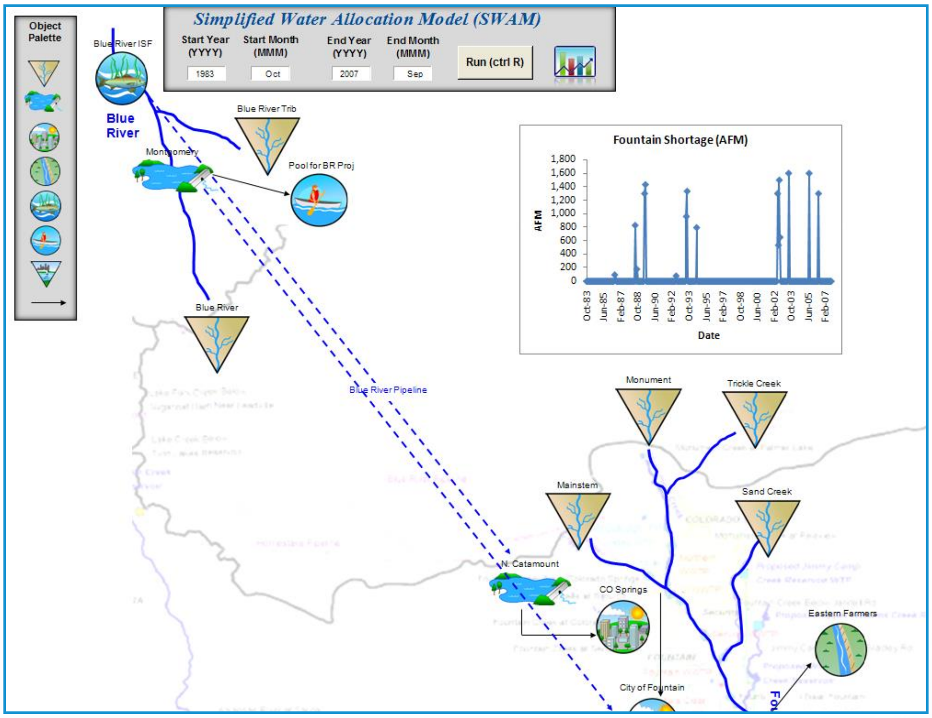
Simplified Water Allocation Model (SWAM)



VERSION 2.0

USER'S MANUAL

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Section 1

Introduction and Overview

CDM's Simplified Water Allocation Model (SWAM) was developed to address an identified need for a networked generalized water allocation modeling tool that could be easily and simply applied for planning studies by a wide range of end-users. Unlike most other water allocation software, SWAM is designed to be intuitive in its use and streamlined in functionality and data requirements, while still maintaining the key elements of water allocation modeling. SWAM was designed to provide efficient planning-level analyses of water supply systems.

Like most water allocation models, SWAM calculates physically and legally available water, diversions, storage, consumption, and return flows at user-defined nodes in a networked river system. Both municipal and agricultural demands can be specified and/or calculated in the model. Legal availability of water is calculated based on prioritized permitted withdrawals, downstream physical availability, and anticipated return flows. Additional features in SWAM include easily-parameterized municipal and industrial (M&I) conservation and reuse programs, agricultural land transfers, groundwater pumping, and transbasin diversion projects. Multiple layers of complexity are available as options in SWAM to allow for easy development of a range of systems, from the very simple to the more complex. As an example, SWAM's reservoir object can include only basic hydrology-dependent calculations (storage as a function of inflow, outflow, and evaporation) or can include operational rules of varying complexity: prescribed monthly releases, a set of prioritized monthly releases, or a set of conditional release rules (dependent on hydrology). The model user chooses the appropriate level of complexity given the modeling objectives and data availability.

SWAM operates on a monthly timestep, and the current version of the model is constrained to a total of up to eighty (80) M&I water user and eighty (80) agricultural water user nodes. The program is coded in Visual Basic with a Microsoft Excel-based interface.

Note that for the South Carolina surface water modeling study, updates and enhancements to the current model may be incorporated as required or desired. An example is the option for daily timestep simulations. The User's Manual contained herein will be updated accordingly at that time.

Section 2

Model Description

2.1 Worksheet

The SWAM user interface is primarily comprised of a single worksheet (Figure 2-1) with drop and drag graphical features for defining and parameterizing a water supply network. On-screen representation of specific model objects, hereafter referred to as "visual objects," are created by clicking on the appropriate button in the "Object Palette" (1.). To drop and drag the created visual objects (2.), the user must first select the object by clicking on the edge of the object (hidden rectangle). Once a visual object is selected, it can be deleted using the "delete" key stroke or by right-clicking with the mouse and selecting "cut." Visual object names can be edited by single-clicking on the object label.

