SRD location to meet its demand.
FRAC	An optional input that specifies the fraction, <b>FLOAT</b> , of the WBS demand that the semi-routed delivery attempts to satisfy. If a WBS has only one SRD location, then FRAC is set to 1.0. If a WBS has more than one SRD location and FRAC is either not specified or is a negative number, then the delivery to meet demand follows the order in which the SRD locations are specified. That is, the WBS's smallest ISRD first attempts to satisfy the demand with its supply. If there is a deficit, then the WBS's next lowest ISRD attempts to satisfy the demand. This continues until all the WBS's SRDs deliver all their water or the demand is met.  An example use of FRAC is a WBS has two SRD locations that have FRAC set to 0.7 and 0.3 and a demand of 60 [L <sup>3</sup> /T]. The water that each point delivers 42 and 18 [L <sup>3</sup> /T], respectively. If the supply at a SRD location is less than what is calculated by FRAC, the deficit is shifted to the SRD locations to ensure demand is fully met.

**Figure 6.60.** SURFACE\_WATER block SEMI\_ROUTED\_DELIVERY input definition. A total of NSFR\_DELIV records are read with each record containing ISRD, WBS, SEG, RCH, and optionally FRAC. A, Expected input structure for each List Style input record. B, Explanation of input variables. [SEG and RCH may be replaced with a name defined in the GLOBAL DIMENSION block's keyword SFR\_NAMES. Input enclosed in brackets, [ ], indicates it is optional. Abbreviations: FLOAT, floating-point number; INT, integer number; ID, water balance subregion identification number; WBS, water-balance subregion; SFR, streamflow routing package; [L<sup>3</sup>/T], volumetric rate in model units]

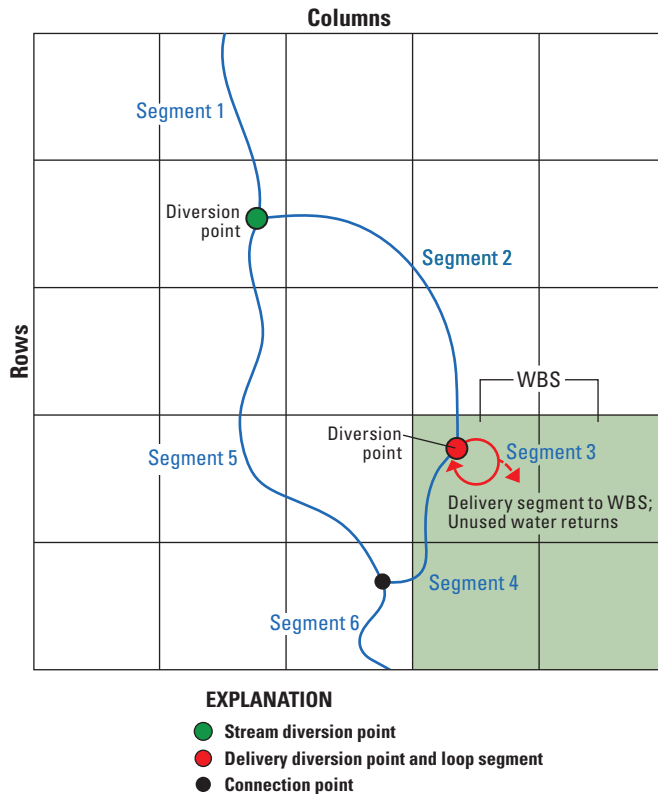
```

BEGIN GLOBAL DIMENSION
NWBS      5  # Number of water balance subregions (WBS)
NRD_TYPES 0  # Number of non-routed delivery types defined (NRD)
NCROP     5  # Assume the following are defined elsewhere
NSOIL     1
NIRRIGATE 1
NSFR_DELIV 6  # Number of SEMI_ROUTED_DELIVERY locations defined
#
SFR_NAMES INTERNAL
# ID SFRNAME  ISEG IRCH
1 WBS1_SRD   22  1
2 WBS2_SRD   2   3
#
END GLOBAL DIMENSION

BEGIN SURFACE_WATER
# NSFR_DELIV = 6, so SEMI_ROUTED_DELIVERY reads 6 records (ISRD = 1 to 6)
#
SEMI_ROUTED_DELIVERY STATIC LIST INTERNAL
#
# ISRD  WBS  SEG  RCH [FRAC]
1      1   WBS1_SRD  # Using SFR_NAMES to point to SEG 22, RCH 1
2      2   WBS2_SRD  # Using SFR_NAMES to point to SEG 2, RCH 3
3      4   5         1  # WBS 4 has 3 delivery points. 1st choice to meet demand
4      4   8         1  # WBS 4 has 3 delivery points. 2nd choice to meet demand
5      4   12        2  # WBS 4 has 3 delivery points. 3rd choice to meet demand
6      0   0         0  # ISRD record is ignored because WBS is 0
#
END SURFACE_WATER

```

**Figure 6.61.** Semi-Routed Delivery input example consisting of the FMP Global Dimension and Surface\_Water blocks.



**Figure 6.62.** Example SFR stream network that delivers water to an FMP semi-routed delivery location (SRD) at segment 3 to meet a WBS water demand. [Water is conveyed from segment 1 to segment 2 to segment 3, then removed by the WBS, and the unused portion returns to segment 4. Abbreviations: SFR, streamflow routing package; WBS, water-balance subregion.]

The second method is to control the water consumed by a WBS is using surface-water allotments described in the “Allotment Block” section of this appendix. A surface-water allotment imposes a total constraint of surface-water supply for a WBS but does not control the available supply at an individual SRD location. The third option is to use the keywords **SEMI\_ROUTED\_DELIVERY\_LOWER\_LIMIT** and **SEMI\_ROUTED\_DELIVERY\_UPPER\_LIMIT** (fig. 6.57A) to limit the available supply from each SRD location.

The **SEMI\_ROUTED\_DELIVERY\_LOWER\_LIMIT** and **SEMI\_ROUTED\_DELIVERY\_UPPER\_LIMIT** are optional keywords that define the range of available flow for each SRD location. If they are not included in the input, then their default values are 0 and 1E100 [L<sup>3</sup>/T], respectively, which imposes no limit on the delivery location. The expected input is LAI[S, T, L] that reads **NSFR\_DELIV** records. Figure 6.63 is an example input that defines the **SEMI\_ROUTED\_DELIVERY\_LOWER\_LIMIT** and **SEMI\_ROUTED\_DELIVERY\_UPPER\_LIMIT** as if they were placed in the **SURFACE\_WATER** block in figure 6.61.

**SEMI\_ROUTED\_DELIVERY\_LOWER\_LIMIT** is the flow rate that the delivery location must exceed before water is available to the WBS for delivery. This type of limit is analogous to an SFR flood-control type diversion (IPRIOR = -3). For example, if the lower limit is set to 10 [L<sup>3</sup>/T], then only flows greater than 10 [L<sup>3</sup>/T] are available for delivery. If the flow at the delivery segment is 15 [L<sup>3</sup>/T], then only 5 [L<sup>3</sup>/T] is available for delivery (from 5=15-10). If the flow is 8 [L<sup>3</sup>/T], then no water is available for delivery (because 8≤10).

**SEMI\_ROUTED\_DELIVERY\_UPPER\_LIMIT** is an upper flow limit that a delivery location must exceed before water is available to the WBS for delivery. This type of limit is analogous to an SFR specified-diversion flow diversion (IPRIOR = 0). For example, if the upper limit was set to 60 [L<sup>3</sup>/T], then a WBS may only remove from that delivery location at most 60 L<sup>3</sup>/T minus any imposed lower flow limit. For example, a delivery location that has a lower limit of 10 [L<sup>3</sup>/T] and upper limit of 60 [L<sup>3</sup>/T] would have a maximum potential delivery of 50 [L<sup>3</sup>/T] (from 60 - 10). If the upper limit is set to a negative number, then it is automatically changed to 1E100 to disable it—this assumes that SFR flow is never greater than 1E100 [L<sup>3</sup>/T].

```

# Example assumes that the GLOBAL DIMENSION block defines NSFR_DELIV = 6
:
: Example excerpt from SURFACE_WATER block
:
#
# Note that NSFR_DELIV = 6,
# so SEMI_ROUTED_DELIVERY_LOWER_LIMIT and SEMI_ROUTED_DELIVERY_UPPER_LIMIT
# each read 6 records. That is, ISRD = 1, 2, 3, 4, 5, and 6.
#
SEMI_ROUTED_DELIVERY_LOWER_LIMIT STATIC LIST INTERNAL
#
# ISRD Lower_Limit
1      10.0      # Only flow greater than 10 [L3/T] is available for delivery
2       0.0      # No lower limit on delivery point
3      20.0      # Only flow greater than 20 [L3/T] is available for delivery
4       0.0      # No lower limit on delivery point
5       0.0      # No lower limit on delivery point
6       0.0      # No lower limit on delivery point
#
SEMI_ROUTED_DELIVERY_UPPER_LIMIT STATIC LIST INTERNAL
#
# ISRD Upper_Limit
1      60.0      # Only flow less than 60 [L3/T] is available, max potential delivery is 50 [L3/T]
2      75.0      # Only flow less than 75 [L3/T] is available, max potential delivery is 75 [L3/T]
3      50.0      # Only flow less than 50 [L3/T] is available, max potential delivery is 30 [L3/T]
4     1E100      # Upper limit so large it cannot be exceeded, so no upper limit on delivery point
5      -1.0      # Negative number, so no upper limit on delivery point
6       0.0      # Upper limit set to 0 [L3/T], no flow is available; no delivery is possible
#
:
: Continue with the rest of the SURFACE_WATER block

```

**Figure 6.63.** Example input of the SEMI\_ROUTED\_DELIVERY\_LOWER\_LIMIT and SEMI\_ROUTED\_DELIVERY\_UPPER\_LIMIT within a Surface Water Block. These impose lower and upper limits on semi-routed delivery locations. [[L<sup>3</sup>/T], volumetric rate in model units; SFR, streamflow routing package; SRD, semi-routed delivery; NSFR\_DELIV, number of SRD locations; ISRD, number that identifies the SRD, which is between 1 and NSFR\_DELIV]

## Return Flow

Surface runoff in the FMP is flow that results from excess irrigation or precipitation that is not consumed by the landscape nor infiltrates to groundwater. Surface runoff is calculated for all surface model cells that are assigned a non-zero WBS ID—that is, it is calculated as a surface cell-by-cell. The resulting runoff can either entirely re-infiltrate to groundwater as deep percolation or be aggregated by the WBS. The aggregated surface runoff is called return flow and is applied to the SFR package as runoff. By specifying the keyword **NO\_RETURN\_FLOW** all surface runoff is designated for re-infiltration to groundwater. If it is desired to specify this disposition of surface runoff individually for each WBS, then the keyword **NO\_RETURN\_FLOW** should be followed with **LAI[S, T, L]**, which loads **NWBS List Style** records that are either a 1 to indicate **NO\_RETURN\_FLOW** for that WBS and that surface runoff should re-infiltrate or a 0 to indicate that surface runoff should be handled as return flow. This is useful if a WBS is far from any SFR segments or it is known that the agricultural setting does not allow for runoff—which could be required by State or local regulations. If SFR package is not in use—as specified in the Name file—and the keyword **NO\_RETURN\_FLOW** is not included, then any resulting runoff is removed from the simulation domain and a warning is raised. If the keyword **NO\_RETURN\_FLOW** is present, then it supersedes all the other return flow keywords.

If surface runoff is aggregated as return flow, then it may either be applied to user-specified SFR segment and reaches or automatically applied to all SFR reaches in a WBS. A semi-routed return (SRR) flow point is an SFR segment and reach that receives the flow that results from surface runoff. As with the semi-routed delivery (SRD) input, a WBS may contain multiple defined semi-routed return flow points and has the same general input structure (fig. 6.64). The **GLOBAL DIMENSION** keyword **NSFR\_RETURN** defines the *List Style* input number of records that **SEMI\_ROUTED\_RETURN** expects. Note that figure 6.64A has nearly an identical input structure for each record as figure 6.60A (SRD input), but their meanings are slightly different.

Any WBS that is not defined with **NO\_RETURN\_FLOW** or **SEMI\_ROUTED\_RETURN** may optionally use fully routed return flow to automatically determine the SFR return flow points. Fully routed return flow is similar to semi-routed return flow, except it automatically identifies all the SFR reaches in a WBS and prorates the return flow by the length of each reach. If fully routed return flow is enabled, but there are no SFR segments or reaches in the WBS, then the return flow is removed from the model—this is the same as specifying a semi-routed return flow to segment zero (that is, setting an **ISRR** with **WBS>0** and **SEG=0**). If a fully routed return flow has the return flow leave the model, then a warning is raised indicating that it be specified as a semi-routed return flow with a segment set to zero. Fully routed return flow is enabled if the keyword **ROUTED\_RETURN\_ANY\_NON\_DIVERSION\_REACH** or **ROUTED\_RETURN\_ANY\_REACH** is specified in the **SURFACE\_WATER** block. The difference between the two is the former applies return flow to all non-diversion SFR reaches, and the latter applies return flow to any reach in the WBS. When SFR is part of the simulation, it is recommended to always include **SEMI\_ROUTED\_RETURN** and **ROUTED\_RETURN\_ANY\_NON\_DIVERSION\_REACH**.

Figure 6.65 presents different combinations of return flow keywords that are applied to 5 WBS. Figure 6.65A is an example **GLOBAL DIMENSION** keyword that is used by the other figure parts. Figure 6.65B illustrates the use of **NO\_RETURN\_FLOW** and having it apply to all WBSs. Figure 6.65C shows how to specify **NO\_RETURN\_FLOW** by WBS. In this example WBSs 3, 4, and 5 do not have their return flow associated with an SRR point or have a fully-routed return flow keyword present, so if they have any return flow it will be removed from the simulation domain. Figure 6.65D enables fully-routed return flow, so if there are any non-diversion reaches in WBSs 3, 4 and 5, then runoff is returned to them. Figure 6.65E includes a single semi-routed return flow point for WBS 3. In this example (fig. 6.65E), the aggregated surface runoff from WBSs 4 and 5 is not defined with **NO\_RETURN\_FLOW** or **SEMI\_ROUTED\_RETURN**, but the fully routed keyword **ROUTED\_RETURN\_ANY\_NON\_DIVERSION\_REACH** is present, so WBSs 4 and 5 will have their return flow length prorated across any non-diversion reaches in their respective subregions (that is, return flow from WBS 4 returns to reaches in WBS 4, and return flow from WBS 5 returns to reaches in WBS 5). If WBS 4 and 5 do not have any SFR reaches in them, then their return flow is removed from the model and a warning is raised. Figure 6.65F does not include **NO\_RETURN\_FLOW** nor any fully routed return flow keywords, so any WBS that is not defined with **SEMI\_ROUTED\_RETURN** has its return flow removed from the model. Because figure 6.65F does not specify **NO\_RETURN\_FLOW**, all surface runoff is aggregated as return flow, which is direction specified for WBS 3 and prorated across multiple SFR reaches for WBS 1, 2, 4 and 5.

## Supported SFAC DIMKEY

**NON\_ROUTED\_DELIVERY** is the only **SURFACE\_WATER** keyword that supports advanced, **SFAC DIMKEY**, scale factors. The scale factors that are loaded are only applied to **NRD\_VOL**—the quantity of water delivered. **NON\_ROUTED\_DELIVERY** only supports the **DIMKEY ByWBS** and **ByNRD**. The **DIMKEY ByWBS** reads **NWBS** scale factors that are applied by WBS. The **DIMKEY ByNRD** reads **NRD\_TYPES** scale factors that are applied by each NRD type for all WBS.



**A**

ISRR	WBS	SEG	RCH	[FRAC]
------	-----	-----	-----	--------

**B**

Input Format Keyword	Description
ISRR	<i>List Style</i> input record ID, <b>INT</b> , for the semi-routed return (SRR) flow location. Its value is read, but not used. It must be sequential from 1 to <b>NSFR_RETURN</b> .
WBS	The WBS ID, <b>INT</b> , that has a return flow location defined at SEG and RCH. A WBS may be specified in multiple ISRD records allowing for the WBS to have more than one semi-routed return flow locations. If the WBS is set to 0, then the rest of the input line is ignored. This allows for fewer than <b>NSFR_RETURN</b> to be in use during a stress period.
SEG	Is the SFR segment, <b>INT</b> , that receives return flow from the defined WBS. If WBS > 0 and SEG = 0, then the WBS's return flow is removed from the model. That is, FMP assumes it flows to a point outside the simulation's domain.
RCH	Is the semi-routed return flow's SFR reach, <b>INT</b> , that receives return flow from the defined WBS. If SEG > 0 and RCH = 0, then the return flow is length prorated to all the reaches in SEG. This allows for the ISRR to be defined for multiple segments without having to repeat for every reach.
FRAC	An optional input that specifies the fraction, <b>FLOAT</b> , of the total WBS return flow that is passed as runoff to the defined SEG and RCH as runoff. If a WBS only has one semi-routed return location, then FRAC is set to 1.0. For a given WBS, if FRAC is not specified or is set to a negative number, then the fraction is determined by prorating the reach length to the total length of all the WBS' reaches not specified with a FRAC.

**Figure 6.64.** SURFACE\_WATER block SEMI\_ROUTED\_RETURN input definition. A total of NSFR\_RETURN records are read with each record containing ISRR, WBS, SEG, RCH, and optionally FRAC. **A**, Expected input structure for each List Style input record. **B**, Explanation of input variables. [SEG and RCH may be replaced with a name defined in the GLOBAL DIMENSION block's keyword SFR\_NAMES. Input enclosed in brackets, [ ], indicates it is optional. Abbreviations: FLOAT, floating-point number; INT, integer number, ID, water balance subregion identification number; WBS, water-balance subregion; SFR, streamflow routing package; [L<sup>3</sup>/T], volumetric rate in model units]

**A****BEGIN GLOBAL DIMENSION**

```

NWBS          5  # Number of water balance subregions (FARMS)
NRD_TYPES     0  # Number of non-routed delivery types defined (NRD)
NCROP         5  # Assume the following are defined elsewhere
NSOIL         1
NIRRIGATE     1
NSFR_DELIV    0  # No SEMI_ROUTED_DELIVERY locations defined
NSFR_RETURN   10 # Number of SEMI_ROUTED_RETURN points defined

```

**END GLOBAL DIMENSION****B****BEGIN SURFACE\_WATER**

```

#
# Keyword forces all surface runoff re-infiltrates to groundwater as deep percolation
#
# It supersedes all other return flow keywords (because there is no return flow)
# Note this makes the global dimension NSFR_RETURN = 10 as wasted spaces.
#
NO_RETURN_FLOW # No LAI[S, T, L], indicates keyword applies to all WBS for all time steps
#

```

**END SURFACE\_WATER****C****BEGIN SURFACE\_WATER**

```

#
# The optional [ LAI[S, T, L] ] input is included, which specifies NO_RETURN_FLOW by WBS.
#
# Input indicates that surface runoff re-infiltrates to deep percolation for WBSs 1 and 2
#
# WBSs 3, 4 and 5 do not have specified a return flow point—no return flow,
#   semi-routed return, or fully-routed return—so their return flow leaves the simulation domain
#
NO_RETURN_FLOW STATIC LIST INTERNAL
1  1
2  1
3  0
4  0
5  0
#

```

**END SURFACE\_WATER**

**Figure 6.65.** Surface Water block return flow keyword examples. *A*, GLOBAL DIMENSION block input used for other figure parts. *B*, Surface Water block input that defines no return flow for the entire model. *C*, Surface Water block input that defines no return flow for select water balance subregions (WBS). *D*, Surface Water block input that defines no return flow for select WBS and includes a fully-routed return flow keyword. *E*, Surface Water block input that includes the three main types of return flow keywords. *F*, Surface Water block input that defines semi-routed return flow.

