

Agricultural Water Use Package for MODFLOW and GSFLOW

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Preface

This report describes the Agricultural Water Use (AWU) Package for MODFLOW and GSFLOW. The program can be downloaded from the USGS for free. The performance of the AWU Package has been tested in a variety of applications. Future applications, however, might reveal errors that were not detected in the test simulations. Users are requested to send notification of any errors found in this model documentation report or in the model program to the contact listed on the Web page (https://doi.org/10.5066/F70C4TQ8). Updates might be made to both the report and to the model program. Users can check for updates on the MODFLOW and GSFLOW Web pages.

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Agricultural Water Use Package for MODFLOW and GSFLOW

By Richard G Niswonger

# Abstract

The Agricultural Water Use (AWU) Package was developed for simulating water use by agriculture in MODFLOW and GSFLOW models. Previously, simulating agricultural water use in MODFLOW and GSFLOW required external calculations for applying irrigation to model cells or HRUs, making it difficult to link surface water and groundwater supply to applied irrigation amounts. The AWU Package calculates irrigation demands, irrigation amounts, evapotranspiration, and return flows that are dependent on dynamic soil-water conditions, and surface water and groundwater availability. Irrigation is explicitly simulated by applying diverted surface water and pumped groundwater to fields. The AWU Package is integrated with the UZF1 and SFR2 Packages for MODFLOW simulations, and it is integrated with the PRMS Soilzone Module and the SFR2 Package for GSFLOW simulations. Surface water diversions simulated by the SFR2 Package can be automatically applied as irrigation to UZF1 cells or PRMS HRUs. Irrigation supplied by groundwater is calculated by the AWU Package, using the same approach of the MODFLOW-NWT WELL Package, and pumped groundwater can be automatically applied to UZF1 cells or PRMS HRUs as irrigation. Groundwater irrigation can be the sole source of irrigation water or it can be calculated as the difference between the irrigation demand and surface water diversion when the surface water diversion is less than the irrigation demand.

# Introduction

Agriculture is a major water-use component in many basins in the western United States, and representation of this water-use sector in hydrologic models is important for water resources planning and management. Existing MODFLOW-based codes can simulate water use by agriculture, however these approaches have not been combined with GSFLOW, or they rely on external calculations to represent agricultural water use. Capabilities were added to MODFLOW and GSFLOW by creating a new MODFLOW package that can simulate dynamic soil water balance on farmlands and the feedbacks between supply and demand. Because this new package is fully integrated into the MODFLOW and GSFLOW solutions, it can simulate water supply-limited conditions that leaves a portion of water demands unsatisfied. The new package can also simulate agricultural water use in systems that conjunctively use surface water and groundwater.

Agricultural demand is dependent on regional hydrologic states that are not measured but can be simulated using a hydrologic model, including dynamic soil, vadose zone, and groundwater storages. In water limited environments, decisions must be made regarding whether to fallow land or modify irrigation practices. These types of regional shifts in agricultural demand that follow climatic conditions impact ET directly due to reductions in irrigated area, and also indirectly as reductions in return flows. Interactions such as these occur over time periods that span irrigation events or irrigation seasons, or they can span much longer time periods due to multi-year shifts in climate.

The Agricultural Water-Use (AWU) Package was developed for MODFLOW-NWT and GSFLOW (Niswonger and others, 2011; Markstrom and others, 2008). The AWU Package works with the Streamflow-Routing (SFR2) and the Unsaturated Flow (UZF1) Packages, and includes capabilities for simulating pumping wells, similar to the WELL Package for MODFLOW-NWT. The AWU Package has 4 major capabilities, including 1) apply water flowing in SFR2 diversion segments as infiltration to UZF1/PRMS cells/HRUs; 2) apply water pumped by wells in the AWU Package as infiltration to UZF1/PRMS cells/HRUs; 3) automatically pump water in wells to supplement SFR2 diversions when the available flow in a diversion segment is less than demand; and 4) calculate irrigation demand using the UZF1/PRMS ET deficit (ETo-ETa). Option 4 includes sub-irrigation where the ET demand can be supplemented by groundwater. As irrigation water can be explicitly applied to cells/HRUs, and water consumption by plants (evapotranspiration; ET) is simulated using soil-water balance, both surface water and groundwater return flows also can be simulated.