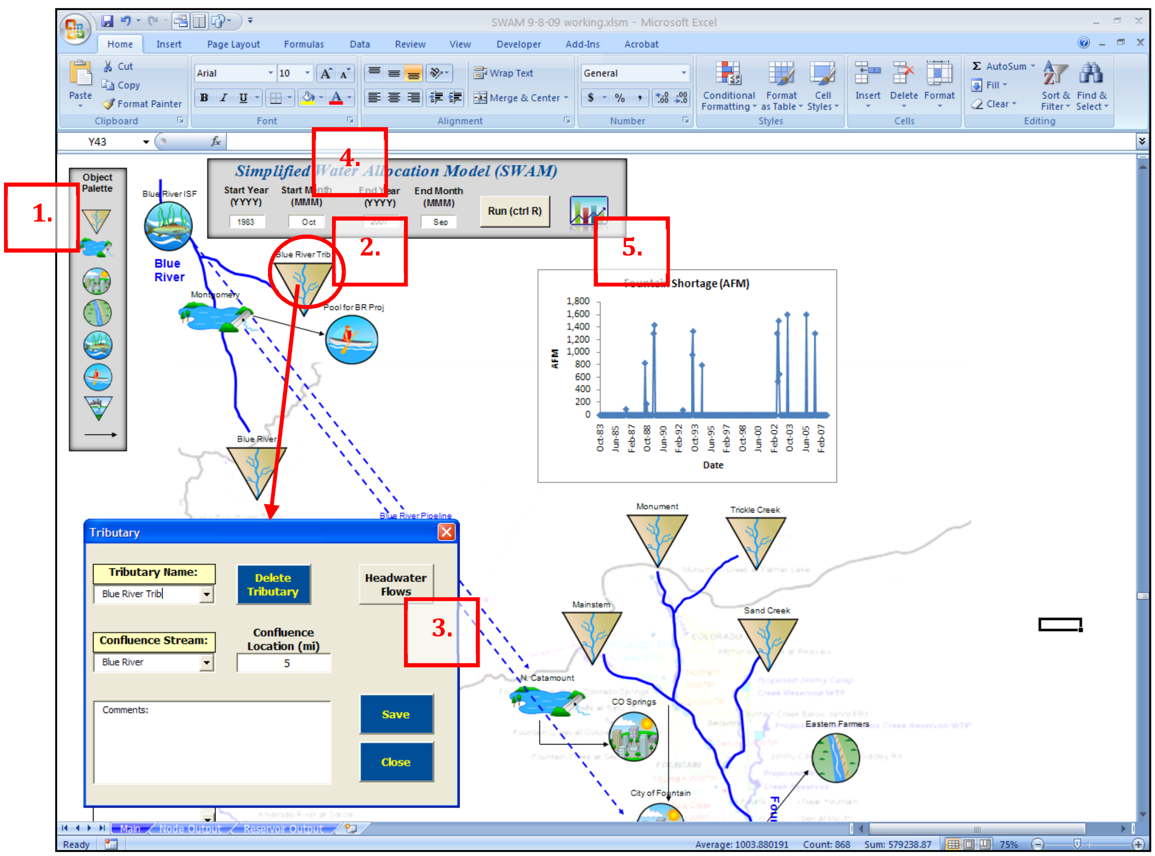


Figure 2-1. SWAM Main Screen

It is important to note that visual objects are merely placeholders and portals to the true model data objects. In other words, the model does not recognize any links between visual objects and simulated model objects (as defined below). **Consequently, deleting the visual object from the white space will not delete the actual model object.** Similarly, simply creating a visual object, as described above, will not result in inclusion of that object in the model simulation. However, that being said, creating a network of visual objects that accurately represents the simulated model objects is of great benefit to the user and is strongly advised.

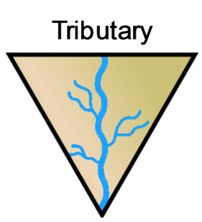
Model objects are created and deleted using the input forms (3**.**) accessed by clicking on the visual objects. Input forms, specific to the appropriate category of objects, must be populated and saved to create objects that are incorporated into the model simulation. Previously-created model object data are accessed using drop down menus on each of the object forms. The "Save" button must be used each time an update is made to a model object. **Simply closing the input form will not save the updates!** Specific objects and the calculations associated with these objects are described in detail below.

Also on the Main screen is the title tool bar. Here, the simulation period (start and end dates) is specified (4.) and a button for creating output graphs is available (5.). The simulation “Run” button is clicked to start a simulation. The keystroke “control-R” can also be used to start a simulation.

2.2 Model Objects

SWAM requires a user-constructed network of streams, demand nodes, and reservoirs. Each element in a constructed network is referred to as a model “object”. Each object has its own set of equations and calculations in the underlying SWAM Visual Basic program (often referred to as “object-oriented” code) and its own set of user inputs (described below). In SWAM, relationships between objects are specified through the individual objects themselves, as described below. Spatial locations of objects, and the flows associated with the objects, are inferred by SWAM based on user-specified relative mile markers for each object. The actual magnitudes of these mile markers are irrelevant. Only the relative values are important, as these describe upstream (lower mile markers) and downstream (higher mile markers) positions of objects and flows. SWAM calculates stream flows at each node based on this positioning. Details of individual model objects are provided below.