**D**

```

BEGIN SURFACE_WATER
#
# All surface runoff re-infiltrates for WBS 1 and 2
#
# WBSs 3, 4 and 5 do not have specified a return flow point,
#   but the keyword ROUTED_RETURN_ANY_NON_DIVERSION_REACH is present to indicate that
#   any WBS that does not have its return flow point defined uses fully-routed return flow.
#   Consequently, any return flow from 3, 4 and 5 is prorated to SFR non-diversion segments
#
NO_RETURN_FLOW STATIC LIST INTERNAL
1  1
2  1
3  0
4  0
5  0
#
ROUTED_RETURN_ANY_NON_DIVERSION_REACH # Fully-routed return flow keyword
#
END SURFACE_WATER

```

**Figure 6.65.** —Continued

E

```

BEGIN SURFACE_WATER
#
# All surface runoff re-infiltrates for WBSs 1 and 2 (no return flow)
# Any runoff from WBS 3 flows to SFR segment 12, reach 2 (semi-routed return)
# Any runoff from WBSs 4 and 5 is prorated to SFR non-diversion segments (fully-routed return)
#
NO_RETURN_FLOW STATIC LIST INTERNAL
1 1
2 1
3 0
4 0
5 0
#
# NSFR_RETURN = 10, so SEMI_ROUTED_RETURN reads 10 records (ISRR = 1 to 10)
#
SEMI_ROUTED_RETURN STATIC LIST INTERNAL
#
# ISRR WBS SEG RCH [FRAC]
1 3 12 2 # WBS 3 Return Flow sent to SFR SEG 12, RCH 2 ←
2 0 0 0 # WBS = 0, ISRR is ignored
3 0 0 0
4 0 0 0
5 0 0 0
6 0 0 0
7 0 0 0
8 0 0 0
9 0 0 0
10 0 0 0
#
ROUTED_RETURN_ANY_NON_DIVERSION_REACH
#
END SURFACE_WATER

```

Figure 6.65. —Continued

F

```

BEGIN SURFACE_WATER
#
# NSFR_RETURN = 10, so SEMI_ROUTED_RETURN reads 10 records (ISRR = 1 to 10)
#
SEMI_ROUTED_RETURN STATIC LIST INTERNAL
#
#ISRR WBS  SEG RCH [FRAC]
1    1    0    0      # WBS 1: return flow leaves the model domain
2    2    5    0      # WBS 2: return flow length prorated across all reaches of
3    2    6    0      #           segments 5 and 6 (defined via ISRR 2 and 3).
4    3    8    0 0.4  # WBS 3: 40% of return flow is sent to segment 8 and
#           length prorated among its reaches
5    3    9    0 0.5  # WBS 3: 50% of return flow is sent to segment 9 and
#           length prorated among its reaches
6    3   10    1 0.1  # WBS 3: 10% of return flow is sent to Seg 10, Reach 1
7    4   15    4      # WBS 4: All return flow is sent to Seg 15, Reach 4
8    5    1    1 -1.0 # WBS 5: FRAC = -1 indicates that return flow is length prorated
9    5    1    2 -1.0 #           across Seg 1, Reaches 1 and 2. (Note FRAC = -1 is optional.)
10   0    0    0      # ISRR is ignored due to WBS = 0
#
END SURFACE_WATER

```

Figure 6.65. —Continued

## Allotment Block

The **ALLOTMENT** block is an optional block that specifies global constraints of water supplies for a WBS. The allotments in the FMP provide a convenient method of imposing a maximum limit on the water sources available to a WBS. The use of allotments as constraints is useful for representing limits such as water rights or operating agreement allocations or for analysis of sustainability by limiting supply in a deficit irrigation option. The latter can be useful for analysis related to meeting statutory requirements such as under California's Sustainable Groundwater Management Act (SGMA; State of California, 2014). With this release of MF-OWHM2, there are two Allotment constraints that can be applied: one for SFR surface-water deliveries and another for total groundwater pumpage. The surface-water allotment imposes a limit on the amount of water a WBS can receive from the **SURFACE\_WATER** block's **SEMI\_ROUTED\_DELIVERY**. The groundwater allotment imposes a limit on the amount of water a WBS can remove from groundwater through wells defined in the **SUPPLY\_WELL** block. Allotment constraints are imposed by stress period, to limit the quantity of water withdrawals during a stress period. To convert an allotment to an equivalent volumetric rate is to divide the allotment volume by the stress-period length. Figure 6.66 presents the keywords that are supported in the **ALLOTMENT** block.

In figure 6.66, an X in the **SFAC DIMKEY** column indicates that it is supported in the **ALLOTMENT** block. Keywords not specified in the table do not support the **SFAC DIMKEY**s. Both **SURFACE\_WATER** and **GROUNDWATER** support using the **SFAC** keyword, but only allow for the keyword option **ByWBS**. The option loads a list of **NWBS** scale factors.

First Keyword Second Keyword	Input	Description
<b>SURFACE_WATER</b> { <b>RATE</b> , <b>VOLUME</b> , <b>HEIGHT</b> }	LAI[S, T, L]	<p><i>List Style</i> reads <b>NWBS</b> records that specify, for each WBS, a total delivery limit from the WBS's <b>SEMI_ROUTED_DELIVERY</b>. If the WBS has multiple <b>SEMI_ROUTED_DELIVERY</b>'s, then their sum cannot exceed the limit.</p> <p>The second keyword is required and specifies the model units of the surface water allotment. Only one second keyword may be in use during a simulation.</p> <p><b>RATE</b> allotment is a volumetric rate [<math>L^3/T</math>]  <b>VOLUME</b> allotment is a volume per stress period [<math>L^3</math>]  <b>HEIGHT</b> allotment is a length per stress period [L] that is multiplied by the WBS's irrigated area to obtain a volume per stress period.</p>
<b>GROUNDWATER</b> { <b>RATE</b> , <b>VOLUME</b> , <b>HEIGHT</b> }	LAI[S, T, L]	<p><i>List Style</i> reads <b>NWBS</b> records that specify, for each WBS, a total pumpage limit from the WBS's <b>SUPPLY_WELLS</b> (that is, a global limit on a WBS groundwater pumping).</p> <p>The second keyword is required and specifies the model units of the groundwater allotment. Only one second keyword may be in use during a simulation.</p> <p><b>RATE</b> allotment is a volumetric rate [<math>L^3/T</math>]  <b>VOLUME</b> allotment is a volume per stress period [<math>L^3</math>]  <b>HEIGHT</b> allotment is a length per stress period [L] that is multiplied by the WBS's irrigated area to obtain a volume per stress period.</p>

**Figure 6.66.** ALLOTMENT block keyword list. Both the first and second keywords must be present to complete the input. [The first keyword is specified on the first line of each row and the second keyword options are enclosed in { }. Only one of the second keywords may be used during a simulation. Note that VOLUME and HEIGHT second keywords indicate that input is a stress period-based limit rather than a model time unit limit. Abbreviations: FMP, farm process; WBS, water-balance subregion; [L], length in model units; [ $L^3$ ], volume in model units; [ $L^3/T$ ], volumetric rate in model units; SFR, streamflow routing package; LAI, list-array input with the following letters representing the supported keywords: S for STATIC, T for TRANSIENT, A for ARRAY, and L for LIST]

First Keyword	<b>DIMKEY</b>		
	ByWBS	ByCrop	ByIrrigate
<b>SURFACE_WATER</b>	X		
<b>GROUNDWATER</b>	X		

**Figure 6.67.** ALLOTMENT block keywords that support **SFAC DIMKEY**. The only supported word for **DIMKEY** is ByWBS. [Supported keyword and **DIMKEY** combinations are marked with an X.]

## Land-Use Block—Land-Use and Crop Properties

The **Land\_Use** (Crop) block defines a land-use type and properties associated with each land use. Please review appendix 4 for a detailed explanation of the properties of the **Land\_Use** block. Land use is the main determinant of water consumption in the FMP and consumes groundwater, precipitation, and irrigation water as evaporation and transpiration. In MF-OWHM2, the term “Crop” is synonymous with the term land use. A crop is simulated in the FMP only if it resides in a WBS—that is, its model location is defined with a WBS ID from 1 to **NWBS**. In FMP, the block name can be declared as **Land Use** or **Land\_Use**, but the later version, with an underscore, is recommended for clarity (note that input is also not case sensitive).

The **Land\_Use** block includes keywords that define crop names and locations, crop coefficients and irrigation methods, root depths and suction pressures, fractions of transpiration and evaporation for each crop/land-use type, losses to runoff from precipitation and irrigation waters, and the type of interaction with groundwater (see “appendix 4” for formal definitions of these properties). The keywords are briefly described here and, unless otherwise noted, all *List Style* input expects **NCROP** records, where **NCROP** is the number of land-use types and specified in the **GLOBAL DIMENSION** block.

### Spatial Location Keywords

Land-use types can be specified on a cell-by-cell basis—that is, only one crop per model cell—or defined as a fraction of a model cell—allowing for multiple crops in the same model cell. Land-use fractions—keyword **MULTIPLE\_LAND\_USE\_PER\_CELL**—provide a means of simulating multiple crops within a model cell. This can be valuable if constructing composite properties is problematic or if a higher accuracy is desired for cells containing a diverse set of crops. A negative aspect to using land-use fractions is that the input structure becomes more challenging if an array-based input is desired. If the input uses crop fractions and one of its properties requests an array-based input, then it requires a two-dimensional array for each crop—that is, the non-fraction *Array Style* input is  $NROW \times NCOL$ , but crop fraction *Array Style* input is  $NCROP \times NROW \times NCOL$ . *List Style* input does not present this challenge because it maps each crop’s property to any model cell that contains the crop.

The **Land\_Use** block must include either the keyword **SINGLE\_LAND\_USE\_PER\_CELL** or the keyword **MULTIPLE\_LAND\_USE\_PER\_CELL** to indicate if the input assumes one crop per model cell or allows for multiple crops per cell, respectively. If **SINGLE\_LAND\_USE\_PER\_CELL** is specified, then the keyword **LOCATION** LAI[S, T, A] is required and defines the spatial location of each crop. The **LOCATION** input is specified as a 2D **INT** array that contains the Crop number, from 1 to **NCROP**, where the crop is simulated; however, if a number less than 1 or greater than **NCROP** is input, then bare soil is simulated for that cell, as described in appendix 4. Crops are only simulated in model cells that are associated with a WBS—that is, the same row and column are defined in the **WATER\_BALANCE\_SUBREGION LOCATION** keyword with a WBS number between 1 and **NWBS**. If it is known that a crop does not occupy the entire model cell, then the keyword **LAND\_USE\_AREA\_FRACTION** LAI[S, T, A] can be included to specify the fraction of the cell area that the crop is grown on—the fraction must be between 0 and 1. The remaining part of the model cell, one minus the fraction, is treated as bare soil and only allows for evaporation. The fraction should specify the total cropped area and not the leaf covered area—the leaf covered area is defined with the Fraction of Transpiration as described in appendix 4. The **LAND\_USE\_AREA\_FRACTION** keyword is optional when defining one crop per model cell. Figure 6.68 is an example input that assigns a single crop per model cell for a model grid with three rows and four columns.

The input is structured differently if it is desired to specify multiple crops per model cell. First the keyword **MULTIPLE\_LAND\_USE\_PER\_CELL** must be present, and the keyword **LAND\_USE\_AREA\_FRACTION** is required. Because there are multiple crops per model cell the use of the keyword **LOCATION** is not allowed because it signifies assignment of a single crop per model cell. Instead, the **LAND\_USE\_AREA\_FRACTION** usage specifies where the crop is and the fraction of cell area it occupies. As described before, the **LAND\_USE\_AREA\_FRACTION** keyword requires reading **NCROP**  $NROW \times NCOL$  arrays that are contiguous—making the final array size as  $NCROP \times NROW \times NCOL$ . The cell fractions can be specified with *IXJ Style* input, which is described in the “IXJ Style Input Support” section. If multiple crops are simulated and the sum of the specified cell fractions are not equal to 1, then the remaining area is treated as bare soil. Figure 6.69 is an example input that assigns multiple crops per model cell and is using the previous example’s **GLOBAL DIMENSION** and **WATER\_BALANCE\_SUBREGION** blocks.

Because the FMP inputs allow for comments between input lines it may be advantageous to specify the fraction input with a full-line comment before each crop’s input. Figure 6.70 illustrates how you can use full-line comments to break apart the different crops’ cell-fraction arrays. Figure 6.71 summarizes the location-based keywords used by the **Land\_Use** block.

```

# Example assumes that model grid is 3 by 4 (NROW = 3, NCOL = 4)
# Note only the necessary keywords are defined
BEGIN GLOBAL DIMENSION
#
NWBS    5    # Number of water balance subregions (WBS)
NCROP   2    # Number of land use types (Crops)
#
END GLOBAL DIMENSION
BEGIN WATER_BALANCE_SUBREGION
#
LOCATION  STATIC ARRAY INTERNAL # Only WBSs 1 and 5 are in use during the simulation
0  1  5  5
0  1  5  5
0  5  5  5
#
END WATER_BALANCE_SUBREGION
BEGIN LAND_USE
#
SINGLE_LAND_USE_PER_CELL # Indicates use of LOCATION keyword and only one crop per surface cell
#
# Only Crops 1 and 2 are in use
# Column 1 is not simulated because it is not assigned to a WBS
# (that is "WATER_BALANCE_SUBREGION LOCATION" = 0 in column 1)
#
# Row 3, Columns 2 and 3 are treated as bare soil, having no crop
#
LOCATION  STATIC ARRAY INTERNAL
0  2  2  1
0  2  2  1
0  0  0  1
#
# The following is optional when using the LOCATION keyword.
# The fractions define that Crop 2 located at Rows 1 and 2, column 2
# occupies 60% of the model cell and 40% of the model cell is bare soil.
# The fraction is meaningless on cells not assigned a Crop number.
LAND_USE_AREA_FRACTION  STATIC ARRAY INTERNAL
0  0.6  1.0  1.0
0  0.6  1.0  1.0
0  0    0    1.0
#
END LAND_USE

```

**Figure 6.68.** Example FMP block input assigns a single crop per surface model cell for a model grid with three rows and four columns. [This example on includes the keywords necessary to specifies crop locations and fractions.]



```

# Example assumes that model grid is 3 by 4 (NROW = 3, NCOL = 4)
# Note only the necessary keywords are defined
BEGIN GLOBAL DIMENSION
#
NWBS    5    # Number of water balance subregions (WBS)
NCROP   2    # Number of land use types (Crops)
#
END GLOBAL DIMENSION
BEGIN WATER_BALANCE_SUBREGION
#
LOCATION  STATIC ARRAY INTERNAL # Only WBSs 1 and 5 are in use during the simulation
0  1  5  5
0  1  5  5
0  5  5  5
#
END WATER_BALANCE_SUBREGION
BEGIN LAND_USE
#
# Indicates not to use of LOCATION keyword, but instead
# LAND_USE_AREA_FRACTION specifies each crops location and allows for more than one crop in a surface cell
MULTIPLE_LAND_USE_PER_CELL
#
# The fractions define that Crop 1 as occupying 60% of Rows 1 and 2, column 2;
# Crop 2 then occupies 40% of Rows 1 and 2, column 2;
# Crop 1 occupies all of Row 1, Column 3 and Rows 2 and 3, Column 4
# Crop 1 occupies 50% of Row 1, Column 4 and the remaining area,
#   except for Row 2, Column 3 (which is fully covered by Crop 2),
#   is treated as bare soil—since it is undefined.
#
# Note that input expects an (NCROP × NROW) by NCOL array.
#
LAND_USE_AREA_FRACTION  STATIC ARRAY INTERNAL
0  0.6  1.0  0.5    # Crop 1 Fractions -----
0  0.6  0    1.0
0  0    0    1.0
0  0.4  0    0      # Crop 2 Fractions -----
0  0.4  1.0  0
0  0    0    0
#
END LAND_USE

```

**Figure 6.69.** Example FMP block input specifies multiple crops per surface model cell for a model grid with three rows and four columns. [This example on includes the keywords necessary to specifies crop locations and fractions.]

```

:
: Example excerpt from LAND_USE block
:
#
LAND_USE_AREA_FRACTION  STATIC ARRAY  INTERNAL
#
# Crop 1 Fractions
#
0  0.6  1.0  0.5
0  0.6  0    1.0
0  0    0    1.0
#
# Crop 2 Fractions      – ULOAD can skip commented or empty lines
#
0  0.4  0    0
0  0.4  1.0  0
0  0    0    0
#
:
: Continue with the rest of the LAND_USE block

```

**Figure 6.70.** Example excerpt from the LAND\_USE block input to illustrate using comments between lines of input. [ULOAD, the universal loader, automatically skips lines that are either blank or only contain a comment. If it encounters a line with input, then it expects to read the entire input before a comment appears. For example, ULOAD expects four numbers on a line, then if there is one number successful read, then all four must be present before a comment is placed.]