Use of the AWU Package does not require changes to the input files for any other MODFLOW Package or GSFLOW Module. All exchanges between different packages (SFR2, UZF1, and AWU) are calculated within the AWU Package; however, the SFR2 and UZF1 Packages must be active in MODFLOW and GSFLOW in order to divert surface water and apply irrigation water to cells/HRUs. Diversion segments must be specified within the SFR2 Package in order to apply diverted water as irrigation. All data for supplementary and irrigation wells is specified within the AWU Package input file; the AWU Package calculates and applies its own boundary conditions to the groundwater flow equation for representing groundwater pumped by wells.

The AWU Package can be used to simulate agricultural water use with three different configurations (Figure 1): 1) Surface water diversions are specified in the SFR2 Package and represent irrigation demand, all or a portion of irrigation water is explicitly applied to UZF1 cells or PRMS HRUs and ET and return flows are simulated, or diverted water is removed from the model, assuming complete consumption of diverted water; 2) Surface water diversions are specified in the SFR2 Package or groundwater pumping rates are specified in the AWU Package and represent irrigation demand, or surface water diversions are specified to represent irrigation demand and surface water shortfalls are used to calculate supplementary groundwater pumping, irrigation water is removed from the model assuming complete consumption or is applied to cells/HRUs to simulate ET and return flows; 3) irrigation demand is calculated using the ET deficit in UZF1 or PRMS, and surface water diversions and groundwater pumping rates are calculated by the model and applied to cells/RHUs to minimize the ET deficit, maximum surface water diversions and pumping rates are specified in the SFR2 and AWU Packages, respectively.

The AWU Package is activated by specifying a file type of “AWU” within the MODFLOW-NWT Name file. The AWU input file contains 3 types of data, including 1) Options, 2) Well List, and 3) Stress Period data for specifying connectivity between segments and irrigation cells, supplemental wells and diversion segments, and irrigation wells and irrigation cells.

1. Illustration of using proportionally sized circles to represent well withdrawal magnitudes. Modified from Kresse and others (2014).

The

## Limitation

As The footprint is NOT the area that contributes recharge to the wells. It is solely a visualization of the magnitude of pumping, centered on the wells (Goode, 2016).

# Description of the Modified Footprint Algorithm

The

## Initial Redistribution

The Steps in selecting cells in the initial redistribution process. Around the two wells, (black, solid cells), a neighborhood is selected in which all the cells are active, sufficiently close to the well, and connected by other candidate cells to the well cell.

## Redistribute to Perimeter Cells when Stalled

The

1. Example redistribution to perimeter cells when stalled. Modified from Goode (2016).

# Using ModelMuse with WellFootprint

ModelMuse (Winston, 2009, 2014) has been modified to generate the input for WellFootprint and to display the output from WellFootprint.

## Starting a New Footprint Project

When

## Editing the Grid

If the

## Non Spatial Data

The various

## Input Data Sets

There

## Running WellFootprint

To

1. Extensions Used with WellFootprint Files

|  |  |
| --- | --- |
| WellFootprint File type | Extension |
| Input | .fpi |
| Listing | .fplst |
| Binary results | .fpb |
| Text results | .fpt |

## Displaying Results

To d

# WellFootprint Input file format

An e

# WellFootprint Output file formats

## Format of text result file

The text result file contains two arrays Distributed\_Withdrawals and Footprint\_Code (table 2).

1. The data for each array starts with a line containing the name of the array.
2. This is followed by two lines containing the number of rows and number of columns in the grid respectively.
3. This is followed by a value for each cell in the grid in row-major order. Commas and white space are used to separate values.
4. Meaning of Footprint Codes

|  |  |
| --- | --- |
| Footprint code | Meaning1 |
| 0 | Inactive |
| 1 | Q = 0 |
| 2 | 0 < Q < D |
| 3 | Q = D |
| 4 | Q > D |

1 Q = Withdrawal rate; D = Cell capacity

## Format of binary results file.

# Discussion

While the use of WellFootprint to display well withdrawals has been emphasized here, there are other sorts of data that could be displayed using WellFootprint. For instance, disease frequency could be displayed to create maps that are easier to understand. In general, the footprint method might be useful when plotting any type of closely spaced point data of varying intensity.

# References Cited

Goode, D.J., 2016, Map visualization of groundwater withdrawals at the sub-basin scale: Hydrogeology Journal, v. 24, no. 4, p. 1057-1065.

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