2.2.1 Tributaries

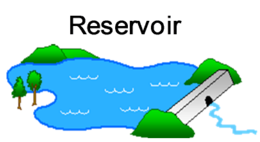


Tributary objects provide the hydrologic drivers for the entire water allocation system. SWAM requires at least one tributary object (“Mainstem”) for a simulated system. The Mainstem tributary object cannot be renamed or deleted. A timeseries of monthly “headwater” flows is specified for each tributary object in the system, as well as the downstream confluence stream and the relative location (on the receiving stream) of the confluence (Table 2-1). The downstream confluence stream for the Mainstem object is set as “none”.

Table 2-1. Tributary Input Parameters

Parameter Name	Units	Description
Tributary name	NA	A unique name must be assigned to each object; "Mainstem" name cannot be modified
Headwater flows	AFM	Monthly timeseries of inflows to the top of the stream
Confluence stream	NA	Name of confluence receiving stream immediately downstream of tributary (specified via a drop-down list of previously-created tributaries)
Confluence location	miles	Relative mile marker, on the receiving stream, of tributary confluence

2.2.2 Reservoirs



Reservoir objects provide for the physical storage of water. The total storage of a reservoir is generally comprised of multiple storage "accounts" associated with various water users (described below). However, the reservoir object is used to define the physical characteristics (including total capacity) of the total reservoir (Table 2-2), including spatial location, storage capacity, surface area, and evaporative (and/or seepage) losses. Monthly reservoir operating release requirements can also be specified in this object.

Evaporative losses can be specified using monthly-varying seasonal rates (inches per day or percent volume) or with a user-specified timeseries of monthly flow losses. Calculated evaporative losses are distributed to individual accounts based on relative volumes of storage in each account at the given timestep. In other words, accounts with larger stored water will realize a greater evaporative loss than accounts with less stored water.

There are two options for defining reservoir release operations in SWAM: simple and advanced. Simple reservoir release rules consist of twelve prescribed mandatory monthly releases. These releases are prioritized ahead of all water user withdrawals. Advanced reservoir release rules can be defined by the user to include up to five (5) different sets of rules governing release operations. Each of these five rules, implemented in order of priority, can consist of either prescribed monthly values (see simple rules) or "conditional" rules based on hydrologic parameter values associated with other objects in the system. Conditional rules can be specified based on storage values (AF) in either individual water user accounts or entire reservoirs, or based on headwater flow rates (AFM). For conditional releases, the user defines the targeted release volume and the conditions (e.g. >, <, = a prescribed value) that must be satisfied for the release to occur. Note that due to the numerical approach utilized in SWAM (see Section 3), for any given timestep (t), conditional releases are determined as a function of the start-of-month storage or the previous month's (t-1) headwater flow.

Reservoir releases are distributed across individual accounts based on storage permit priority (lowest to highest priority). SWAM attempts to assign all of a regulated release to the lowest priority account. If this account is unable to meet the total release volume required (due to lack of physical availability), the model moves on to the next lowest priority account, and so on.

Reservoirs can be defined in SWAM as either "offline" or "online". There are effectively only subtle calculation differences between the two in the model. For online reservoirs, a "flood control pool" is automatically created and handled as a water user, with unlimited physical and legal diversion capacity, in internal model calculations. This ensures that all upstream water gets routed through the online reservoir at each timestep. The size of the flood control pool is calculated internally as the difference between total reservoir capacity and the sum of individual water user accounts. When creating an online reservoir object in SWAM, the user must define how flows are released from the flood control pool via an outflow-capacity table. This type of table would typically express a direct relationship between the magnitude of monthly outflow and the reservoir volume (greater storage equates to greater outflow). In this way, by providing temporary storage and gradual release, an online reservoir smooth's out downstream hydrographs during periods of high flow.

Note that offline reservoir inflows can only be created via the "diversions" of various account-holder objects (water users, agricultural users, and recreational pools) (described below). Without user accounts, offline reservoirs will not fill with water.