Keyword	Input	Description
<p>{ <b>SINGLE_LAND_USE_PER_CELL</b></p> <p>or</p> <p><b>MULTIPLE_LAND_USE_PER_CELL</b> }</p>		<p>One of these two keywords must be present within the <b>Land_Use</b> block.</p> <p>The keywords indicate if the FMP should simulate a single-land use per model cell or allow for more than one (multiple) land-use type per model cell.</p>
<b>LOCATION</b>	LAI[S, T, A]	<p>Required if <b>SINGLE_LAND_USE_PER_CELL</b> is specified. <b>INT</b> array that specifies the spatial location of the land-use types (Crops).</p> <p>Within the array an <b>INT</b> between 1 and <b>NCROP</b> indicates the crop that is grown there; otherwise, it is assumed to be bare-soil area.</p>
<b>LAND_USE_AREA_FRACTION</b>	LAI[S, T, L]	<p><b>FLOAT</b> array that specifies the fraction of the model cell's surface area that the land use occupies.</p> <p>Optional, if <b>SINGLE_LAND_USE_PER_CELL</b> is specified and has a default value of 1.0 for all model cells. Array Style expects an array of fractions from 0.0 to 1.0 structured as <math>NROW \times NCOL</math>. The portion of the cell that is not specified by a crop is simulated as bare-soil area.</p> <p>Required, if <b>MULTIPLE_LAND_USE_PER_CELL</b> is specified. Array Style expects an array of fractions from 0.0 to 1.0 structured as <math>NCROP \cdot NROW \times NCOL</math>.</p> <p>This structure can be thought of as <b>NCROP</b> arrays that are stacked one after the next with the dimension of <math>NROW \times NCOL</math>. The crop's spatial location is signified by where the fraction is greater than 0.</p> <p>That is, crop 1 is located anywhere the fraction is greater than 0.0 in the first <math>NROW \times NCOL</math> array, and crop 2 is located anywhere the fraction is greater than 0.0 in the second <math>NROW \times NCOL</math> array.</p> <p>If the fractions do not sum to 1, then the remaining area is assumed to be bare soil.</p>

**Figure 6.71.** LAND\_USE block keywords that define crop locations. [FLOAT, floating-point number; INT, integer; FMP, farm process; WBS, water-balance subregion; LAI, list-array input with the following letters representing the supported keywords: S for STATIC, T for TRANSIENT, A for ARRAY, and L for LIST]

## Base Land-Use Properties

The base land-use properties are the necessary features to describe the crop and how to simulate it. Some of the base properties are optional and have default values when not specified, whereas others are conditionally dependent—that is, describing one property may necessitate defining another. Figure 6.72 summarizes the keywords that define the base crop properties, and the rest of this section discusses in greater depth selected keywords.

A simulation that includes the **Land\_Use** block must include either the **CONSUMPTIVE\_USE** or **CROP\_COEFFICIENT** keywords. **CONSUMPTIVE\_USE** LAI[S, T, A, L] directly specifies for each crop the potential consumptive use [L/T], which is the same as potential evapotranspiration. **CROP\_COEFFICIENT** specifies a crop coefficient ( $K_c$ ) that is converted to a potential consumptive use (CU) by multiplying it by the crop's reference evapotranspiration ( $ET_{ref}$ ), which is defined in the **CLIMATE** block with the keyword **REFERENCE\_ET**. It is recommended to consult with local agricultural expertise and water districts to obtain crop coefficients for the simulated region. If local crop coefficient data are not available, then Figure 6.73 provides estimates of  $K_c$  at three growth stages of selected crops from Allen and others (1998).

If **CONSUMPTIVE\_USE** and **CROP\_COEFFICIENT** are specified, then the total potential CU is the sum of the two—that is,  $CU = \text{CONSUMPTIVE\_USE} + \text{CROP\_COEFFICIENT} \times \text{REFERENCE\_ET}$ . If the CU is set to zero, then the FMP assumes the land use does not have any evapotranspiration. The FMP treats CU as the crop demand and attempts to satisfy it directly from groundwater, precipitation, or applied irrigation.

The keyword **IRRIGATION** defines which crops have access to applied water. Applied water is only used when the crop's transpiration demand—calculated from its potential CU—is not fully met from the root uptake of groundwater or precipitation. The **IRRIGATION** keyword may only be specified if the **GLOBAL\_DIMENSION** block keyword **NIRRIGATE** is greater than 0, which indicates the number of irrigation types available in the FMP. The input for **IRRIGATION** may be *Array Style* or *List Style* that specifies an integer from 0 to **NIRRIGATE**. If the **IRRIGATION** is set to 0, then the crop does not have access to applied water—note that this is the opposite of previous versions of the FMP. If the **IRRIGATION** is greater than 0, then the crop has irrigation and the integer specified refers to the irrigation type. If the keyword **EFFICIENCY**, from the **WATER\_BALANCE\_SUBREGION** block, uses *List Style* input, then the irrigation type refers to the column in the Irrigation Efficiency input to use (see the “Water Balance Subregion (WBS) Block” section). Additionally, the irrigation type determines the *List Style* record (row) when the keywords **EVAPORATION\_IRRIGATION\_FRACTION** and **SURFACEWATER\_LOSS\_FRACTION\_IRRIGATION** are followed with the keyword **BY\_IRRIGATE**—which indicates that the *List Style* input reads **NIRRIGATE** records. If **EFFICIENCY**, **EVAPORATION\_IRRIGATION\_FRACTION** and **SURFACEWATER\_LOSS\_FRACTION\_IRRIGATION** are specified with *Array Style*, then the property is determined by the crop's spatial location in the model grid—that is, **IRRIGATION** only serves as a flag to indicate the crop is irrigated.

If a crop has access to irrigation only during part of the simulation, then the **IRRIGATION** flag needs to vary by stress period. During periods when the crop does not receive applied water, the **IRRIGATION** flag is set to 0, and when it does have applied water, the flag is set to the irrigation type that supplies the crop. Figure 6.73 illustrates the relationship between **WATER\_BALANCE\_SUBREGION** block **EFFICIENCY** keyword and the **LAND\_USE** block **IRRIGATION** keyword—note that the example does not include the complete FMP input for either the **WATER\_BALANCE\_SUBREGION** or **LAND\_USE** input blocks, just the sections pertinent to this example. The keyword **TRANSIENT** with **DATAFILE** IRR\_Flag.txt (fig. 6.73B) indicates the file IRR\_Flag.txt is a direct data file (DDF, appendix 1). That is, the irrigation flag is specified in IRR\_Flag.txt for each stress period, consecutively, in the same file (fig. 6.73C). It only shows nine monthly stress periods with three crops that are not irrigated in January nor February. It assumes that crop 2 is drip irrigated from March to August and then harvested in September—so there is no longer a need to irrigate. It assumes that Crop 3 has flood irrigation in May and June and then switches to sprinkler irrigation for July and August before being harvested in September.

A

Keyword	Input	Description
<b>CONSUMPTIVE_USE</b>	LAI[S, T, A, L]	<p><b>FLOAT</b> input that defines the potential consumptive use rate of the crop [L/T].</p> <p>This value is multiplied by the crop area to get a volumetric rate [L<sup>3</sup>/T].</p> <p>Either <b>CONSUMPTIVE_USE</b> or <b>CROP_COEFFICIENT</b> must be specified if <b>NCROP</b> &gt; 0.</p> <p>If both are specified, then their sum is the potential volumetric consumptive-use rate. If the sum is 0, then zero evapotranspiration occurs.</p>
<b>CROP_COEFFICIENT</b>	LAI[S, T, A, L]	<p><b>FLOAT</b> input that defines crop coefficients (<math>K_c</math>) that are multiplied by reference evapotranspiration (<math>ET_{ref}</math>) to determine the potential consumptive use rate [L/T].</p> <p>If specified, then it is required to specify in the <b>CLIMATE</b> block <b>REFERENCE_ET</b>.</p> <p>This value is multiplied by the crop area to get a volumetric rate [L<sup>3</sup>/T].</p> <p>Either <b>CONSUMPTIVE_USE</b> or <b>CROP_COEFFICIENT</b> must be specified if <b>NCROP</b> &gt; 0.</p> <p>If both are specified, then their sum is the potential volumetric consumptive-use rate. If the sum is 0, then zero evapotranspiration occurs.</p>
<b>TRANSPIRATION_FRACTION</b>	LAI[S, T, A, L]	<p><b>FLOAT</b> input that defines fraction of consumptive use (FTR) that corresponds to the potential transpiration of the crop.</p> <p>It is formally defined as the ratio of the Basal Crop Coefficient (<math>K_{cb}</math>) divided by the <b>CROP_COEFFICIENT</b>, that is <math>FTR = K_{cb} / K_c</math>.</p> <p>It can be viewed as the fraction of a unit-cropped area that is covered by crop foliage.</p>
<b>ROOT_DEPTH</b>	LAI[S, T, A, L]	<p><b>FLOAT</b> input (&gt;0) that defines the root depth below land surface for each crop.</p> <p>If the root depth is less than 1E-30, then it is changed to 1E-30.</p>
<b>CROP_NAME</b>	ULOAD	<p>Optional, <b>CHAR</b> input that assigns a name of each crop for output files (max size of 20 characters).</p> <p>If not specified, then the crop names default to "CROP_XX", where the XX is the crop number.</p>

**Figure 6.72.** LAND\_USE block keywords that define the base properties that should be included in a farm process (FMP) simulation. Secondary keywords enclosed in brackets, [ ], are optional and at most one can be used during a simulation. [Some of the keywords are specified over two lines because of their length, but should be a single, contiguous word in the input. Abbreviations: CHAR, character input; FLOAT, floating-point number; INT, integer number; LAI, list-array input with the following letters representing the supported keywords: S for STATIC, T for TRANSIENT, A for ARRAY, and L for LIST.]

B

Keyword	Input	Description
<b>IRRIGATION</b>	LAI[S, T, A, L]	<p><b>INT</b> input that defines whether a crop has irrigation water applied, and the irrigation type. Only specified if <b>NIRRIGATE</b> &gt; 0.</p> <p>If <b>IRRIGATION</b> is set to 0, then the crop does not have irrigation water; otherwise, input must be specified between 1 and <b>NIRRIGATE</b> to indicate that the crop is irrigated with and irrigation efficiency defined by the corresponding column in the <b>EFFICIENCY</b> table (OFE).</p> <p>For example, if set to 3, then the crop is irrigated and uses the efficiency defined in the third column in the <b>EFFICIENCY</b> table.</p> <p>If not specified, then <b>IRRIGATION</b> = 0 for all crops.</p>
<b>EVAPORATION_</b> <b>IRRIGATION_FRACTION</b>	<p>[ <b>BY_CROP</b>, <b>BY_IRRIGATE</b> ]</p> <p>LAI[S, T, A, L]</p>	<p><b>FLOAT</b> input that defines the fraction of the unit-cropped area that is irrigated but is only exposed to sunlight and evaporates (FEI). This portion of the unit-cropped area has negligible transpiration.</p> <p>This fraction should be between 0 and less than one minus the <b>TRANSPIRATION_FRACTION</b> (1 - FTR).</p> <p>If keyword is not specified or input specifies FEI &lt; 0, then FEI = 1 - FTR.</p> <p>FEI can be viewed as the portion of irrigation that is not available for consumption as transpiration (such as the space between row crops) and includes any water that evaporates before reaching the crop or evaporates from atop the crop's leaves.</p> <p>If FTR + FEI &gt; 1, then the final consumptive use will be greater than what is specified in the input due to evaporation of irrigation water.</p> <p>The optional secondary keywords <b>BY_CROP</b> and <b>BY_IRRIGATE</b> indicate the number of records that <i>List Style</i> input reads and applies the input.</p> <p><b>BY_CROP</b> expects <b>NCROP</b> records and applies the fractions by crop.</p> <p><b>BY_IRRIGATE</b> expects <b>NIRRIGATE</b> records and applies the fractions by irrigation type.</p> <p>If neither of the <b>BY_</b> keywords are specified, then the default is <b>BY_CROP</b>.</p>

Figure 6.72. —Continued

c

Keyword	Input	Description
<b>SURFACEWATER_LOSS_ FRACTION_PRECIPITATION</b>	LAI[S, T, A, L]	<p><b>FLOAT</b> input is a runoff coefficient for water that originated as precipitation (FIESWP). It is a fraction of precipitation that is not consumed by the crop that becomes surface runoff; one minus this fraction is the portion that becomes deep percolation.</p> <p>For example, a FIESWP value of 0.8 indicates that 80 percent of unconsumed (excess) precipitation becomes runoff and 20 percent infiltrates as deep percolation.</p> <p>If keyword is not specified, then the FIESWP is set to 0.8 if SFR is in use; otherwise, is set to zero.</p>
<b>SURFACEWATER_LOSS_ FRACTION_IRRIGATION</b>	<p>[ <b>BY_CROP</b>, <b>BY_IRRIGATE</b> ]</p> <p>LAI[S, T, A, L]</p>	<p><b>FLOAT</b> input is a runoff coefficient for excess irrigation water (FIESWI). The excess irrigation is determined from the quantity of irrigation water and the irrigation type's <b>EFFICIENCY</b>.</p> <p>FIESWI specifies the portion of excess irrigation that becomes surface runoff.</p> <p>If keyword is not specified, then FIESWI is set to 0.</p> <p>For example, a FIESWI value of 0.8 indicates that 80 percent of excess irrigation becomes runoff and 20 percent infiltrates as deep percolation.</p> <p>The optional secondary keywords <b>BY_CROP</b> and <b>BY_IRRIGATE</b> indicate the number of records that <i>List Style</i> input reads and applies the input.</p> <p><b>BY_CROP</b> expects <b>NCROP</b> records and applies the fractions by crop.</p> <p><b>BY_IRRIGATE</b> expects <b>NIRRIGATE</b> records and applies the fractions by irrigation type.</p> <p>If neither of the <b>BY_</b> keywords are specified, then the default is <b>BY_CROP</b>.</p>

Figure 6.72. —Continued

Plant Group	Initial stage	Mid-season stage	Late-season stage
Alfalfa hay	0.401	1.201	1.151
Apples, cherries, pears	0.600	0.950	0.752
Apricots, peaches, stone fruit	0.550	0.900	0.652
Berries (bushes)	0.300	1.050	0.500
Cereal crops	0.300	1.150	0.400
Citrus	0.650	0.600	0.650
Cotton	0.000	1.200	0.700
Cucurbitaceae family	0.500	1.000	0.800
Fibre crops	0.350	1.200	0.700
Grapes-wine	0.300	0.700	0.450
Hops	0.300	1.050	0.850
Legumes (leguminosae)	0.400	1.150	0.550
Oil crops	0.350	1.150	0.350
Pistachios	0.400	1.100	0.450
Roots and tubers	0.500	1.100	0.950
Small vegetables	0.700	1.050	0.950
Solanum family	0.600	1.150	0.800
Turf grass	0.800	0.850	0.850
Walnut orchard	0.500	1.100	0.652

**Figure 6.73.** CROP\_COEFFICIENT ( $K_c$ ) values for select crops (Allen and others, 1998). [Initial stage refers to the start of the crop's life cycle after planting or when the crop ends its winter dormancy, mid-season stage refers to the peak of the crop's life cycle, and late season refers to the end of the crop's life cycle or just before the crop enters its winter dormancy (for more details see Allen and others, 1998).]

The keyword **TRANSPIRATION\_FRACTION** is a required input that specifies the fraction of cropped area contributing transpiration (FTR). This fraction must be between 0 and 1 and is formally defined as the ratio of the Basal Crop Coefficient divided by the **CROP\_COEFFICIENT** ( $FTR = K_{cb}/K_c$ ) and is discussed in detail in appendix 4. If FTR is set to 0.0, then the unit cropped area only has evaporation losses and no transpiration. However, if FTR is set to 1.0, then the unit cropped area could potentially only have transpiration. If the actual transpiration is less than the potential CU, then there is a potential for evaporation. It is important to note that FMP only irrigates to satisfy transpiration, so larger values of FTR increase the FMP estimation of irrigation. Typically, in the early stages of plant growth the FTR is small and increases as the plant becomes more developed with more leaf matter. Although it is recommended to investigate locally applicable values of FTR based on the simulated region, a set of example values are presented in figure 6.75. These example values are calculated from basal and crop coefficients published in Allen and others (1998). Fallowed land can have a wide range of FTR depending on type and vigor of the natural vegetation growing on the idle landscape, and the season of year. Values of FTR can range from 0.1 to 0.75 for fallowed land depending on seasonal growth of the natural vegetation. If the land becomes completely devoid of plant life, then setting  $FTR = 0$  is acceptable.

If a crop receives applied water (**IRRIGATION**), then the **EVAPORATION\_IRRIGATION\_FRACTION** keyword represents the fraction of evaporation from irrigation (FEI; appendix 4) for the crop. The FEI can be viewed as the fraction of a unit cropped area that receives irrigation water, is exposed to the sun and evaporates, but is not consumed as transpiration. The value of FEI is normally less than or equal to  $1 - FTR$  but is not required. If  $FEI + FTR > 1$ , then the final CU can be larger than what is specified in the input. This larger CU is the result of irrigation water that evaporates before it reaches the crop or evaporates while sitting atop of the leaves.



**A**

```
# Multipart example to show the relationship between EFFICIENCY and IRRIGATION
#
# Example simulates 9 stress periods, assumes a model grid that is 3 by 4, with
#   1 Water Balance Subregion (WBS), 3 simulated crops, and 3 irrigation types.
# That is, NPER = 9, NROW = 3, NCOL = 4, NWBS = 1, NCROP = 3, NIRRGATE = 3
#
# :
# : Excerpt from WATER_BALANCE_SUBREGION block to defines EFFICIENCY
# :
# EFFICIENCY keyword specifies for each WBS the irrigation efficiency (OFE) for each irrigation type
# List Style input reads NWBS records that have NIRRGATE columns
#
# Note, the irrigation style (drip, sprinkler, flood) is included for perspective on what the OFE represents,
#   but FMP does not simulate the actual irrigation and uses OFE to calculate irrigation losses.
#   In this manner, it is better to think of the irrigation types as "Irrigation Type 1" or "IRR1"
#
EFFICIENCY  STATIC LIST INTERNAL
#           Drip  Sprinkler  Flood
# WBS  IRR1  IRR2  IRR3
#   1    0.9  0.7    0.6
#
# :
# : Continue with the rest of the WATER_BALANCE_SUBREGION block
```

**B**

```
# Multipart example to show the relationship between EFFICIENCY and IRRIGATION
#
# :
# : Excerpt from LAND_USE block to defines EFFICIENCY
# :
#
# IRRIGATION keyword specifies which Crops are irrigated and the irrigation type used.
#
# TRANSIENT indicates input is read by stress period with the Transient File Reader or Direct Data File.
# DATAFILE indicates "IRR_Flag.txt" is a Direct Data File, so read each stress period (SP) directly from that file.
#
IRRIGATION  TRANSIENT LIST DATAFILE  IRR_Flag.txt
#
# :
# : Continue with the rest of the LAND_USE block
```

**Figure 6.74.** Example that demonstrates the relationship between FMP irrigation efficiency (OFE) and the irrigation flag. *A*, Partial input of the WATER\_BALANCE\_SUBREGION block. *B*, Partial input of the LAND\_USE block. *C*, Direct Data File that specifies irrigation flags for three crops for nine stress periods.

c

```

# File: IRR_Flag.txt — Direct Data File reads one List Style input at start of each stress period (SP).
# Input assumes, NCROP = 3, so irrigation is specified for 3 crops — Note that Crop 1 is never irrigated
# CropID  IrrigationFlag
  1      0      # No irrigation for any crops      SP 1 — January
  2      0
  3      0
# SP 2 — February
  1      0      # No irrigation for any crops
  2      0
  3      0
# SP 3 — March
  1      0      #
  2      1      # Crop 2 has irrigation 1 (drip), which has EFFICIENCY = 0.9
  3      0      # No irrigation Crop 3
# SP 4 — April
  1      0      #
  2      1      # Crop 2 has irrigation 1 (drip), which has EFFICIENCY = 0.9
  3      0      # No irrigation Crop 3
# SP 5 — May
  1      0      #
  2      1      # Crop 2 has irrigation 1 (drip), which has EFFICIENCY = 0.9
  3      3      # Crop 3 has irrigation 3 (Flood), which has EFFICIENCY = 0.6
# SP 6 — June
  1      0      #
  2      1      # Crop 2 has irrigation 1 (drip), which has EFFICIENCY = 0.9
  3      3      # Crop 3 has irrigation 3 (Flood), which has EFFICIENCY = 0.6
# SP 7 — July
  1      0      #
  2      1      # Crop 2 has irrigation 1 (drip), which has EFFICIENCY = 0.9
  3      2      # Crop 3 has irrigation 2 (Sprinkler), which has EFFICIENCY = 0.7
# SP 8 — August
  1      0      #
  2      1      # Crop 2 has irrigation 1 (drip), which has EFFICIENCY = 0.9
  3      2      # Crop 3 has irrigation 2 (Sprinkler), which has EFFICIENCY = 0.7
# SP 9 — September
  1      0      # Crops have been harvested, so no irrigation for any crops
  2      0
  3      0

```

Figure 6.74. —Continued

Plant Group	Initial stage	Mid-season stage	Late-season stage
Alfalfa hay	0.751	0.958	0.957
Apples, cherries, pears	0.833	0.947	0.934
Apricots, peaches, stone fruit	0.818	0.944	0.923
Berries (bushes)	0.667	0.952	0.800
Cereal crops	0.500	0.957	0.625
Citrus	0.923	0.917	0.923
Cotton	0.100	0.958	0.714
Cucurbitaceae family	0.300	0.950	0.875
Fibre crops	0.429	0.958	0.714
Grapes-wine	0.500	0.929	0.889
Hops	0.500	0.952	0.941
Legumes (leguminosae)	0.375	0.957	0.909
Oil crops	0.429	0.957	0.714
Pistachios	0.500	0.955	0.889
Roots and tubers	0.300	0.909	0.895
Small vegetables	0.214	0.905	0.895
Solanum family	0.250	0.957	0.875
Turf grass	0.938	0.941	0.941
Walnut orchard	0.800	0.955	0.923

**Figure 6.75.** Example values of TRANSPIRATION\_FRACTION (FTR) calculated from crop coefficients presented in Allen and others (1998). [Initial stage refers to the start of the crop's life cycle after planting or when the crop ends its winter dormancy, mid-season stage refers to the peak of the crop's life cycle, and late season refers to the end of the crop's life cycle or just before the crop enters its winter dormancy (for more details, see Allen and others, 1998).]

The FEI can vary on the basis of agricultural practices and the type and quality of irrigation equipment used. Although it is recommended to research locally applicable FEI values based on the simulated region, typical values of FEI are 0.05 to 0.1 for drip irrigation, 0.1 to 0.3 for sprinkler, and 0.3 to 1 – FTR for flood irrigation. If FEI is set to a negative value, then FMP automatically sets  $FEI = 1 - FTR$ . That is, setting  $FEI < 0$  ensures that the sum of FEI and FTR is always unity.

As with FTR, increasing FEI increases the FMP estimated irrigation requirement. However, the estimated irrigation requirement is the same for all values of FTR and FEI so long as  $FEI = 1 - FTR$ . The reason for this relationship is that the corresponding evaporative loss from irrigation compliments the necessary irrigation to satisfy transpiration.

Excess water originates from precipitation that is not consumed by the crop. Excess water either becomes surface runoff, which is aggregated as return flow, or infiltrates to groundwater as deep percolation. In previous releases of the FMP, the excess water was called an “inefficient loss.” The keyword **SURFACEWATER\_LOSS\_FRACTION\_PRECIPITATION** (FIESWP) specifies the fraction of the excess water from precipitation that becomes surface runoff; consequently,  $1 - FIESWP$  is the excess water that becomes deep percolation. The choice of FIESWP depends on the properties of the land surface. Typically, areas that are urban or hilly areas have large values of FIESWP ( $> 0.8$ ). Large values also can occur if the surface soil is not permeable or known to contain a lot of clay. Small values ( $< 0.2$ ) occur when the surface is very permeable, such as sandy beaches or other coarse-grained deposits. Developed agriculture designed to minimize runoff will consequently have very small values of FIESWP. Undeveloped riparian areas that contain phreatophytes also may have very small values. Although it is recommended to investigate locally applicable values of FIESWP for the simulated region, a set of example values are presented in figure 6.76. These values are best viewed as an initial estimate when there is no other information available. Further refinement is advised based on the soil permeability, landscape topography, and degree of development of the landscape.

Land-Use Category or Crop Type	FIESWP
Agricultural trees	0.50
Burned and barren	0.95
Carrots	0.20
Citrus and subtropical	0.90
Corn	0.10
Cotton	0.15
Crucifers	0.10
Deciduous fruits and nuts	0.50
Fallow	0.70
Field crops	0.60
Field crops-irrigated	0.50
Golf-course turf	0.60
Grain and hay crops	0.90
Legumes (leguminosae)	0.10
Native and natural vegetation	0.95
Nurseries	0.95
Pasture	0.95
Phreatophytes	0.10
Rice	0.80
Riparian	0.15
Roots and tubers	0.10
Strawberries	0.10
Tomato	0.10
Upland grasslands	0.90
Upland shrub lands	0.90
Urban	0.95
Vineyards	0.50
Woodland	0.90

**Figure 6.76.** Example values of SURFACEWATER\_LOSS\_FRACTION\_PRECIPITATION (FIESWP) for different land use and crop types. [The fraction, FIESWP, represents the portion of excess water from precipitation that becomes surface runoff. These values are best viewed as an initial estimate when there is no other information available.]

As with **SURFACEWATER\_LOSS\_FRACTION\_PRECIPITATION**, excess water that originates from irrigation is defined by a fraction of inefficient loss to surface water. The excess irrigation water is determined from the irrigation efficiency (**EFFICIENCY** keyword from the **WATER\_BALANCE\_SUBREGION** block). The keyword **SURFACEWATER\_LOSS\_FRACTION\_IRRIGATION** specifies the fraction (FIESWI) of the excess water from irrigation that becomes surface runoff—that is,  $1 - \text{FIESWI}$  is the fraction of excess water that becomes deep percolation. This input is not used by crops that do not have irrigation (**IRRIGATION** = 0), and its input is only required when **NIRRIGATE** is greater than zero. **SURFACEWATER\_LOSS\_FRACTION\_IRRIGATION** may optionally be followed by the post-keyword **BY\_CROP** or **BY\_IRRIGATE** to indicate if *List Style* input is mapped to model cells by crop type or irrigation type. If neither optional keyword is present, then **BY\_CROP** is assumed. If the post-keyword is **BY\_CROP**, then the FMP reads **NCROP** *List Style* input records and applies the FIESWI by crop type—unless the crop is not irrigated (then the value is never used). If the post-keyword is **BY\_IRRIGATE**, then the *List Style* input reads **NIRRIGATE** records and applies the FIESWI by the crop's irrigation type that is defined with the keyword **IRRIGATION**. Typically, values of FIESWI are small ( $< 0.3$ ) because most irrigation systems are designed to infiltrate the majority of applied water. In addition, the input values may be small to reflect possible limitations on surface runoff, which could originate from State or local regulations to minimize pesticide runoff to nearby streams. The choice of FIESWI values depends the land surface is development and the properties of the irrigation method. Users are advised to investigate locally applicable values of FIESWI on the basis of the simulated region; nevertheless, a set of example values for different land uses—**BY\_CROP** input option—are presented in figure 6.77 and for different irrigation methods—**BY\_IRRIGATE** input option—are presented in figure 6.78.

Land-Use Category or Crop Type	FIESWI
Agricultural trees	0.05
Carrots	0.10
Citrus and subtropical	0.70
Corn	0.02
Cotton	0.80
Crucifers	0.05
Deciduous fruits and nuts	0.05
Field crops	0.40
Field crops-irrigated	0.40
Golf-course turf	0.05
Grain and hay crops	0.05
Legumes (leguminosae)	0.05
Nurseries	0.01
Pasture	0.10
Rice	0.75
Roots and tubers	0.05
Strawberries	0.01
Tomato	0.05
Urban	0.35
Vineyards	0.05

**Figure 6.77.** Example values of **SURFACEWATER\_LOSS\_FRACTION\_IRRIGATION** (FIESWI) for different land use and crop types. [The fraction, FIESWI, represents the portion of excess water from irrigation that becomes surface runoff. These values are best viewed as an initial estimate when there is no other information available.]

Irrigation Type	FIESWI
Drip	0.01
Sprinkler-developed	0.10
Sprinkler-undeveloped	0.30
Flood-developed	0.10
Flood-undeveloped	0.50

**Figure 6.78.** Example values of **SURFACEWATER\_LOSS\_FRACTION\_IRRIGATION** (FIESWI) for different irrigation types. [The fraction, FIESWI, represents the portion of excess water from irrigation that becomes surface runoff. These values are best viewed as an initial estimate when there is no other information available.]

**ROOT\_DEPTH** defines the vertical depth below land surface to which a crop's root system extends, expressed as a positive number. The sum of root depth plus the capillary fringe height (**CAPILLARY\_FRINGE** from the **SOIL** block) determines if there is direct uptake of groundwater through the roots and if the potential transpiration is reduced as a result of anoxia and soil-moisture stress. **ROOT\_DEPTH** may be set to zero, but it is not recommended. If the advance option **ROOT\_PRESSURE**, discussed in the next section, is included, then **ROOT\_DEPTH** must be positive; if zero is specified for root depth, then an error is raised and the simulation stops.

## Advanced Land-Use Properties

The advanced land-use properties are optional and allow for advanced simulation features or customization of land-use properties. Figure 6.79 presents the list of advanced keywords supported by the **Land\_Use** block.

There are three methods available in the FMP to define the groundwater-root uptake and anoxia for each crop. The first method is no groundwater uptake, the second is a linear groundwater-root uptake and anoxia-limitation concept that accounts for the overlap between the capillary fringe and the root depth (*linear root response*), and the third is an analytical pseudo steady-state soil moisture, soil-stress concept (*analytical root response*). If the *analytical root response* is used, then the user is required to specify, with the **ROOT\_PRESSURE** keyword, four stress-response root pressures, symbolized as PSI or  $\psi$ , and the soil type that the crop is grown in (**COEFFICIENT** from the **SOIL** block). The four PSI values represent the upper limit pressure head at which the root uptake becomes zero because of anoxia, then two pressure heads that represent the range of optimal root uptake, and then a lower limit pressure head that results in wilting (zero root uptake), respectively. It should be noted that for most crops that the **ROOT\_PRESSURE** PSI values should all be negative, with the first value being the largest and the fourth value being the most negative—that is, they must be in descending order. Only the first two PSI values may be positive, which indicate that the crop or land use can tolerate ponding of water—that is, a water table above the land surface. If the first value is zero or positive, then the second value also must be zero or positive. If a crop has its four **ROOT\_PRESSURE** PSI values set to 0.0, then the FMP will use the *linear root response* method instead. It is recommended to inquire with local agriculture and water districts to obtain the appropriate pressures for each crop or land use within a simulated region. If locally applicable data are not available, then figure 6.80 provides estimates of **ROOT\_PRESSURE** for select crops.

The **GROUNDWATER\_ROOT\_INTERACTION** keyword defines how a crop's roots directly interact with groundwater. The FMP is capable of simulating five groundwater-root interaction levels that are outlined in figure 6.81. The different levels determine if a crop's root is capable of consuming groundwater (root groundwater uptake = Yes), if it has its CU reduced from anoxia (anoxia reduction = Yes), or a reduction in CU as a result of soil related stresses (soil-stress reduction = Yes). The default setting is level 5 in FMP and was the only option in previous FMP releases. The **GROUNDWATER\_ROOT\_INTERACTION** keyword only supports *List Style* input that loads for each crop type an **INT**, which must be a 0, 1, 2, 3, 4, or 5. If the level is set to 1 or 2, then the crop can only meet its CU through precipitation and irrigation. If **GROUNDWATER\_ROOT\_INTERACTION** is not specified, then it defaults to level 5 for all crops.

The **ADDED\_DEMAND** keyword allows for specifying additional irrigation, in addition to the requirement for CU, that is to be applied to a land use. When additional irrigation demand is specified, the FMP applies water to the land use that either becomes runoff or deep percolation. The amount that becomes runoff is defined by the **WATER\_BALANCE\_SUBREGION** block keyword **ADDED\_DEMAND\_RUNOFF\_SPLIT**. If it is not specified, then by default all additional irrigation water required will be split to have 10 percent become runoff and 90 percent infiltrated—that is, the default **ADDED\_DEMAND\_RUNOFF\_SPLIT** = 0.1. This keyword is advantageous if it is known that a land use receives additional irrigation, such as pre-wetting a field, beyond meeting the CU requirement of the land use—that is, the demand specified through **CONSUMPTIVE\_USE** or **CROP\_COEFFICIENT**.

The **ADDED\_DEMAND** keyword is identical to the **ADDED\_CROP\_DEMAND** keyword from the **WATER\_BALANCE\_SUBREGION** block, except that for **ADDED\_DEMAND** the expected *List Style* input is **NCROP** records with **NWBS** columns (the transpose of **ADDED\_CROP\_DEMAND**) or the **ADDED\_DEMAND** can be specified with *Array-Style*. **ADDED\_DEMAND** has two possible option keywords that indicate how the input is interpreted. **ADDED\_DEMAND\_FLUX** indicates that the input is in units of length (L/T) and multiplied by the crop's irrigated area to determine the additional demand as a volumetric rate (L<sup>3</sup>/T). **ADDED\_DEMAND\_RATE** indicates that the input is in volumetric rate (L<sup>3</sup>/T) units. A simulation may only specify **ADDED\_DEMAND\_FLUX** or **ADDED\_DEMAND\_RATE**, but not both at the same time. If a simulation includes **ADDED\_DEMAND** and the **WATER\_BALANCE\_SUBREGION** block **ADDED\_CROP\_DEMAND**, and they both are applied to the same land use, then their sum determines the total additional irrigation that the FMP will apply to the crop.

If a cell's CU is set to zero, then the FMP disables simulation of evaporation and transpiration of the model cell. The **ZERO\_CONSUMPTIVE\_USE\_BECOMES\_BARE\_SOIL** keyword tells the FMP that if a land use has zero CU, then it should switch to bare-soil calculation. The bare-soil calculation only allows for evaporation of groundwater and precipitation, which is limited by either the **POTENTIAL\_EVAPORATION\_BARE** or one-half of the **REFERENCE\_ET**. The keyword **ZERO\_CONSUMPTIVE\_USE\_BECOMES\_BARE\_SOIL** may optionally be followed by a *List Style* input that consists of **NCROP** records that either specify a 1, to indicate the crop is treated as bare soil, or 0 to indicate the crop is not.

A

Keyword	Input	Description																								
ROOT_PRESSURE	LAI[S, T, L-4]	<p><b>FLOAT</b> input that defines crop stress-response pressures [L] for the <i>analytical root response</i> option (appendixes 4 and 5). If keyword is specified, then the <b>SOIL</b> block must specify the <b>COEFFICIENT</b> keyword.</p> <p>Input expects four root pressures, <math>\psi</math> (PSI), that are species in units of hydraulic head [L].</p> <p>The four root pressures specify the extent to which the crop is under (1) anoxia conditions, (2 and 3) optimally consumes groundwater, or (4) undergoes wilting.</p> <p>For any crop that has all four root pressures set to zero, or if the keyword is not specified, then FMP uses the <i>linear root response</i> concept.</p>																								
GROUNDWATER_ROOT_INTERACTION	LAI[S, T, L]	<p><b>INT</b>, optional flag that specifies the crop root processes that are simulated, which are a function of the water table elevation and capillary fringe.</p> <p>The first process is the ability to consume groundwater directly called root-groundwater uptake (RGU).</p> <p>No RGU indicates that the crop’s potential transpiration can only be satisfied from surface sources (precipitation and irrigation).</p> <p>The other processes reduce in potential transpiration due to anoxia or soil-stress.</p> <p>The flag must be set to one of the following levels:</p> <table><tr><th>Level</th><th>RGU</th><th>Anoxia</th><th>Soil-Stress</th></tr><tr><td>1</td><td>no</td><td>no</td><td>no</td></tr><tr><td>2</td><td>no</td><td>yes</td><td>yes</td></tr><tr><td>3</td><td>yes</td><td>no</td><td>no</td></tr><tr><td>4</td><td>yes</td><td>no</td><td>yes</td></tr><tr><td>5</td><td>yes</td><td>yes</td><td>yes</td></tr></table> <p>It is recommended to only use option 1, 3, or 5.</p> <p>If keyword is not specified, the default value is 5.</p>	Level	RGU	Anoxia	Soil-Stress	1	no	no	no	2	no	yes	yes	3	yes	no	no	4	yes	no	yes	5	yes	yes	yes
Level	RGU	Anoxia	Soil-Stress																							
1	no	no	no																							
2	no	yes	yes																							
3	yes	no	no																							
4	yes	no	yes																							
5	yes	yes	yes																							

**Figure 6.79.** LAND\_USE block advanced keywords. All are optional and provide additional land-use properties or alter the behavior or the landscape simulation. Secondary keywords enclosed in curly braces, {}, indicate that only one of the keywords may be selected and used during a simulation. LAI input enclosed in curly braces, {}, indicate that it is optional. [FLOAT, floating-point number; INT, integer number; [L] is length in model units; [L/T], length per time in model units; [L<sup>3</sup>/T], volumetric rate in model units; FMP, farm process; WBS, water-balance subregion; NWBS, maximum number of water-balance subregions; LAI, list-array input with the following letters representing the supported keywords: S for STATIC, T for TRANSIENT, A for ARRAY, and L for LIST]