Table 2-2. Reservoir Input Parameters

Parameter Name	Units	Description
Reservoir name	NA	A unique name must be assigned to each object;
Reservoir type	NA	Offline or online
Storage capacity	AF	Total physical storage capacity of reservoir
Initial storage	AF	Start of simulation initial volume of water in reservoir
Evaporation input type	NA	Monthly rates of inches per day (option 1) or percent of total volume (option 2), or user-specified timeseries of flow rates (option 3)
Evaporation rates, option 1	in. day^{-1}	Seasonal rates of evaporation (multiplied by calculated surface area, via area-capacity table, to get volumetric losses)
Evaporation rates, option 2	%	Seasonal rates of evaporation (multiplied by calculated volume to get volumetric losses)
Evaporation rates, option 3	AFM	User-defined timeseries of volumetric evaporation losses
Area-Capacity table, option 1	AF / Ac	Surface area vs. storage volume based on bathymetry of reservoir
Reservoir release receiving stream	NA	Name of receiving stream for mandatory reservoir releases
Release location	mi	Relative mile marker (on receiving stream) of reservoir releases
Monthly minimum releases	AFM	Required (regulated) minimum releases for reservoir (if applicable)
Outflow-Capacity table	AFM / % capacity	For online reservoirs only, defines outflows from flood control pool as a function of reservoir storage (percent capacity)

Advanced Release Rules:		
Advanced rules option	NA	Option button for user-specified advanced release rules, rather than simple method; allows for up to 5 different condition release rules that model attempts to meet in order of priority
User-prescribed monthly release targets	AFM	If selected, monthly minimum release targets that model attempts to satisfy at each timestep, in order of release rule priority (1 – 5)
Conditional release rules	NA	If selected, reservoir release rules that are internally determined and conditional on user-specified storage or flow conditions. Storage conditions can be associated with either total reservoir storage or a specific user account storage. Flow conditions are based on headwater flows associated with a specified tributary object. The actual release flow targets, if conditions are met, are specified by the user (AFM).
Conditional object	NA	Name of the object (water user, reservoir, or tributary) whose conditions dictate whether given release occurs
Criteria	NA	<, >, or =
Trigger value	AF or AFM	Storage or flow value threshold that triggers or activates the given release
Release target	AFM	Monthly reservoir release that is targeted if prescribed conditions are met
Release accounts	NA	Name of user account from which release is apportioned; if "all users" is selected then monthly release is apportioned across all user accounts associated with the reservoir in reverse order of storage permit priority (i.e. lowest priority loses water first)

2.2.3 Water Users

Water User

The water user object is the most generalized and versatile of the available demand node objects. It is primarily intended to represent aggregated municipal and/or industrial (M&I) water users.

On the demand side, water users are parameterized by monthly water usage requirements, including specification of indoor vs. outdoor use and consumptive vs. non-consumptive portions of each (Table 2-3). To simplify the parameterization process, preset patterns of seasonal usage, including indoor/outdoor and consumptive/non-consumptive components, are available for typical M&I or agricultural users.

Reuse and conservation demand management options are available that reduce the net demands on water. The reuse option in SWAM assumes a one-time use only of recaptured indoor use return flows (effluent) that can only be applied toward outdoor (irrigation) demands. For conservation, SWAM allows for the use of manual monthly reductions in water use or combinations of previously-parameterized conservation program initiatives. For the latter, SWAM calculates the net final reductions in monthly usage expected for any given combination of conservation programs. The assumed reduction parameters associated with the preset option were derived based on independent analyses and experience and may not be entirely accurate for any site-specific application. However, they are included to provide for quick and easy "what if" simulations of the potential impacts of conservation.

On the supply side, multiple sources of supply (up to five) are available, including direct diversions, storage account withdrawals, and groundwater pumping. SWAM simulates the use of this water according to the preference order (1 – 5) of each source. In other words, if the entire monthly demand can be met with water from source water 1, then no water is used from other available sources (although there still may be accrual in storage accounts). Storage accounts are defined through the water user object with reference to specific reservoir objects. The ability to divert water (for direct use or into a storage account) is dependent on calculated physical and legal availability of the water at the point of diversion. Legal availability is one of the key calculations in SWAM and is based on specified permitted withdrawals and associated priority dates and the prior appropriations doctrine. This doctrine, often referred to as "first in time, first in line", recognizes earlier priority dates as higher priority in the water allocation scheme. SWAM attempts to meet the water demands of water users in order of their priority. Further details of the legal availability algorithm in SWAM are provided in Section 3. Lastly, groundwater pumping as a source of supply can be specified according to monthly pumping rates and an aquifer source (Aquifer object, see Section 2.2.7). Groundwater pumping is applied to meet water user demands at the full prescribed pumping rates, subject to aquifer storage availability (see Section 2.2.7).

Supplemental water supplies can also be specified for the given water user, namely agricultural land transfers and transbasin imports. Agricultural land transfers are simulated as steady seasonal supplies available for direct use or storage augmentation. Transbasin imports provide the user with the ability to move water from a reservoir in one river basin (source) to an account in another river basin (destination). Monthly target inflows are prescribed which define the amount of water transferred, subject to physical availability.

Note that, with respect to transbasin imports, SWAM also has the ability to directly divert (no source-side storage) from a different basin as one of the standard sources of supply for a given water user. In this case, the "transbasin import" option is not needed and the user can simply specify an out-of-basin stream as one of its sources of diverted water. However, if it is desired to move water across basins reservoir to reservoir, then the transbasin import option must be used.