B

Keyword	Input	Description
<b>ADDED_DEMAND</b>	<p>{ <b>FLUX</b>, <b>RATE</b> }</p> <p>LAI [S, T, A, L-<b>NWBS</b>]</p>	<p><b>FLOAT</b> input that defines additional irrigation demand for a crop, specified by each WBS.</p> <p>This is identical to the <b>WATER_BALANCE_SUBREGION</b> block keyword, <b>ADDED_CROP_DEMAND</b>, except here it is specified with <b>NCROP</b> records or <i>Array-Style</i>.</p> <p><b>FLUX</b> indicates that input is specified as [L/T] and multiplied by the crop area to get [L<sup>3</sup>/T].</p> <p><b>RATE</b> indicates that input is specified as [L<sup>3</sup>/T].</p>
<b>POND_DEPTH</b>	LAI [S, T, L]	<p><b>FLOAT</b> input that defines a depth of water above land surface [L] that a crop can tolerate before death occurs (no transpiration).</p> <p>This only applies to <i>linear root response</i> concept crops. That is, <b>ROOT_PRESSURE</b> is not specified or all four <b>ROOT_PRESSURE</b>'s set to zero.</p> <p>If not specified, the ponding depth tolerance is zero.</p>
<b>MIN_BARE_FRACTION</b>	<b>FLOAT</b>	<p><b>FLOAT</b> input that specifies a minimum required fraction of cell area to simulate bare soil. This only pertains to model cells that are not defined with a land use (Crop).</p> <p>For example, if a model cell has two crops that fractionally compose 0.66 and 0.33 of the model-cell area, then the bare-soil area is 0.01 of model-cell area. If the minimum fraction of area is set to 0.02, then FMP ignores the bare-soil portion of this example model cell.</p> <p>If keyword is not specified, then the default minimum fraction is 1E-12.</p>

Figure 6.79. —Continued



c

Keyword	<b>ZERO_CONSUMPTIVE_USE_BECOMES_BARE_SOIL</b> { LAI[S, T, L] }
Description	<p>Keyword indicates that when a land use has a consumptive use equal to zero, then it should be treated as bare-soil area. This only allows for evaporation with a potential rate equal to half of reference evapotranspiration or the potential evaporation rate.</p> <p>If LAI[S, T, L] is specified, then <i>List Style</i> input reads <b>NCROP</b> INT flags to indicate which crops use this option. The flag must be set to:</p> <p style="padding-left: 40px;">0 to not use option for crop. 1 to use the option for crop.</p> <p>If keyword is not specified, then when the consumptive use is set to zero there is no evaporation nor transpiration possible because the potential is zero.</p>
Keyword	<b>EVAPORATION_IRRIGATION_FRACTION_SUM_ONE_CORRECTION</b> { LAI[S, T, L] }
Description	<p>Keyword indicates that when the sum of <b>TRANSPIRATION_FRACTION</b> (FTR) with <b>EVAPORATION_IRRIGATION_FRACTION</b> (FEI) is greater than 1, then FEI should be reduced to make the sum equal 1.</p> <p>That is, if <math>FTR + FEI &gt; 1</math>, then <math>FEI = 1 - FTR</math></p> <p>If <math>FTR + FEI &gt; 1</math>, then actual consumptive use can be larger than the specified potential consumptive use due to irrigation evaporation.</p> <p>If LAI[S, T, L] is specified, then the <i>List Style</i> reads <b>NCROP</b> INT flags to indicate which crops use this option. The flag must be set to:</p> <p style="padding-left: 40px;">0 to not use option for crop. 1 to use the option for crop.</p> <p>If keyword is not specified, then input allows for <math>FTR + FEI &gt; 1</math>.</p>

Figure 6.79. —Continued

By default, if a crop's sum of **TRANSPIRATION\_FRACTION** (FTR) with **EVAPORATION\_IRRIGATION\_FRACTION** (FEI) is greater than 1, no correction is made. The FMP assumes the user intends to simulate over-evaporation from FEI because of irrigation evaporating before reaching the crop or evaporation from the surface of the leaves. If it is desired to never allow the sum to be greater than 1, the keyword **EVAPORATION\_IRRIGATION\_FRACTION\_SUM\_ONE\_CORRECTION** indicates that a check should be made. With this keyword, if  $FTR + FEI > 1$ , then FEI is reduced so that  $FTR + FEI = 1$ . The keyword **EVAPORATION\_IRRIGATION\_FRACTION\_SUM\_ONE\_CORRECTION** may optionally be followed by a *List Style* input that reads **NCROP** records that are either a 1, to indicate the crop is to be checked for the correction, or 0 to indicate the crop does not need to be checked.

Land-Use Category or Crop Type	PSI 1 [m]	PSI 2 [m]	PSI 3 [m]	PSI 4 [m]
Alfalfa	-0.15	-0.30	-5.45	-80.0
Apples	-0.13	-0.27	-6.94	-115.0
Apricots	-0.15	-0.30	-5.45	-80.0
Artichokes	-0.15	-0.30	-5.45	-80.0
Barley	-0.15	-0.30	-5.45	-80.0
Berries	-0.15	-0.30	-5.45	-80.0
Broccoli	-0.15	-0.30	-5.45	-80.0
Carrots	-0.13	-0.28	-11.40	-80.0
Cauliflower	-0.13	-0.28	-11.40	-80.0
Cherries	-0.13	-0.28	-11.40	-80.0
Citrus and subtropical	-0.15	-0.30	-6.00	-80.0
Cotton	0.07	0.00	-27.83	-153.3
Deciduous forest	0.13	0.00	-5.45	-80.0
Deciduous fruits and nuts	-0.13	-0.27	-6.94	-115.0
Dry beans	-0.13	-0.27	-6.94	-11.0
Durum wheat	-0.15	-0.30	-5.45	-80.0
Evergreen forest	-0.15	-0.30	-5.45	-80.0
Fallow or idle cropland	-0.15	-0.30	-5.45	-80.0
Field crops	-0.15	-0.30	-30.00	-123.7
Grapes-wine	-0.15	-0.30	-7.25	-80.0
Grassland herbaceous	-0.15	-0.30	-5.45	-80.0
Hay-general	-0.15	-0.30	-30.00	-123.7
Irrigated row and field crops	-0.13	-0.28	-11.40	-80.0
Mixed forest	-0.15	-0.30	-5.45	-80.0
Nectarines	-0.13	-0.27	-11.40	-80.0
Nurseries	-0.15	-0.30	-5.45	-80.0
Oats	-0.15	-0.30	-5.45	-80.0
Olives	0.15	0.10	-0.30	-0.4
Onions	-0.15	-0.30	-7.25	-80.0
Open water	0.50	0.10	-0.30	-0.4
Pasture-grass	-0.15	-0.30	-52.10	-160.1
Peaches	-0.15	-0.30	-5.45	-80.0
Phreatophytes	0.50	0.13	-8.25	-115
Pistachios	-0.15	-0.30	-52.10	-160.1
Potatoes	-0.15	-0.30	-6.00	-80.0
Rice	0.50	0.13	-1.78	-160
Shrubland	-0.15	-0.30	-5.45	-80.0
Strawberries	-0.15	-0.30	-5.45	-80.0
Walnuts	-0.15	-0.30	-5.45	-80.0

**Figure 6.80.** Example values of ROOT\_PRESSURE for different land use and crop types. [The ROOT\_PRESSUREs are in meters [m] of hydraulic head. PSI 1, 2, 3, and 4 represent the upper limit pressure head at which the root uptake becomes zero because of anoxia, then two pressure heads that represent the range of optimal root uptake, and then a lower limit pressure head that results in wilting (zero root uptake), respectively. These values are best viewed as an initial estimate when there is no other information available.]

Level	Root Groundwater Uptake	Anoxia Reduction	Soil-Stress Reduction
0	—	—	—
1	No	No	No
2	No	Yes	Yes
3	Yes	No	No
4	Yes	No	Yes
5	Yes	Yes	Yes

**Figure 6.81.** GROUNDWATER\_ROOT\_INTERACTION supported options. The List Style input must set the option for each crop to one of the defined Levels. [Root Groundwater Uptake indicates that the farm process (FMP) will evaluate if the water table is close enough to the crop that its roots can take up water directly from groundwater. Anoxia Reduction indicates that the FMP will evaluate if the crop's potential consumptive use is reduced as a result of anoxia conditions. Soil-Stress Reduction indicates that the FMP will evaluate if the crop's potential consumptive use is reduced as a result of non-ideal soil-moisture conditions. Abbreviation: —, no input values apply]

## Output Keywords

The **LAND\_USE** block additionally has a set of optional, output keywords that provide detailed information of the CU, CU reduction, irrigation, infiltration, and runoff associated with each land use (fig. 6.82). The difference among the output options is how the output data are sampled—for example, it can be presented by WBS, by land-use type, or by each land-use type in each WBS. To initiate the output options, write in the **LAND\_USE** block the keyword **PRINT** followed by the output type and then the output file, specified with *Generic\_Output\_OptKey*. The available output types are specified by the option keywords **ByWBS**, **ByWBS\_ByCROP**, **ByCROP**, **BARE**, **ALL**, **ALL\_VERBOSE**, and **INPUT**. The keyword **PRINT INPUT** provides an echo of the input for checking if there are input file errors. The keywords **PRINT ByWBS**, **PRINT ByWBS\_ByCROP**, and **PRINT ByCROP** provide the same output, but will aggregate it to be by WBS, by CROP or all crops in a WBS. It is recommended for all FMP simulations to include the **PRINT ByWBS\_ByCROP** keyword to evaluate each land-use's consumption by WBS.

The keywords **PRINT ALL** and **PRINT ALL\_VERBOSE** provide cell-by-cell output for all crops. The difference between the **ALL** and **ALL\_VERBOSE** is the amount of output. The **ALL\_VERBOSE** option provides output for almost every crop property from its raw input to its simulated results. This can be advantageous for finding errors in the simulation, but caution is advised because the file size can be enormous. To prevent the **PRINT ALL** and **PRINT ALL\_VERBOSE** output files from becoming too large, the keyword **SPECIFY\_PRINT\_ALL\_CROPS** LAI[S, T, L] allows for specifying which crops should be printed. **SPECIFY\_PRINT\_ALL\_CROPS** input is *List Style* that consists of **NCROP** records that specify a 1 if the crop is to be included in the output or 0 if it is not. This allows the **PRINT ALL** and **PRINT ALL\_VERBOSE** output files to only include cell-by-cell output for cells that contain specific crops.

### PRINT ByWBS\_ByCROP Header

The keyword **PRINT ByWBS\_ByCrop** writes to the *Generic\_Output\_OptKey* file the summarized crops' simulated results for each WBS for every time. If a WBS had bare-soil calculations, then those are included with a Crop ID set to 0 and crop name of BARE\_LAND. The keyword **PRINT ByWBS** has the same headers, except it does not include the CROP header because it aggregates all crops and bare soil together by WBS. The keyword **PRINT ByCrop** has the same headers, except it does not include the WBS header because it aggregates information across all WBS for each crop. The output for **PRINT ByWBS\_ByCrop** may be in text or binary format and has the header defined in figure 6.83.

Keyword Input	Description
<b>PRINT ByWBS_ByCROP</b>	Summarize crop output information by WBS and by crop. Each crop within the WBS is summarized separately. Bare-soil evaporation by WBS also is included in the output (Recommended output option).
<b>PRINT ByWBS</b>	Summarize crop output information by the WBS. All crops in the WBS are summed to report a total quantity. Bare-soil evaporation by WBS also is included in the output.
<b>PRINT ByCROP</b>	Summarize crop output information by crop type across the entire simulation domain.
<b>PRINT BARE</b>	Summarize bare-soil calculation and simulation output for cells that contain bare soil. Output only includes model cells that had bare-soil calculations.
<b>PRINT ALL</b>	Write simulated results for each crop for every model cell that contains the crop.
<b>PRINT ALL_VERBOSE</b>	Write input and simulated results for each crop for every model cell that contains the crop.
<b>PRINT INPUT</b>	Write the land-use block input that is loaded.
<b>SPECIFY_PRINT_ALL_CROPS</b> LAI[S, T, L]	Does not specify an output file, but instead defines which crops should be included in output written for the keywords <b>PRINT ALL</b> and <b>PRINT ALL_VERBOSE</b> . <i>List Style</i> input; FMP reads <b>NCROP</b> records that have a 1, if the crop is to be included, or 0 if it is not. This helps prevent the PRINT ALL files from becoming too large.

**Figure 6.82.** LAND\_USE block optional output keywords. [All the PRINT keywords should be followed by a GENERIC\_OUTPUT\_OptKey, which is the file that the output is written to. The only keyword not associated with an output file is SPECIFY\_PRINT\_ALL\_CROPS, which specifies what crops should be included as part of the PRINT ALL and ALL\_VERBOSE options. Abbreviation: WBS, water-balance subregion; LAI, list-array input with the following letters representing the supported keywords: S for STATIC, T for TRANSIENT, and L for LIST]

A

PER	is the stress period number	
STP	is the time step number	
WBS	is the Water Balance Subregion (Farm) ID number	
CROP	is the Land-use (Crop) ID number	
CROP_NAME	is the name of the specific crop	
AREA	is the area of land the crop occupies for the specified WBS	[L <sup>2</sup> ]
IRRIGATED_AREA	is the area of land the crop occupies that is irrigated for the specified WBS	[L <sup>2</sup> ]
EFFICIENCY	is the calculated irrigation efficiency (OFE), which is the consumptive irrigation requirement / irrigation water demand.	
CU_INI	is the initial-potential consumptive use of crop, which is the user-specified input CU plus $K_c \cdot ET_{ref}$	[L <sup>3</sup> /T]
CU	is the actual crop consumptive use based on water supply	[L <sup>3</sup> /T]
CIR_INI	is the crop irrigation requirement to meet CU_INI, assuming no irrigation losses	[L <sup>3</sup> /T]
CIR	is the crop irrigation requirement, assuming no irrigation losses, to meet CU_INI after it has been reduced by anoxia and soil-stresses	[L <sup>3</sup> /T]
DEMAND_INI	is the irrigation demand to meet CIR_INI considering irrigation losses	[L <sup>3</sup> /T]
DEMAND	is the irrigation demand, and actual water supplied, necessary to satisfy CIR (includes irrigation losses).	[L <sup>3</sup> /T]
ADDED_DEMAND_INI	is the initial additional irrigation demand specified for the crop	[L <sup>3</sup> /T]
ADDED_DEMAND	is the final additional irrigation demand that was satisfied with supply	[L <sup>3</sup> /T]
TOT_DEEP_PERC	is the total loss of water to deep percolation (groundwater recharge)	[L <sup>3</sup> /T]
TOT_SURF_RUNOFF	is the total loss of water to surface runoff	[L <sup>3</sup> /T]
ADDED_DMD_DPERC	is the amount of ADDED_DEMAND irrigation that is lost as deep percolation	[L <sup>3</sup> /T]
ADDED_DMD_RUNOFF	is the amount of ADDED_DEMAND irrigation that is lost as surface runoff	[L <sup>3</sup> /T]
TRAN_POT	is the potential transpiration from the cropped area for the given CU_INI	[L <sup>3</sup> /T]
ANOXIA_LOSS	is the reduction in TRAN_POT due to plant anoxia (high groundwater level)	[L <sup>3</sup> /T]
SOIL_STRESS_LOSS	is the reduction in TRAN_POT due to non-idealized soil stress	[L <sup>3</sup> /T]
TRAN	is the actual crop transpiration (TRAN_IRR + TRAN_PRECIP + TRAN_GW)	[L <sup>3</sup> /T]
TRAN_SURF_INI	is the initial-potential transpiration from precipitation and irrigation water	[L <sup>3</sup> /T]
TRAN_SURF	is actual transpiration from precipitation and irrigation water	[L <sup>3</sup> /T]
TRAN_IRR	is the portion of transpiration (TRAN) from irrigation water supply	[L <sup>3</sup> /T]
TRAN_PRECIP	is the portion of transpiration (TRAN) from precipitation	[L <sup>3</sup> /T]
TRAN_GW	is the portion of transpiration (TRAN) from groundwater	[L <sup>3</sup> /T]
EVAP_IRR	is the evaporation of water that originated from irrigation water supply	[L <sup>3</sup> /T]
EVAP_PRECIP	is the evaporation of water that originated from precipitation	[L <sup>3</sup> /T]
EVAP_GW	is the evaporation of water that originated from groundwater	[L <sup>3</sup> /T]
PRECIPITATION	is the total precipitation	[L <sup>3</sup> /T]
DELT	is the time step length	[T]
DYEAR	is the date at the end of the time step as a decimal year	
DATE_START	is the calendar date at the start of the time step (yyyy-mm-ddThh:mm:ss)	

**Figure 6.83.** Land\_Use block keyword PRINT ByWBS\_ByCrop text file header explanation and binary record structure. *A*, Text-header explanation. *B*, Binary-record structure. [T], unit of time in model units; [L<sup>3</sup>/T], volumetric rate in model units; CHARACTER(20) indicates record is 20 characters long (20 bytes); CHARACTER(19) indicates record is 19 characters long (19 bytes); INTEGER is a 4-byte integer record; DOUBLE is a 8-byte floating-point number record.]

**B**

DATE_START	CHARACTER(19), starting date formatted as 'yyyy-mm-ddThh:mm:ss'
DYEAR	DOUBLE
DELT	DOUBLE
PER	INTEGER
STP	INTEGER
WBS	INTEGER
CROP	INTEGER
CROP_NAME	CHARACTER(20)
AREA	DOUBLE
IRRIGATED_AREA	DOUBLE
EFFICIENCY	DOUBLE
CU_INI	DOUBLE
CU	DOUBLE
CIR_INI	DOUBLE
CIR	DOUBLE
DEMAND_INI	DOUBLE
DEMAND	DOUBLE
ADDED_DEMAND_INI	DOUBLE
ADDED_DEMAND	DOUBLE
TOT_DEEP_PERC	DOUBLE
TOT_SURF_RUNOFF	DOUBLE
ADDED_DMD_DPERC	DOUBLE
ADDED_DMD_RUNOFF	DOUBLE
TRAN_POT	DOUBLE
ANOXIA_LOSS	DOUBLE
SOIL_STRESS_LOSS	DOUBLE
TRAN	DOUBLE
TRAN_SURF_INI	DOUBLE
TRAN_SURF	DOUBLE
TRAN_IRR	DOUBLE
TRAN_PRECIP	DOUBLE
TRAN_GW	DOUBLE
EVAP_IRR	DOUBLE
EVAP_PRECIP	DOUBLE
EVAP_GW	DOUBLE
PRECIPITATION	DOUBLE

**Figure 6.83.** —Continued**PRINT ALL Header**

The keyword **PRINT ALL** writes to the *Generic\_Output\_OptKey* file the crop and bare-soil information for every model cell. Bare soil is identified with a crop ID of 0 and crop name of BARE LAND. The output for **PRINT ALL** may be in text or binary format. The output may be text or binary format and has the header defined in figure 6.84.