Water exchange programs can be established between two water user supply accounts. Because it requires two supply accounts acting in concert, water exchanges are only available if the "multiple sources of supply" checkbox is selected. A water exchange is defined in SWAM as an agreement whereby an upstream diversion account can only divert water if a downstream partner account releases water from storage of the same amount and in the same timestep. Practically, this allows for diversion and storage to occur at the downstream location during wet periods and direct diversion to occur at the upstream location during dry periods, with no impact on downstream users (since the diversion is offset by releases from the downstream stored water). In SWAM, the downstream storage account in an exchange program can only store and release water to the stream. Water can't be used for consumption from this storage account. Diversion to the downstream storage account can only occur in timesteps where there is no release requirement (i.e. no upstream diversion) and as allowed according to standard water user supply account calculations of physically and legally available flow. For the upstream direct diversion in an exchange program, the model calculates legally and physically available flow at the node following the standard algorithms but then constrains the legally available flow to less than or equal to the total available for release from the downstream partner account. When the seasonality flag is selected (under "Water Exchange" tab), the user can specify the months in which the exchange program is active. For the selected months, upstream diversions and downstream releases can occur as described above. For months when the exchange program is not active (un-selected checkboxes), no diversions to the upstream account are allowed even if downstream storage is available for releases. Note that the downstream account in an exchange program must be assigned to the #5 preference supply account and thus is forced to be the less preferred account in the exchange partnership.

Finally, water user return flows are calculated in the model as a function of water usage and consumptive vs. non-consumptive fractions of this usage. The user must specify where these returns take place (single location or multiple locations) and whether or not the returns are lagged.

Table 2-3. Water User Input Parameters

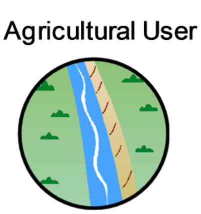
Parameter Name	Units	Description
User name	NA	A unique name must be assigned to each object;
Multiple sources flag	NA	Flag specifying whether multiple sources of water are to be defined
Water Usage:		
Monthly use distribution	NA	Options for populating monthly usage values: with either an annual total use and preset distribution patterns (M&I or Agricultural) or manually by month
Total annual use	AFY	If either of the automated monthly distribution options are selected, then this annual total gets distributed across months according to preset distribution patterns
Monthly usage	AFM	Monthly water usage (before conservation or reuse)
% Indoor use	%	Percent of total monthly usage that is indoor (outdoor usage is calculated internally as the difference)
% CU indoor	%	Percent of total monthly indoor usage that is consumptive (no return flows) (the non-consumptive fraction is calculated internally as the difference)
% CU outdoor	%	Percent of total monthly outdoor usage that is consumptive (no return flows) (the non-consumptive fraction is calculated internally as the difference)

Source Water:		
Source stream	NA	Name of stream from which water is diverted
Source type	NA	Either direct diversion, via reservoir storage account, or groundwater pumping
Downstream location	mi	Relative location of diversion on source stream
Priority date	dd/mm/yyyy	Date of withdrawal permit
Ditch capacity	AFM	Physical capacity of diversion ditch
Diversion right	AFM	Uniform or monthly-varying diversion right
Reservoir name (if applicable)	NA	Name of physical reservoir in which storage account is held
Storage capacity	(AF)	Capacity of storage account
Storage right	(AFY)	Annual total cumulative diversion right associated with storage account
Water year start month	NA	Starting month for tracking annual storage right
Carry over rule	NA	Flag indicating whether stored water remaining in account at the end of the previous year counts toward the annual storage right of the following year
Monthly groundwater pumping rates	AFM	If selected, monthly groundwater pumping rates used to meet demands (subject to aquifer storage availability)
Aquifer name	NA	if selected, name of Aquifer Object that groundwater pumping draws from
Return Flows:		
Locations option	NA	All return flows to a single location or return flows spread out over multiple locations
Receiving stream	NA	Name of receiving stream for return flows
Location	mi	Relative mile marker on receiving stream for location(s) of return flow discharge to the stream
Lag	months	Lag (if any) associated with return flows, relative to month of water use
% of Return flow (for multiple locations only)	%	Percent of total return flow, for given month, that is discharged at each location (sum across locations must equal 100% for each month)

Conservation: (optional)		
Manual vs. preset option	NA	Manual option requires user inputs of monthly water usage reductions (indoor and outdoor), while preset option uses assumed parameters associated with various selected conservation mechanisms to calculate net monthly usage reductions
Indoor/outdoor reduction	%	Percent reduction in water use, by month
% CU indoor/outdoor	%	Percent of indoor/outdoor reduction that is consumptive; these parameters are used for internal calculations of adjustments to overall consumptive use after conservation is applied
Drought-only flag	NA	Flag indicating whether conservation is activated only during user-defined drought conditions
Min-res volume (for drought-only conservation)	%	Percentage of water user storage capacity (for each source water account) that, when reached, triggers conservation
% of pop. (preset option only)	%	Percentage of service area population that is participating in given conservation activity
Reuse: (optional)		
% recapture	%	Percentage of indoor use effluent that gets recaptured for outdoor reuse
Graywater recycling flag	NA	Flag indicating whether to simulate graywater recycling
Ag Transfer (optional)		
Ag lands retired	acres	Total area of agricultural land involved in transfer
Annual CU	AF/acre	Average annual consumptive use of crops in retired ag lands
Irrigation efficiency	%	Amount of water consumed divided by amount of water diverted at farm headgate, expressed as %
Monthly distribution of supply	%	Percentage of annual total water delivery provided by month