A

PER	is the stress period number	
STP	is the time step number	
CROP	is the Land-use (Crop) ID number	
CROP_NAME	is the name of the specific crop	
WBS	is the Water Balance Subregion (Farm) ID number	
ROW	is the model row number	
COL	is the model column number	
AREA	is the area of land the crop occupies for the specified WBS	[L <sup>2</sup> ]
EFFICIENCY	is the irrigation efficiency (OFE)	
CU_INI	is the initial-potential consumptive use of crop, which is the user-specified input CU plus $K_c \cdot ET_{ref}$	[L <sup>3</sup> /T]
CU	is the actual crop consumptive use based on water supply	[L <sup>3</sup> /T]
CIR_INI	is the crop irrigation requirement to meet CU_INI, assuming no irrigation losses	[L <sup>3</sup> /T]
CIR	is the crop irrigation requirement, assuming no irrigation losses, to meet CU_INI after it has been reduced by anoxia and soil-stresses	[L <sup>3</sup> /T]
DEMAND_INI	is the irrigation demand to meet CIR_INI considering irrigation losses	[L <sup>3</sup> /T]
DEMAND	is the irrigation demand necessary to satisfy CIR (includes irrigation losses).	[L <sup>3</sup> /T]
ADDED_DEMAND_INI	is the initial additional irrigation demand specified for the crop	[L <sup>3</sup> /T]
ADDED_DEMAND	is the final additional irrigation demand that was satisfied with supply	[L <sup>3</sup> /T]
TOT_DEEP_PERC	is the total loss of water to deep percolation (groundwater recharge)	[L <sup>3</sup> /T]
TOT_SURF_RUNOFF	is the total loss of water to surface runoff	[L <sup>3</sup> /T]
ADDED_DMD_DPERC	is the amount of ADDED_DEMAND irrigation that is lost as deep percolation	[L <sup>3</sup> /T]
ADDED_DMD_RUNOFF	is the amount of ADDED_DEMAND irrigation that is lost as surface runoff	[L <sup>3</sup> /T]
TRAN_POT	is the potential transpiration from the cropped area for the given CU_INI	[L <sup>3</sup> /T]
ANOXIA_LOSS	is the reduction in TRAN_POT due to plant anoxia (high groundwater level)	[L <sup>3</sup> /T]
SOIL_STRESS_LOSS	is the reduction in TRAN_POT due to non-idealized soil stress	[L <sup>3</sup> /T]
TRAN	is the actual crop transpiration (TRAN_IRR + TRAN_PRECIP + TRAN_GW)	[L <sup>3</sup> /T]
TRAN_SURF_INI	is the initial-potential transpiration from precipitation and irrigation water	[L <sup>3</sup> /T]
TRAN_SURF	is actual transpiration from precipitation and irrigation water	[L <sup>3</sup> /T]
TRAN_IRR	is the portion of transpiration (TRAN) from irrigation water supply	[L <sup>3</sup> /T]
TRAN_PRECIP	is the portion of transpiration (TRAN) from precipitation	[L <sup>3</sup> /T]
TRAN_GW	is the portion of transpiration (TRAN) from groundwater	[L <sup>3</sup> /T]
EVAP_IRR	is the evaporation of water that originated from irrigation water supply	[L <sup>3</sup> /T]
EVAP_PRECIP	is the evaporation of water that originated from precipitation	[L <sup>3</sup> /T]
EVAP_GW	is the evaporation of water that originated from groundwater	[L <sup>3</sup> /T]
PRECIPITATION	is the total precipitation	[L <sup>3</sup> /T]
GW_HEAD	is the groundwater elevation (head) beneath the crop	[L]
GSE	is the ground surface elevation	[L]
ROOT_ELEV	is the lowest elevation of the crop's root zone	[L]
LOW_EXTINC_ELEV	is the lowest elevation for root-groundwater uptake (ROOT_ELEV – capillary fringe)	[L]
DELT	is the time step length	[T]
DYEAR	is the date at the end of the time step as a decimal year	
DATE_START	is the calendar date at the start of the time step (yyyy-mm-ddThh:mm:ss)	

**Figure 6.84.** Land\_Use block keyword PRINT ALL text file header explanation and binary record structure. *A*, Text-header explanation. *B*, Binary-record structure. [[T], unit of time in model units; [L<sup>3</sup>/T], volumetric rate in model units; CHARACTER(20) indicates record is 20 characters long (20 bytes); CHARACTER(19) indicates record is 19 characters long (19 bytes); INTEGER is a 4-byte integer record; DOUBLE is a 8-byte floating-point number record.]

**B**

DATE_START	CHARACTER(19), starting date formatted as 'yyyy-mm-ddThh:mm:ss'
DYEAR	DOUBLE
DELT	DOUBLE
PER	INTEGER
STP	INTEGER
CROP	INTEGER
CROP_NAME	CHARACTER(20)
WBS	INTEGER
ROW	INTEGER
COL	INTEGER
AREA	DOUBLE
EFFICIENCY	DOUBLE
CU_INI	DOUBLE
CU	DOUBLE
CIR_INI	DOUBLE
CIR	DOUBLE
DEMAND_INI	DOUBLE
DEMAND	DOUBLE
ADDED_DEMAND_INI	DOUBLE
ADDED_DEMAND	DOUBLE
TOT_DEEP_PERC	DOUBLE
TOT_SURF_RUNOFF	DOUBLE
ADDED_DMD_DPERC	DOUBLE
ADDED_DMD_RUNOFF	DOUBLE
TRAN_POT	DOUBLE
ANOXIA_LOSS	DOUBLE
SOIL_STRESS_LOSS	DOUBLE
TRAN	DOUBLE
TRAN_SURF_INI	DOUBLE
TRAN_SURF	DOUBLE
TRAN_IRR	DOUBLE
TRAN_PRECIP	DOUBLE
TRAN_GW	DOUBLE
EVAP_IRR	DOUBLE
EVAP_PRECIP	DOUBLE
EVAP_GW	DOUBLE
PRECIPITATION	DOUBLE
GW_HEAD	DOUBLE
GSE	DOUBLE
ROOT_ELEV	DOUBLE
LOW_EXTINC_ELEV	DOUBLE

**Figure 6.84.** —Continued



## PRINT ALL\_VERBOSE Header

The keyword **PRINT ALL\_VERBOSE** writes to the *Generic\_Output\_OptKey* file the crop and bare-soil information for every model cell—including crop input features. Bare soil is identified with a crop ID of 0 and crop name of BARE\_LAND. The output for **PRINT ALL\_VERBOSE** may be in text or binary format. The output may be text or binary format and has the header defined in figure 6.85.

A

PER	is the stress period number	
STP	is the time step number	
CROP	is the Land-use (Crop) ID number	
CROP_NAME	is the name of the specific crop	
WBS	is the Water Balance Subregion (Farm) ID number	
ROW	is the model row number	
COL	is the model column number	
LAY	is the upper most active model layer	
GW_INT	is root groundwater interaction level (0 – 5)	
IRR	is the irrigation flag and type	
AREA	is the area of land the crop occupies for the specified WBS	[L <sup>2</sup> ]
EFFICIENCY	is the irrigation efficiency (OFE)	
FRAC_TRAN	is the TRANSPIRATION_FRACTION (FTR)	
FRAC_EVAP_IRR	is the EVAPORATION_IRRIGATION_FRACTION (FEI)	
FRAC_SW_LOSS_PRE	is the SURFACEWATER_LOSS_FRACTION_PRECIPITATION	
FRAC_SW_LOSS_IRR	is the SURFACEWATER_LOSS_FRACTION_IRRIGATION	
CU_INI	is the initial-potential consumptive use of crop, which is the user-specified input CU plus $K_c \cdot ET_{ref}$	[L <sup>3</sup> /T]
CU	is the actual crop consumptive use based on water supply	[L <sup>3</sup> /T]
CIR_INI	is the crop irrigation requirement to meet CU_INI, assuming no irrigation losses	[L <sup>3</sup> /T]
CIR	is the crop irrigation requirement, assuming no irrigation losses, to meet CU_INI after it has been reduced by anoxia and soil-stresses	[L <sup>3</sup> /T]
DEMAND_INI	is the irrigation demand to meet CIR_INI considering irrigation losses	[L <sup>3</sup> /T]
DEMAND	is the irrigation demand necessary to satisfy CIR (includes irrigation losses).	[L <sup>3</sup> /T]
ADDED_DEMAND_INI	is the initial additional irrigation demand specified for the crop	[L <sup>3</sup> /T]
ADDED_DEMAND	is the final additional irrigation demand that was satisfied with supply	[L <sup>3</sup> /T]
TOT_DEEP_PERC	is the total loss of water to deep percolation (groundwater recharge)	[L <sup>3</sup> /T]
TOT_SURF_RUNOFF	is the total loss of water to surface runoff	[L <sup>3</sup> /T]
ADDED_DMD_DPERC	is the amount of ADDED_DEMAND irrigation that is lost as deep percolation	[L <sup>3</sup> /T]
ADDED_DMD_RUNOFF	is the amount of ADDED_DEMAND irrigation that is lost as surface runoff	[L <sup>3</sup> /T]
TRAN_POT	is the potential transpiration from the cropped area for the given CU_INI	[L <sup>3</sup> /T]
ANOXIA_LOSS	is the reduction in TRAN_POT due to plant anoxia (high groundwater level)	[L <sup>3</sup> /T]
SOIL_STRESS_LOSS	is the reduction in TRAN_POT due to non-idealized soil stress	[L <sup>3</sup> /T]
	:	

**Figure 6.85.** Land\_Use block keyword PRINT ALL\_VERBOSE text file header explanation and binary record structure. A, Text-header explanation. B, Binary-record structure. [T], unit of time in model units; [L<sup>3</sup>/T], volumetric rate in model units; CHARACTER(20) indicates record is 20 characters long (20 bytes); CHARACTER(19) indicates record is 19 characters long (19 bytes); INTEGER is a 4-byte integer record; DOUBLE is a 8-byte floating-point number record.]

*A (continued)*

	:	
TRAN	is the actual crop transpiration (TRAN_IRR + TRAN_PRECIP + TRAN_GW)	[L <sup>3</sup> /T]
TRAN_SURF_INI	is the initial-potential transpiration from precipitation and irrigation water	[L <sup>3</sup> /T]
TRAN_SURF	is actual transpiration from precipitation and irrigation water	[L <sup>3</sup> /T]
TRAN_IRR	is the portion of transpiration (TRAN) from irrigation water supply	[L <sup>3</sup> /T]
TRAN_PRECIP	is the portion of transpiration (TRAN) from precipitation	[L <sup>3</sup> /T]
TRAN_GW	is the portion of transpiration (TRAN) from groundwater	[L <sup>3</sup> /T]
EVAP_IRR	is the evaporation of water that originated from irrigation water supply	[L <sup>3</sup> /T]
EVAP_PRECIP	is the evaporation of water that originated from precipitation	[L <sup>3</sup> /T]
EVAP_GW	is the evaporation of water that originated from groundwater	[L <sup>3</sup> /T]
PRECIPITATION	is the total precipitation	
GW_HEAD	is the groundwater elevation (head) beneath the crop	[L]
POND_DEPTH_TOL	is the the total depth of ponded water that crop can tolerate	[L]
PSI_1	is the root pressure that crop dies from anoxia occurs	[L]
PSI_2	is the upper bounding root pressure that is the optimal for groundwater-root	[L]
PSI_3	is the lower bounding root pressure that is the optimal for groundwater-root	[L]
PSI_4	is the wilting-root pressure	[L]
GSE	is the ground surface elevation	[L]
UP_EXTINC_ELEV	is the lowest groundwater elevation where crop death occurs as a result of anoxia	[L]
MID_EXTINC_ELEV	is the groundwater elevation where optimal uptake transitions to anoxia	[L]
ROOT_ELEV	is the lowest elevation of the crop's root zone	[L]
LOW_EXTINC_ELEV	is the lowest elevation for root-groundwater uptake (ROOT_ELEV – capillary fringe)	[L]
DELT	is the time step length	[T]
DYEAR	is the date at the end of the time step as a decimal year	
DATE_START	is the calendar date at the start of the time step (yyyy-mm-ddThh:mm:ss)	

**Figure 6.85.** —Continued

**B**

DATE_START	CHARACTER(19), starting date formatted as 'yyyy-mm-ddThh:mm:ss'	:	
DYEAR	DOUBLE	TRAN	DOUBLE
DELT	DOUBLE	TRAN_SURF_INI	DOUBLE
PER	INTEGER	TRAN_SURF	DOUBLE
STP	INTEGER	TRAN_IRR	DOUBLE
CROP	INTEGER	TRAN_PRECIP	DOUBLE
CROP_NAME	CHARACTER(20)	TRAN_GW	DOUBLE
WBS	INTEGER	EVAP_IRR	DOUBLE
ROW	INTEGER	EVAP_PRECIP	DOUBLE
COL	INTEGER	EVAP_GW	DOUBLE
LAY	INTEGER	PRECIPITATION	DOUBLE
GW_INT	INTEGER	GW_HEAD	DOUBLE
IRR	INTEGER	POND_DEPTH_TO	DOUBLE
AREA	DOUBLE	PSI_1	DOUBLE
EFFICIENCY	DOUBLE	PSI_2	DOUBLE
FRAC_TRAN	DOUBLE	PSI_3	DOUBLE
FRAC_EVAP_IRR	DOUBLE	PSI_4	DOUBLE
FRAC_SW_LOSS_PRE	DOUBLE	GSE	DOUBLE
FRAC_SW_LOSS_IRR	DOUBLE	UP_EXTINC_ELEV	DOUBLE
CU_INI	DOUBLE	MID_EXTINC_ELEV	DOUBLE
CU	DOUBLE	ROOT_ELEV	DOUBLE
CIR_INI	DOUBLE	LOW_EXTINC_ELEV	DOUBLE
CIR	DOUBLE		
DEMAND_INI	DOUBLE		
DEMAND	DOUBLE		
ADDED_DEMAND_INI	DOUBLE		
ADDED_DEMAND	DOUBLE		
TOT_DEEP_PERC	DOUBLE		
TOT_SURF_RUNOFF	DOUBLE		
ADDED_DMD_DPERC	DOUBLE		
ADDED_DMD_RUNOFF	DOUBLE		
TRAN_POT	DOUBLE		
ANOXIA_LOSS	DOUBLE		
SOIL_STRESS_LOSS	DOUBLE		
:			

**Figure 6.85.** —Continued

Supported **SFAC DIMKEY**

In figure 6.86, an X signifies by keyword each **SFAC DIMKEY** that is supported. Keywords not specified in the table do not support the **SFAC DIMKEY**s.

Keyword	<b>DIMKEY</b>		
	ByWBS	ByCrop	ByIrrigate
LAND_USE_AREA_FRACTION	X	X	
CONSUMPTIVE_USE	X	X	X
CROP_COEFFICIENT	X	X	X
TRANSPIRATION_FRACTION	X	X	X
EVAPORATION_IRRIGATION_FRACTION	X	X	X
SURFACEWATER_LOSS_FRACTION_PRECIPITATION	X	X	
SURFACEWATER_LOSS_FRACTION_IRRIGATION	X	X	X
ROOT_DEPTH	X	X	X
ROOT_PRESSURE		X	
POND_DEPTH	X	X	X
ADDED_DEMAND	X	X	X

**Figure 6.86.** LAND\_USE block keywords that support **SFAC DIMKEY**. The supported words that can be used for **DIMKEY** are ByWBS, ByCrop, and ByIrrigate. [Supported keyword and **DIMKEY** combinations are marked with an X.]

## IXJ Style Input Support

At the time of this report's publication, 10 of the keywords in the **LAND\_USE** block allow for the use of the *IXJ Style* input that serves as an alternative input to the *Array Style* input. If the *IXJ Style* input is used, then the FMP expects to load records containing three integers (I) and one floating-point number (X) and does not read any subsequent integers (J). The three integers are the Crop ID, the model row, and model column. The floating-point number is the keyword property (Prop). For example, for the **LAND\_USE\_AREA\_FRACTION**, the keyword property is the crop's fraction of cell area. The exception to the expected input records being as described applies to the **LOCATION** keyword, where the property is the crop's location in the model grid; it does not include a Prop because the property is fully defined by crop ID, model row, and column. The use of *IXJ Style* input is advantageous when the model input has included the **MULTIPLE\_LAND\_USE\_PER\_CELL** keyword and it is necessary to define an input using *Array Style*. This is because IXJ can replicate the *Array Style* input in a more compact manner that avoids an NCROP×NROW by NCOL array input. It is recommended to use *List Style* input whenever possible as the main input option. Figure 6.87 provides a list of the keywords that support *IXJ Style* input and their expected input.

## Keyword List

Figure 6.88 presents the **LAND\_USE** block with keywords that are relevant to most simulations; the basic definition of each keyword is included as comments.