Transbasin import: (optional)		
Implicit vs. explicit option	NA	Implicit transbasin imports do not simulate water at the source. Rather, the specified monthly volumes are assumed to be available at every timestep and are simply added to the specified water user account. Explicit transbasin imports explicitly simulate diversions and storage within the source basin and require specification of the source reservoir and account. For explicit imports, the monthly targeted imports may not always be met as they are subject to water availability.
Source reservoir (explicit only)	NA	Name of reservoir in source basin that imports draw from
Source account (explicit only)	NA	Name of account in source reservoir that imports draw from
Target inflow	AFM	Desired monthly import flow for transbasin project
Conveyance loss (explicit only)	%	Percent loss associated with transbasin import
Destination account	NA	Source water account number that transbasin import water is placed (augments existing source water)
Water exchange (optional)		
Upstream diversion account	NA	Account number associated with the upstream diversion component of the exchange program
Downstream release account	NA	Account number associated with the downstream storage and release component of the exchange program. Note that currently the model requires that this be Source Water 5 account)
Seasonal water exchange flag	NA	Flag indicating that exchange program is seasonal (as specified by monthly on/off flags). Note that for months where the exchange is not allowed (monthly flag unchecked), no diversions are permitted by upstream diversion account, but downstream storage account can divert and fill storage according to associated withdrawal permit.

2.2.4 Agricultural Users



The primary difference between this object and the water user object (described above) is the way in which water usage (demand) is calculated or input. The agricultural user object allows for explicit calculation of water demands associated with crop agriculture. Monthly stream demands are calculated as a function of calculated monthly evapo-transpiration (ET) rates, irrigated acreage, and irrigation and conveyance efficiencies (Table 2-4). ET rates are calculated using the well-known Blaney Criddle (or Modified Blaney Criddle) equations as a function of crop type, effective mean monthly precipitation, monthly mean temperature, field elevation, latitude, and crop-specific coefficients. Details of these calculations are provided in Section

3. Crop coefficients for seven crop types (corn, wheat, alfalfa, pasture, potatoes, grain, and beans) have been pre-set in the model. However, these coefficients are easily modified by the user. Additionally, a user-defined crop type is available.

Agricultural user demands can also be hard-entered by the modeler as a monthly timeseries. These need to be entered for the full period of simulation. This feature may be useful when historical diversion flows are known at a particular node and no changes to that node are simulated. *Since the water user object does not allow for direct user inputs of a timeseries of demands, the agricultural user object must be used for this type of node representation (even if not strictly an agricultural node).*

As with the generalized water user object, up to five different source water accounts may be utilized for any given agricultural user. Each of these can either use water directly from the source stream (direct diversion), from a reservoir account, or from groundwater pumping. These sources of water are modeled in the same manner described above for the Water User object. Transbasin imports are also available to supplement an agricultural user's local sources.

Return flow percentages are either calculated within the model interface (if demands are calculated) as a function of irrigation efficiency and ditch loss, or are directly input by the user (if demands are input). If calculated, water returned to the stream is equal to the water lost during conveyance (ditch loss) plus the water lost due to irrigation inefficiencies and over-watering. Return flow locations (up to five different locations) are specified by the user in the same manner as the water user object (above).

Table 2-4. Agricultural User Input Parameters

Parameter Name	Units	Description
User name	NA	A unique name must be assigned to each object;
Multiple sources flag	NA	Flag specifying whether multiple sources of water are to be defined
Water Usage:		
Blaney Criddle ET option	NA	Original Blaney Criddle (U = KF) or SCS modified equation (includes extra climatic factor)
Irrigated acres	acres	Area of land to be irrigated associated with given node
Ditch loss	%	Percent of headgate diversion water that gets lost (e.g. via leakage) during conveyance to fields
Irrigation efficiency	%	Represents all on-field losses of water, including excess application, leakage, and evaporation
Elevation	ft (absl)	Approximate elevation of irrigated acreage
Latitude	degrees	Approximate latitude of irrigated acreage (used for calculating daylight hours in given month)
Crop factors (Kc)	unitless	Empirical factors used in Blaney Criddle equations specific to crop type and growth stage