Keywords that support IXJ Input Style	Expected Input
<b>LOCATION</b>	Crop Row Column
<b>LAND_USE_AREA_FRACTION</b>	Crop Row Column Prop
<b>CONSUMPTIVE_USE</b>	Crop Row Column Prop
<b>CROP_COEFFICIENT</b>	Crop Row Column Prop
<b>TRANSPIRATION_FRACTION</b>	Crop Row Column Prop
<b>EVAPORATION_IRRIGATION_FRACTION</b>	Crop Row Column Prop
<b>SURFACEWATER_LOSS_FRACTION_PRECIPITATION</b>	Crop Row Column Prop
<b>SURFACEWATER_LOSS_FRACTION_IRRIGATION</b>	Crop Row Column Prop
<b>ROOT_DEPTH</b>	Crop Row Column Prop
<b>ADDED_DEMAND</b>	Crop Row Column Prop

**Figure 6.87.** LAND\_USE block keywords that support IXJ input as a surrogate for Array Style input. Expected Input uses the structure expected by IXJ. [Crop is the crop ID; Row is the model row; Column is the model column; and Prop is the associated property defined by the keyword.]

```

BEGIN LAND_USE
# A simulation must include one of the two following keywords
SINGLE_LAND_USE_PER_CELL      # Crop location defined by LOCATION
MULTIPLE_LAND_USE_PER_CELL   # Crop location defined by LAND_USE_AREA_FRACTION
#
# Define the spatial location of each crop and fraction of cell area it occupies.
LOCATION                       LAI[S, T, A] # Do not specify MULTIPLE_LAND_USE_PER_CELL
LAND_USE_AREA_FRACTION LAI[S, T, A] # Optional if SINGLE_LAND_USE_PER_CELL
#
PRINT ByWBS_ByCROP   Generic_Output_OptKey # Recommended output option.
#
# At least one of the following two keywords should be defined
CONSUMPTIVE_USE LAI[S, T, A, L] # Specify crop consumptive use directly [L/T]
CROP_COEFFICIENT LAI[S, T, A, L] # Specify crop consumptive use as a crop coefficient
#
ROOT_DEPTH LAI[S, T, A, L] # Define the root depth of crop [L].
#
# Define which crops receive irrigation. If 0, then crop is not irrigated.
# If greater than zero, then the integer indicates the irrigation type used for the crop.
# If NIRRIATE = 0, then keyword is not required.
IRRIGATION LAI[S, T, A, L]
#
TRANSPARATION_FRACTION LAI[S, T, A, L] # Define the fraction of transpiration (Kcb/Kc).
#
# Define the fraction of cropped area that is irrigated but exposed to sunlight and evaporates.
# This fraction can be specified with NCROP records (BY_CROP) or NIRRIATE records (BY_IRRIGATION).
# If NIRRIATE = 0, then keyword is not required.
# Only one of the following two keywords may be in use during a simulation.
EVAPORATION_IRRIGATION_FRACTION BY_CROP LAI[S, T, A, L]
EVAPORATION_IRRIGATION_FRACTION BY_IRRIGATION LAI[S, T, A, L]
#
# Define the fraction of unconsumed precipitation that becomes surface runoff.
SURFACEWATER_LOSS_FRACTION_PRECIPITATION LAI[S, T, A, L]
#
# Define the fraction of unconsumed precipitation that becomes surface runoff.
# This fraction can be specified with NCROP records (BY_CROP) or NIRRIATE records (BY_IRRIGATION).
# If NIRRIATE = 0, then keyword is not required.
# Only one of the following two keywords may be in use during a simulation.
SURFACEWATER_LOSS_FRACTION_IRRIGATION BY_CROP LAI[S, T, A, L]
SURFACEWATER_LOSS_FRACTION_IRRIGATION BY_IRRIGATION LAI[S, T, A, L]
#
END LAND_USE

```

**Figure 6.88.** LAND\_USE block with most of the supported keywords and their input format. [NIRRIATE, number of irrigation types; NCROP, number of land use types; [L/T], length per time in model units; [L<sup>3</sup>/T], volumetric rate in model units; 1, list-array input with the following letters representing the supported keywords: S for STATIC, T for TRANSIENT, A for ARRAY, and L for LIST]

## Salinity Flush Irrigation Block

The **SALINITY\_FLUSH\_IRRIGATION** block optionally allows users to simulate additional irrigation demand for flushing soils to prevent salt accumulation. Note that the block name can be declared as **SALINITY FLUSH IRRIGATION** or **SALINITY\_FLUSH\_IRRIGATION**, but the later version, with underscores, is recommended for clarity. Additional irrigation water can be set to a specific value, use a predefined salinity-flush irrigation function called the Rhoades equation, or use a user supplied custom function. Typically, the quantity of additional applied water is dependent upon the salt tolerance of the specific crop and the salinity of the source water. This requires that the input specify a soil salinity ( $EC_e$ ) threshold for each crop, which is the point when a crop's yield is reduced as a result of soil salinity.

The soil salinity is measured using average electrical conductivity (EC) of a soil sample with units of decisiemens per meter (dS/m). Electrical conductivity represents, within the range of 0.1–5 dS/m, 640 milligrams per liter (mg/L) of total dissolved solids (TDS) per 1 dS/m. For measurements greater than 5 dS/m, EC represents approximately 800 mg/L of TDS per 1 dS/m. Figure 6.89 presents example  $EC_e$  values for select crops in dS/m; soil salinities with higher EC result in less than optimal yield of the crop. The salinity of the sources of irrigation water increases the salinity of the soil. The FMP has four potential sources of irrigation water: **NON\_ROUTED\_DELIVERY** (NRD) from the **SURFACE\_WATER** block, **SEMI\_ROUTED\_DELIVERY** (SRD) from the **SURFACE\_WATER** block, groundwater pumpage from the **SUPPLY\_WELL** block, and external water (EXT) sources that make up a supply shortfall when the **DEFICIENCY\_SCENARIO** is set to 0 (Zero-Scenario deficit irrigation) from the **WATER\_BALANCE\_SUBREGION** block. This requires specifying the EC, in dS/m, for the four sources of water.

Crop Common Name	Soil Salinity Threshold, $EC_e$ (dS/m)
Alfalfa	2.0
Almond	1.5
Barley	8.0
Broccoli	2.8
Cabbage	1.8
Carrot	1.0
Celery	1.8
Corn	1.7
Garlic	3.9
Lemon	1.5
Lettuce	1.3
Peach	1.7
Potato	1.7
Spinach	2.0
Strawberry	1.0
Tomato	2.5
Wheat, durum	5.9

**Figure 6.89.** List of common agricultural crops and their soil salinity ( $EC_e$ ) threshold (Tanji and Kielen, 2002). [The threshold value represents the point when the potential crop yield starts to decrease because of soil salinity. Abbreviation: dS/m, decisiemens per meter]

The Rhoades equation may be used for determining the additional irrigation demand and requires solving two sets of equations. The first equation involves determining the fraction of total irrigation (applied) water that must pass through the soil to prevent the soil salinity from reaching the tolerance of the crop. This unitless fraction is called the Leaching Requirement (LR). The LR is determined from the salinity concentration of irrigation water ( $EC_w$ ) and from the crop tolerance to soil salinity. Both  $EC_w$  and  $EC_e$  are measured as electrical conductivity (dS/m). From Ayers and Wescott (1985), the leaching requirement can be calculated as follows:

$$LR = \frac{EC_w}{(5 \cdot EC_e) - EC_w} \quad (6.1)$$

where

- $LR$  is the minimum leaching requirement needed to control salts, with  $0 \leq LR < 1$  (–);
- $EC_w$  is the salinity of the applied irrigation water, calculated from the mixture of irrigation water used by the FMP to meet the irrigation demand (dS/m); and
- $EC_e$  is the average soil salinity (dS/m) tolerated by the crop as measured on a soil saturation extract. It can be viewed as the desired soil salinity after additional irrigation is applied.

The leaching requirement cannot exceed nor equal one, so salinity flushing is possibly only when  $EC_w < 5 \times EC_e$ . The choice of  $EC_e$  is based on the desired, or obtainable, relative yields of the crop. For example, figure 6.89 represents  $EC_e$  values that calculate a leaching requirement that could obtain a 100-percent relative yield. Once the leaching requirement is determined, the second part of the Rhoades equation uses the crop irrigation requirement—the necessary irrigation to satisfy a crop's evapotranspiration demand—and specifies the total irrigation necessary for salinity flushing:

$$AW = \frac{CIR}{1 - LR} \quad (6.2)$$

where

- $CIR$  is the crop irrigation requirement under perfect irrigation efficiency ( $L^3/T$ ), and
- $AW$  is the necessary applied water for salinity flushing under perfect irrigation efficiency ( $L^3/T$ ).

$$D_{\text{irrigation}} = AW/OFE \quad (6.3)$$

where

- $D_{\text{irrigation}}$  is the irrigation necessary to satisfy the crop's transpiration and sufficiently provide salinity flushing under actual irrigation efficiency ( $L^3/T$ ).

Figure 6.89 presents a list of the soil salinity threshold for common agricultural crops.

How uniformly, in the vertical direction, irrigation is applied can affect the salt accumulation and flushing of salts from the soil. The second part of the Rhoades equation can be modified to include the effects of irrigation uniformity ( $DU$ ).

$$AW = \frac{CIR/DU}{1 - LR} \quad (6.4)$$

where

- $DU$  is the irrigation uniformity—how evenly the irrigation method is spread across the root zone—as a fraction from 0 to 1 (–). A value of 1 indicates that the irrigation is perfectly uniform through the root zone.

$DU$  can be set to 1 to not include this uniformity consideration as part of the simulation, but  $DU$  should never be set to zero.

## Keyword List

Figure 6.90 summarizes the keywords that the **SALINITY\_FLUSH\_IRRIGATION** block supports. They are arranged in order of importance, with required keywords first and optional keywords last.



A

Keyword Input	Description
<b>CROP_SALINITY_TOLERANCE</b>  LAI[S, T, L]	<p>Required input that specifies each Crop's salinity tolerance (<math>EC_e</math>) as an Electrical Conductivity (EC) for the desired yield of the crop.</p> <p><i>List Style</i> input expects <b>NCROP</b> records that read the <math>EC_e</math> as a <b>FLOAT</b>.</p> <p>Input must be in deciSiemens per meter (dS/m).</p>
<b>CROP_LEACHING_REQUIREMENT</b>  LAI[S, T, L]	<p>Required input that specifies each Crop's leaching requirement (LR) as either a <b>FLOAT</b>, Rhoades equation, or a custom expression.</p> <p><i>List Style</i> input expects <b>NCROP</b> records that specify for each crop either:</p> <ul style="list-style-type: none"> <li>the LR as a fraction (<b>FLOAT</b>) between 0 to 1, or</li> <li>the word <b>RHOADES</b> to use the Rhoades equation, or</li> <li>a custom expression whose result is the LR, or</li> <li>the word <b>SKIP</b> to set LR to 0.</li> </ul>
<b>CROP_SALINITY_APPLIED_WATER</b>  LAI[S, T, L]	<p>Required input that defines for each Crop the additional irrigation (AW) for salinity flushing [<math>L^3/T</math>]. This is the amount of water added in addition to the irrigation requirement to ensure salinity flushing.</p> <p>AW may be specified as <b>FLOAT</b> value, calculated with Rhoades equation, which is a function of LR, or determined by a user-specified custom expression.</p> <p><i>List Style</i> input expects <b>NCROP</b> records that specify for each crop either:</p> <ul style="list-style-type: none"> <li>the AW directly, or</li> <li>the word <b>RHOADES</b> to use the Rhoades equation, or</li> <li>a custom expression whose result is the AW, or</li> <li>the word <b>SKIP</b> to set LR to 0.</li> </ul> <p>Note that Rhoades equation is dependent on the leaching ratio (LR) calculated by the <b>CROP_LEACHING_REQUIREMENT</b> keyword</p>

**Figure 6.90.** Salinity\_Flush\_Irrigation block keywords. [The number of records read for List Style input depends on the keyword. Keywords that begin with WBS (water-balance subregion) expect NWBS records, and keywords that begin with CROP expect NCROP records. Note that some of the input is NOT in model units, but instead in parts per million (PPM) or deciSiemens per meter (dS/m). Some of the keyword and input are specified over two lines because of their length, but should be specified on the same line in FMP. Abbreviations: [FLOAT, floating-point number; INT, integer; ID, water balance subregion identification number; WBS, water-balance subregion; [L], length in model units; [ $L^3/T$ ], volumetric rate in model units; *Generic\_Output\_OptKey* specifies the path and file name for an output file; LAI, list-array input with the following letters representing the supported keywords: S for STATIC, T for TRANSIENT, and L for LIST]

B

Keyword Input	Description
<b>WBS_SUPPLY_SALT_CONCENTRATION</b>  LAI[S, T, L-4]	<p>Required input that specifies the source water supply's salt concentration in PPM (milligram/liter).  <u>This is not in model units.</u></p> <p><i>List Style</i> reads <b>NWBS</b> records that specify the salt concentration as a <b>FLOAT</b> from four sources of water:</p> <p>Non-Routed Delivery (NRD),  Semi-routed Delivery (SRD),  Groundwater Pumping, and  External Sources (FMP Zero-Scenario water).</p> <p>Supports use of <b>SFAC DIMKEY</b> with <b>BySource</b> option, which reads four scale that are applied to each of the water sources.</p>
<b>WBS_IRRIGATION_UNIFORMITY</b>  LAI[S, T, L- <b>NIRRIGATE</b> ]	<p>Optional input that specifies for each WBS the vertical, across the root zone, irrigation uniformity (DU).  The fraction is specified in the range <math>0 &lt; DU \leq 1</math>.</p> <p>A value of 1 indicates that the irrigation is perfectly uniform and a value of 0.5 indicates that the irrigation is half uniform. DU may not be set to 0.</p> <p><i>List Style</i> input expects <b>NWBS</b> records that read the DU for each irrigation type (<b>NIRRIGATE</b>) as a <b>FLOAT</b>.</p> <p>If not specified, then DU is set to 1.0 for all irrigation types.</p>
<b>CROP_HAS_SALINITY_DEMAND</b>  LAI[S, T, L]	<p>Optional input that specifies which crops should have additional irrigation for salinity flushing.</p> <p><i>List Style</i> reads <b>NCROP INT</b> flags to indicate if the crop includes additional irrigation for salinity flushing:</p> <p>0 to not have salinity flush irrigation  1 to have salinity flush irrigation</p> <p>If not specified, then all irrigated crops ( <b>IRRIGATION</b> &gt; 0 ) will have additional irrigation for salinity flushing.</p>

Figure 6.90. —Continued

c

Keyword	Input	Description
<b>CROP_MAX_LEACHING_REQUIREMENT</b>	LAI[S, T, L	<p>Optional input that specifies each crop's max allowed leaching requirement (<math>LR_{Max}</math>).</p> <p>The leaching requirement (LR) is specified or calculated with the keyword <b>CROP_LEACHING_REQUIREMENT</b> and must be less than 1.</p> <p>If <math>LR &gt; LR_{Max}</math>, then <math>LR = LR_{Max}</math>.</p> <p><i>List Style</i> input expects <b>NCROP</b> records that read <math>LR_{Max}</math> as a <b>FLOAT</b> between 0 and 0.9999.</p> <p>If keyword is not specified, then the the default is <math>LR_{Max} = 0.99</math> for all crops.</p>
<b>EXPRESSION_LINE_LENGTH</b>	<b>INT</b>	<p>Optional <b>INT</b> input that specifies the maximum length of a custom expression that may be read by <b>CROP_LEACHING_REQUIREMENT</b> and <b>CROP_SALINITY_APPLIED_WATER</b>.</p> <p>If not specified, then the default is 20 characters long. That is the largest expression can be "12345678901234567890", which includes white spaces.</p>
<b>EXPRESSION_VARIABLE_NEARZERO</b>	<b>FLOAT</b>	<p>Optional <b>FLOAT</b> input that specifies the tolerance for converting a custom expression variable to zero.</p> <p>For example, if the tolerance is set to 0.1 and P is a variable in the expression, then its value is set to zero if <math>-0.1 \leq P \leq 0.1</math>.</p> <p>If keyword is not specified, then the default tolerance is 0.0.</p>

Figure 6.90. —Continued

D

Keyword and Input	Description
<b>PRINT ByWBS_ByCROP</b> <i>Generic_Output_OptKey</i>	Writes salinity irrigation flush output that is summarized for each crop within each WBS.
<b>PRINT ByWBS</b> <i>Generic_Output_OptKey</i>	Writes salinity irrigation flush output that is summarized for each WBS.
<b>PRINT ByCROP</b> <i>Generic_Output_OptKey</i>	Writes salinity irrigation flush output that is summarized for each crop across the entire model domain.
<b>PRINT ALL</b> <i>Generic_Output_OptKey</i>	Writes salinity irrigation flush output and simulated results for each crop for every model cell that contains the crop with salinity flush irrigation.
<b>PRINT INPUT</b> <i>Generic_Output_OptKey</i>	Writes the input that is loaded.

Figure 6.90. —Continued

The keywords **CROP\_LEACHING\_REQUIREMENT** and **CROP\_SALINITY\_APPLIED\_WATER** allow defining custom expression for calculating the leaching requirement and additional applied irrigation water. A custom expression is passed to the ExpressionParser and accepts a set of predefined variable names whose values are set at runtime. The list of supported variable names available, at the time of this report's publication, are presented in figure 6.91.

Custom expressions may contain an *Inline IF* statement. The basic syntax is IF[ *Condition*, *TrueResult*, *FalseResult* ], for example, "IF[ *ETc>ETr*, (*ECe/ECw*)\*LOG(*CIR*) + *CIR*, *0.1·CIR* ]". This example checks if the crop evapotranspiration from precipitation and irrigation is greater than the reference evapotranspiration. If it is true, then it returns the result of a custom expression, (*ECe/ECw*) · LOG(*CIR*) + *CIR*, and, if false, returns one-tenth the crop irrigation requirement (*0.1·CIR*).

Figure 6.92 is an example of **SALINITY\_FLUSH\_IRRIGATION** block input for three crops, two WBSs, and one irrigation type (note the irrigation type is not used in the input example). This example is for demonstration purposes only. Generally, users can specify **CROP\_LEACHING\_REQUIREMENT** and **CROP\_SALINITY\_APPLIED\_WATER** with either a single **FLOAT** or use the Rhoades equation.

A

Variable Name	Description—Value Stored in Variable Name
LR	Leaching requirement [-] Value is set by <code>CROP_LEACHING_REQUIREMENT</code> .
ECw	Calculated electrical conductivity of irrigation water (dS/m).
ECe	Crop electrical conductivity tolerance (dS/m).
CU	Potential consumptive use of crop (total potential consumption of water); [L <sup>3</sup> /T].
ETr	Reference evapotranspiration; [L <sup>3</sup> /T].
ETc	Crop evapotranspiration from precipitation and irrigation; [L <sup>3</sup> /T]. Assumes that irrigation needs are fully met.
ETp	Crop evapotranspiration from precipitation; [L <sup>3</sup> /T].
ETi	Crop evapotranspiration from irrigation. Determined as <code>DMD*EFF</code> ; [L <sup>3</sup> /T].
CIR	Crop irrigation requirement that assumes perfect irrigation efficiency; [L <sup>3</sup> /T]. Note, <code>CIR = ETi</code> , if efficiency improvement is disabled ( <code>EFFICIENCY_IMPROVEMENT = 0</code> ).
DMD	Crop irrigation demand that includes irrigation efficiency. This irrigation is necessary to meet the crop's consumptive use. Note, <code>DMD = CIR</code> if irrigation efficiency is 1.0; [L <sup>3</sup> /T].
P	Precipitation that falls on the crop; [L <sup>3</sup> /T]
AREA	Crop area; [L <sup>2</sup> ].
Tgw	Transpiration from root-groundwater uptake; [L <sup>3</sup> /T].
Tp	Transpiration from precipitation; [L <sup>3</sup> /T].
Ti	Transpiration from irrigation; [L <sup>3</sup> /T].