Duration of growth stage	days	User-defined (or pre-set) number of days in given growth stage; used for applying the crop factors (Kc)
% of total acreage	%	For each crop type, the percent of the total node irrigated acreage used for growing given crop
Start month	NA	Growing season starting month for given crop (note that duration of growing season is defined by growth stage durations described above)
Temp	°F	mean monthly temperature
Precip	inches	mean monthly precipitation
Source Water:		
(see water user object)		

2.2.5 Instream Flow Objects

Instream Flow

Instream flow objects allow for the prioritization of stream flows to meet environmental or recreational goals (Table 2-5). Monthly flow rights are specified along with a priority date associated with those rights. Maintaining the target flows then becomes a priority over junior diversion rights. If flow targets are not achieved, a “shortage” is calculated and reported by the model. Instream flow objects are also useful for explicitly tracking and reporting stream flows at specific points in the network. If an instream flow object is to be used merely for outputting stream flows, then the priority date should be set such that it does not impact other water users in the system.

Table 2-5. Instream Flow Object Input Parameters

Parameter Name	Units	Description
Instream Flow name	NA	A unique name must be assigned to each object;
Target stream	NA	Name of stream associated with instream flow target
Downstream location	mi	Relative location of instream flow on source stream
Priority date	dd/mm/yyyy	Date of withdrawal permit
Flow right	AFM	Monthly-variable or constant instream flow right

2.2.6 Recreation Pool Objects

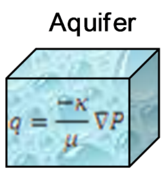
Recreation Pool

Recreation pool objects are used to prioritize the maintenance of a reservoir pool. In other words, water is diverted as needed and as available to maintain a user-specified volume of water in a given reservoir. Often this water might be for recreational purposes, such as boating, fishing, or swimming. The pool target might also be for hydropower purposes. Generally, the only losses associated with a recreation pool are evaporative. In some cases, regulated reservoir releases are also drawn from the recreation pool, depending on the assigned priority of the pool. See discussion on the distribution of reservoir evaporative losses and regulated releases in Section 2.2.2. Note that a recreation pool can only be created for an existing reservoir (which needs to be created first). Object parameters are listed in Table 2-6.

Table 2-6. Recreation Pool Object Input Parameters

Parameter Name	Units	Description
Reservoir name	NA	A rec pool may only be added for an existing reservoir (only 1 rec pool per reservoir allowed)
Source stream	NA	Name of stream from which water is diverted
Downstream location	mi	Relative location of rec pool diversion on source stream
Priority date	dd/mm/yyyy	Date of withdrawal permit
Pool volume	AF	Target volume of recreation pool

2.2.7 Aquifer Objects



Aquifer objects are used to track groundwater storage as subject to pumping by single or multiple users (water users and/or ag users). Storage calculations are performed at each timestep as a function of: total groundwater pumping associated with the aquifer (calculated), monthly aquifer recharge rates (prescribed), and initial aquifer storage (prescribed). Aquifer objects are simulated as a fully contained and lumped storage vessel. Any upgradient or lateral inflows or downgradient lateral outflows are neglected.

In addition to tracking groundwater storage, aquifer objects can be used to estimate water table drawdown, at up to five (5) different monitoring well locations, as a function of aggregate pumping rates and aquifer hydraulic properties. Drawdown calculations are only available for confined aquifers. Aquifer drawdown is calculating using a polynomial approximation to the Theis Equation (Abramowtz and Stegun, 1968). Application of the equation has been extended in SWAM to handle time-variable pumping rates. The equation assumes a homogeneous isotropic confined aquifer and fully penetrating wells. It also assumes that the aquifer is infinite in radial extent. Aquifer hydraulic properties are defined according to user-prescribed storativity and transmissivity values. Drawdown is calculated at each simulation timestep for up to five specified "monitoring well" locations. The locations are parameterized according to a table of user-defined radial distances between monitoring well and pumping well (or wellfield). The impacts of each water user or ag user pumping well /wellfield are included in the cumulative drawdown calculations.

2.3 Model Output

Monthly output for all model nodes are written to the "Node Output" worksheet in SWAM. Brief descriptions of each output parameter are provided below. For water user or agricultural user objects with multiple sources of water, SWAM provides detailed output for each source account as well as the totals for the object.

- <u>Physically available (AFM):</u> This is the physical stream flow just upstream of the point of diversion. Physical availability is calculated as a function of upstream headwater flows, node diversions, and node return flows.
- <u>Legally available (AFM):</u> This is the total flow that can legally be diverted at the point of diversion. As discussed elsewhere, legal availability is calculated in SWAM as a function of downstream priority demands, node monthly diversion and annual storage rights, and physical

flows in the system. Note that in times of surplus water, SWAM reports the non-limiting legal availability as the physical availability + node return flow.

- Diverted (AFM): This is the actual amount diverted for the given node. It is generally the smaller of physical availability, legal availability, and desired diversion total. Note that the "desired diversion total" here refers to the net usage demand plus any storage make-up water to fill available capacity (e.g. make-up for evaporative or release losses).