**Figure 6.91.** SALINITY\_FLUSH\_IRRIGATION block custom expression variable name support for calculating `CROP_LEACHING_REQUIREMENT` and `CROP_SALINITY_APPLIED_WATER`. [The variable names listed are replaced at runtime with their described values. Abbreviations: dS/m, electrical conductivity in decisiemens per meter; [L], length in model units; [L<sup>2</sup>], area in model units; [L<sup>3</sup>/T], volumetric rate in model units; [-], indicates that property is unitless]

**B**

Variable Name	Description—Value Stored in Variable Name
EFF	Irrigation efficiency (OFE, appendix 4); [-].
ROOT	Crop root depth; [L].
CapF	Capillary fringe length; [L].
DP_p	Deep percolation from precipitation; [L <sup>3</sup> /T].
DP_i	Deep percolation from irrigation, if irrigated demand is met; [L <sup>3</sup> /T]. This includes other additional irrigation demands, such as <b>ADDED_CROP_DEMAND</b> , but not deep percolation from salinity irrigation.
DP	Total potential deep percolation from precipitation and irrigation; [L <sup>3</sup> /T].
ADRS	Crop added demand runoff split ( <b>ADDED_DEMAND_RUNOFF_SPLIT</b> ).
ADMD	Sum of added demands, excluding salinity added demand, for the crop; [L <sup>3</sup> /T].

**Figure 6.91.** —Continued

```

# Example Salinity Flush Irrigation Block input
#
# Assume GLOBAL Dimension block defines: NWBS = 2 and NCROP = 3
#
BEGIN SALINITY_FLUSH_IRRIGATION
#
# Define the salinity concentration of the irrigation water
WBS_SUPPLY_SALT_CONCENTRATION STATIC LIST INTERNAL
#WBS  SW    GW    NRD    External
  1    310.  210.  520.  640.  # (mg/L)
  2    300.  200.  510.  640.
#
# Define the soil salinity acceptable tolerance for the crops. Using values for 100% yield.
CROP_SALINITY_TOLERANCE STATIC LIST INTERNAL
#Crop  ECe (dS/m)
  1    1.7  # Corn
  2    8.0  # Barley
  3    1.0  # Strawberry
#
# Define how the leaching requirement is calculated.
CROP_LEACHING_REQUIREMENT STATIC LIST INTERNAL
#Crop  Expression
  1    0.2                # Corn – Define directly a leaching requirement of 0.2
  2    RHOADES            # Barley – Use Rhoades equation for the leaching requirement
  3    ECw/(5*ECe - ECw) # Strawberry – Custom expression that is identical to Rhoades.
#
# Define how the additional irrigation for salinity flushing is calculated.
# The variable LR and Rhoades equation use
# the leaching requirement set by CROP_LEACHING_REQUIREMENT
# Note that the result is only the additional irrigation, not the total irrigation.
CROP_SALINITY_APPLIED_WATER STATIC LIST INTERNAL
#Crop  Expression
  1    SKIP                # Corn – Does not have additional irrigation (no salinity flush).
  2    RHOADES            # Barley – Use Rhoades equation for additional irrigation
  3    CIR/(1-LR) - CIR    # Strawberry – Custom expression that is identical to Rhoades.
#
END SALINITY_FLUSH_IRRIGATION

```

**Figure 6.92.** SALINITY\_FLUSH\_IRRIGATION block input example. [Example assumes that the GLOBAL DIMENSION block set the number of water balance subregions (NBS) to 2 and the number of crops (NCROP) to 3]

## PRINT Headers

The keyword **PRINT ByWBS\_ByCrop** writes to the *Generic\_Output\_OptKey* file the summarized salinity irrigation flush results for each WBS for every time. The keyword **PRINT ByWBS** has the same headers, except it does not include the CROP header because it aggregates all crops together by WBS. The keyword **PRINT ByCrop** has the same headers, except it does not include the WBS header because it aggregates information across all WBSs for each crop. The keyword **PRINT ByCrop** has the same headers, except it is written for every model cell and contains the header ROW and COL, for the model row and column, after the header FARM. The output for **PRINT ByWBS\_ByCrop** may be in text or binary format and has the header defined in figure 6.93.

**A**

PER	is the stress period number	
STP	is the time step number	
WBS	is the Water Balance Subregion (Farm) ID number	
CROP	is the Land-use (Crop) ID number	
CROP_NAME	is the name of the specific crop	
DEMAND%CHANGE	is the percentage increase in irrigation for salinity flushing	[percent]
CROP_AREA	is the area of land the crop occupies	[L <sup>2</sup> ]
IRRIGATED_AREA	is the area of land the crop occupies that is irrigated	[L <sup>2</sup> ]
SALINITY_AREA	is the area of irrigated land that has salinity flushing	[L <sup>2</sup> ]
PRECIPITATION	is the total precipitation	[L <sup>3</sup> /T]
TOT_IRRIGATION	is the total irrigation applied to the crop	[L <sup>3</sup> /T]
TOT_DEEP_PERC	is the total loss of water to deep percolation (groundwater recharge)	[L <sup>3</sup> /T]
LEACH_FRACTION	is the leaching fraction (LF)	
CU	is actual crop consumptive use based on water supply	[L <sup>3</sup> /T]
ET_IRR	is evapotranspiration of water that originated from irrigation water supply	[L <sup>3</sup> /T]
SALT_REQ_IRR	is the necessary, perfect efficiency, irrigation for the salinity flushing requirement	[L <sup>3</sup> /T]
SALT_IRR	is the final irrigation with perfect efficiency applied for salinity flushing	[L <sup>3</sup> /T]
SALT_REQ_DEMAND	is the necessary irrigation demand for the salinity flushing requirement	[L <sup>3</sup> /T]
SALT_DEMAND	is the final irrigation applied for salinity flushing	[L <sup>3</sup> /T]
LEACH_REQ	is the calculated leaching requirement	[L <sup>3</sup> /T]
ECe	is the crop electrical conductivity tolerance	[dS/m]
ECw	is the irrigation water's electrical conductivity	[dS/m]
IRR_UNIFORMITY	is the irrigation uniformity of the all the irrigation applied	[L <sup>3</sup> /T]
DEL T	is the time step length	[T]
DYEAR	is the date at the end of the time step as a decimal year	
DATE_START	is the calendar date at the start of the time step (yyyy-mm-ddThh:mm:ss)	

**Figure 6.93.** SALINITY\_FLUSH\_IRRIGATION block keyword PRINT ByWBS\_ByCrop text file header explanation and binary record structure. *A*, Text-header explanation. *B*, Binary-record structure. [T], unit of time in model units; [L<sup>3</sup>/T], volumetric rate in model units; [dS/m], decisiemens per meter; CHARACTER(20) indicates record is 20 characters long (20 bytes); CHARACTER(19) indicates record is 19 characters long (19 bytes); INTEGER is a 4-byte integer record; DOUBLE is a 8-byte floating-point number record.]



**B**

DATE_START	CHARACTER(19), starting date formatted as 'yyyy-mm-ddThh:mm:ss'
DYEAR	DOUBLE
DELT	DOUBLE
PER	INTEGER
STP	INTEGER
WBS	INTEGER
CROP	INTEGER
CROP_NAME	CHARACTER(20)
DEMAND%CHANGE	DOUBLE
CROP_AREA	DOUBLE
IRRIGATED_AREA	DOUBLE
SALINITY_AREA	DOUBLE
PRECIPITATION	DOUBLE
TOT_IRRIGATION	DOUBLE
TOT_DEEP_PERC	DOUBLE
LEACH_FRACTION	DOUBLE
CU	DOUBLE
ET_IRR	DOUBLE
SALT_REQ_IRR	DOUBLE
SALT_IRR	DOUBLE
SALT_REQ_DEMAND	DOUBLE
SALT_DEMAND	DOUBLE
LEACH_REQ	DOUBLE
ECe	DOUBLE
ECw	DOUBLE
IRR_UNIFORMITY	DOUBLE

**Figure 6.93.** —Continued

## Data Requirements

The data requirements vary depending on the level of complexity and detail desired for the FMP4 simulation. To keep this section simple, it is broken into a set of input questions and responses that indicate which keyword needs to be set for the simulation to incorporate it. There is some redundancy in answers, but that is to include the widest range of questions possible. The first planning decision concerns the number of WBSs that are simulated and their spatial layout—**WATER\_BALANCE\_SUBREGION** block **LOCATION**. The next decision is the total number of land uses simulated, their spatial location, and if there is more than one land use in a model cell—**LAND\_USE** block **SINGLE\_LAND\_USE\_PER\_CELL**, **MULTIPLE\_LAND\_USE\_PER\_CELL**, **LAND\_USE\_AREA\_FRACTION**, and **LOCATION**. The WBS and crops can vary with time, but the best practice is to estimate the maximum number in use at one time—**GLOBAL\_DIMENSION** block **NWBS** and **NCROP**. Figure 6.94 is a flow chart that works through basic considerations of the potentially necessary datasets for an FMP simulation.

## Example Farm Process (FMP) Input File

There are many input options in the latest version of the FMP. Figure 6.95 provides an example showing the minimum input required for an FMP simulation and some examples of internal, list, and array input options. Items in green are the named input blocks. Items in blue are keywords. Items in red indicate how the input is read. Items in black are input values such as values for each grid cell or for named output files. Lines with “#” symbols are comment lines. The items in this section are not discussed at length as each of the input types and options is described in detail in the respective report section corresponding to the block name.

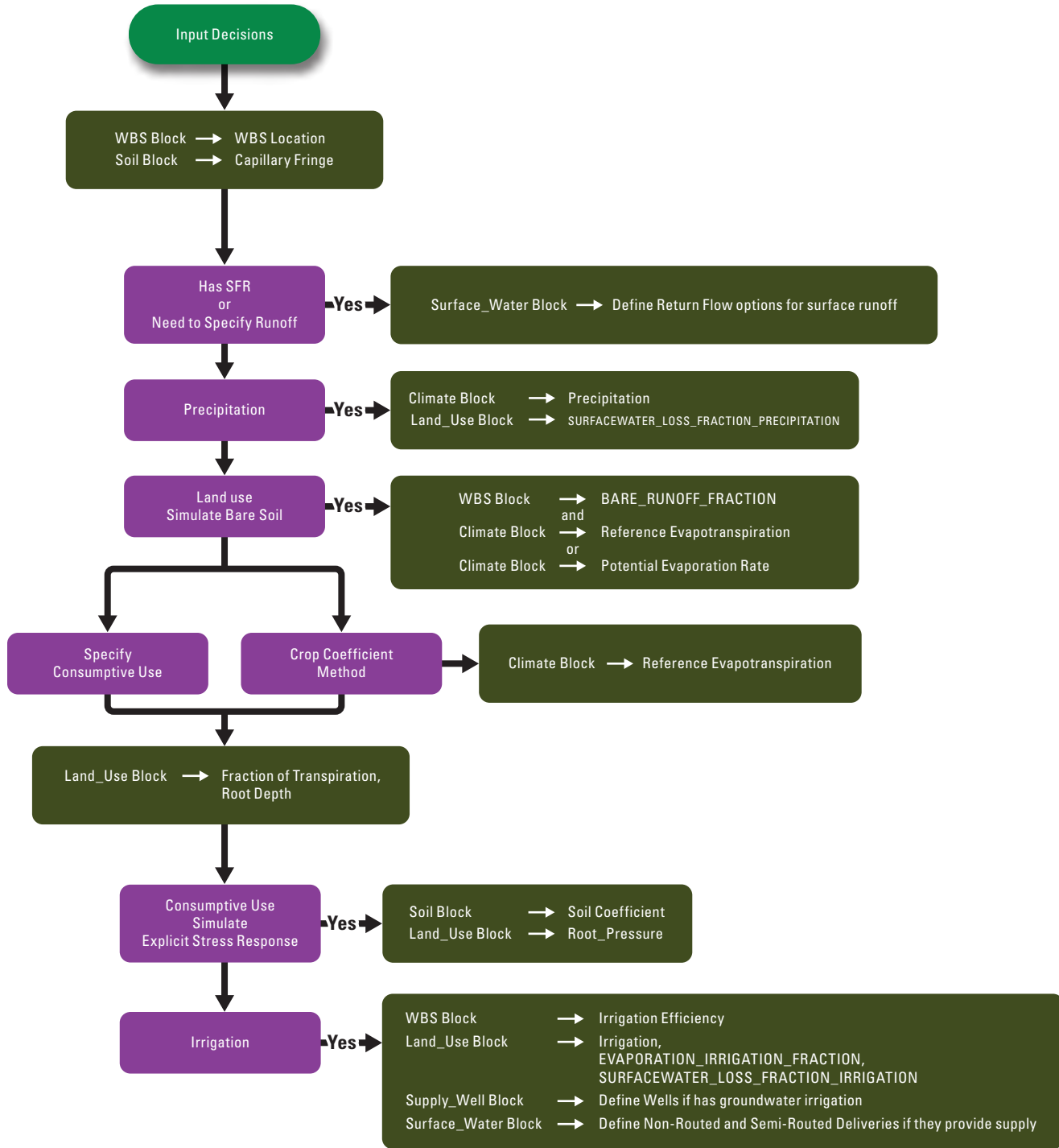


Figure 6.94. Work flow for determining what input is necessary.

A

```

BEGIN GLOBAL DIMENSION           # Model grid is 3 by 4, such that: NROW = 3, NCOL =4
#
NFARM      3
NCROP      3
NSOIL      2
NIRRIGATE  2
NRD_TYPES  1
#
NSFR_DELIV  2
NSFR_RETURN 1
#
SURFACE_ELEVATION INTERNAL
    100.    101.    102.    103.
    100.5   101.    102.    103.
    100.7   101.    102.    103.
END
#
BEGIN WATER_BALANCE_SUBREGION    #WBS
#
LOCATION  STATIC ARRAY INTERNAL
    1  1  2  2
    1  1  2  2
    3  3  2  2
#
EFFICIENCY STATIC LIST INTERNAL
    1  0.7  0.9 #[WBS, Irrigation Type 1, Irrigation Type 2]
    2  0.7  0.9
    3  0.7  0.9
#
END WATER_BALANCE_SUBREGION
#
BEGIN OUTPUT
#
FARM_WELL_CBC           0
FARM_NET_RECHARGE_CBC   0
#
FARM_DEMAND_SUPPLY_SUMMARY ./FDS.OUT
FARM_BUDGET              ./FB_DETAILS.OUT
END
#

```

**Figure 6.95.** Example FMP input file. *A*, Global Dimension, Water Balance Subregion, and Output block input example. *B*, Soil, Climate, and Surface\_Water block input example. *C*, Supply\_Well block input example. *D*, Land\_Use block input example. [This figure is split into multiple parts, but the actual input is one single file.]

B

**BEGIN SOIL**

#

**SOIL\_ID** INTERNAL

1 1 2 2

1 1 2 2

1 1 2 2

#

**CAPILLARY\_FRINGE** STATIC LIST INTERNAL

1 1.00 # [Soil\_ID, Capillary\_Fringe]

2 0.75

#

**END SOIL**

#

**BEGIN CLIMATE**

#

**PRECIPITATION** CONSTANT 0.1

#

**REFERENCE\_ET** STATIC ARRAY INTERNAL # Only required if using Crop Coefficient

1.1 1.2 1.3 1.4

1.1 1.2 1.3 1.4

1.1 1.2 1.3 1.4

**END CLIMATE**

#

**BEGIN SURFACE\_WATER**

#

**NON\_ROUTED\_DELIVERY** STATIC LIST INTERNAL

1 100. 1 0 # [WBS, NRD\_VOL, NRD\_RANK, NRD\_USE]

2 0. 1 0

3 0. 1 0

#

**SEMI\_ROUTED\_DELIVERY** STATIC LIST INTERNAL

1 1 15 1 # [ISRD, WBS, Segment, Reach]

2 2 22 1

#

**SEMI\_ROUTED\_RETURN** STATIC LIST INTERNAL

1 1 15 1 # [ISRR, WBS, SEGMENT, REACH]

#

**ROUTED\_RETURN\_ANY\_NON\_DIVERSION\_REACH** # Fully-routed return flow keyword**END**

#

Figure 6.95. —Continued

c

**BEGIN SUPPLY\_WELL**

#

**QMAXRESET**

#

**MNW\_AUTOMATIC\_ON****MNW\_AUTOMATIC\_OFF**

# Output Options

**PRINT BYWELL**           ./Farm\_Well\_Info.txt**PRINT BYFARM**       ./Farm\_Well\_ByFarm\_Info.txt

#

**TIME FRAME**

#	Well_Name	WBS	LAY	ROW	COL	QMAX	Date_Start	Date_End
	Well1	1	2	1	2	1000.	1	NPER
	Well2	1	2	2	2	1000.	5	10
	WEL_MNW_LNK	2	MNW	2	3	2000.	1	NPER

#

**END SUPPLY\_WELL**

#

Figure 6.95. —Continued

D

```

BEGIN LAND_USE
#
PRINT BYFARM_BYCROP ./Crop_Info.txt
PRINT BYFARM        ./Crop_Info_ByFarm.txt
#
LOCATION    STATIC ARRAY INTERNAL
  2  1  1  2
  2  1  1  2
  3  3  2  2
#
CROP_COEFFICIENT STATIC LIST INTERNAL
1  0.60 # [Crop_ID, Crop_Coefficient]
2  1.10
3  0.15
#
ROOT_DEPTH STATIC LIST INTERNAL
1  0.5 # [Crop_ID, Root_Depth]
2  1.6
3  0.1
#
IRRIGATION STATIC LIST INTERNAL
1  2 # [Crop_ID, Irrigation Type]
2  1 # Uses user-specified irrigation type 1
3  0 # Not irrigated
#
TRANSPIRATION_FRACTION STATIC LIST INTERNAL
1  0.6 # [Crop_ID, FTR]
2  0.8
3  0.4
#
EVAPORATION_IRRIGATION_FRACTION By_Crop STATIC LIST INTERNAL
1  0.15 # [Crop_ID, FEI]
2  0.15
3  0.00 # Never used because it is not irrigated
#
SURFACEWATER_LOSS_FRACTION_PRECIPITATION STATIC LIST INTERNAL
1  0.2 # [Crop_ID, FIESWP]
2  0.1
3  0.9
#
SURFACEWATER_LOSS_FRACTION_IRRIGATION By_Crop STATIC LIST INTERNAL
1  0.01 # [Crop_ID, FIESWI]
2  0.05
3  0.00
#
END LAND_USE

```

Figure 6.95. —Continued

## References Cited

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