- Storage (AF): This is the node storage account volume (if applicable) at the end of the given timestep. This value is calculated as a function of diverted flow (inflow) and demand withdrawals, account evaporative losses, and account regulated releases (outflows). The actual volume resides in the associated "parent" reservoir.

- GW Pumping (AFM): Monthly groundwater pumping rates by the user associated with the given node (if applicable).

- Demand (AFM): This is the net water usage demand on the stream for the given node at the given timestep. Demand is calculated as a function of user-input (or calculated) monthly usage values and reuse and conservation impacts (if applicable).

- Shortage (AFM): This is the monthly shortfall in water supply and represents the difference between demand and demand met. Demands are met through both direct diversion water and storage account withdrawals. In the case of instream flow objects, shortages are simply the difference between the instream flow target and the actual physical flow at the node. For recreation pools, the reported shortage reflects the difference between targeted rec pool volume and actual pool volume.

- Return Flow (AFM): This is the monthly returns to the stream after node usage. These are calculated in SWAM as a function of user-input consumptive use percentages, actual demand met, and reuse considerations (if applicable). Note that if the node return flow lag is > 0, then reported return flows reflect the calculations associated with the timestep at t - lag.

- Release (AFM): This is the monthly storage regulated release associated with the node storage account (if applicable). As discussed in Section 2.2.2, total reservoir regulated releases are distributed by the model across individual storage accounts according to permitted withdrawal priority (lowest to highest priority). These releases decrease storage account volume and are unavailable for node use.

Output specific to reservoir objects are provided in the "Reservoir Output" worksheet. These output are described below.

- Storage (AF): This is the total volume of water in the physical reservoir at the end of the given timestep. This volume is inclusive of all of the individual user accounts and, if applicable, the recreation pool associated with the reservoir. This value is calculated as a function of total inflows to the reservoir ("diversions" to storage by various accounts) and total outflows from the reservoir (evaporation + regulated releases + user withdrawals).

- Excess Volume (AF): Currently, this output variable only reflects the result of specifying an initial reservoir volume that exceeds the sum of all account capacities held by the reservoir. It is water that is not "owned" by any of the child accounts of the reservoir and is included in the output only to provide for complete water balances during the early timesteps of a simulation (when initial conditions are impacting calculations).

- Overflow (AFM): Currently, the output variable is provided only to resolve water balances in the case of the sum of individual account storage capacities exceeding total reservoir physical storage capacity. Since this situation is technically user-input error, the overflow output parameter should be used for debugging purposes only. Note that since SWAM does not explicitly simulate online reservoirs, flood overflows (spills) are implicitly reflected in the stream flows that bypass the model reservoir object.

- Release (AFM): This is the total reservoir regulated release for the given timestep. In most cases (unless there is excess volume) this value will be the sum of the individual account releases provided in the “Node Output” worksheet.

Output specific to aquifer objects are provided in the “Aquifer Output” worksheet. These output are described below.

- Storage (AF): This is the total volume of water stored in the aquifer at the end of the given timestep. This value is calculated as a function of aggregate groundwater pumping rates by all users associated with the aquifer, specified aquifer recharge rates, and a specified initial storage value.

- Recharge (AFM): This is an output of the input values specified by the user on the aquifer input form and represents total monthly recharge to the aquifer.

- Total Pumping (AFM): These are the total pumping withdrawals from the aquifer, representing the sum of all water user and ag user pumping for the given timestep.

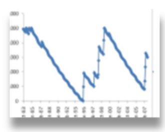
- Drawdown 1 – 5 (ft): Water table drawdown levels at given timestep for monitoring well locations 1 – 5 (defined by user), calculated as a function of pumping rates and aquifer hydraulics using the Theis analytical solution.

Note that neither the “Node Output” nor the “Reservoir Output” worksheets should ever be deleted by the user (the model won’t know where to place output)!

In addition to the raw timeseries output data described above, graphical output summaries can easily be created on the “Main” page using the “Output Plotting” control button (below).

Lastly, an option (button shown below) is available in SWAM to output timeseries data to an external text file rather than to the output worksheets. This is provided as a means of greatly reducing simulation run times for larger, more complex models. Text file outputting can only be for a single user-specified node. Therefore the model must be run multiple times to generate text file output for all nodes (still may save simulation time for larger models). Normal worksheet outputting can be done for all nodes during a single simulation or, for improved efficiency, for a single targeted node.

2.4 Reservoir Firm Yield Calculations



In addition to the normal water allocation simulation mode described above, SWAM contains an alternative simulation option whereby automated firm yield calculations are performed for a specified reservoir object. Under this simulation, full outputting of network parameters is not provided. Instead, only final firm yield values are provided. Firm yields are calculated through internal simulation iterations of the full networked system with adjustments made to targeted reservoir water user demands until the firm yield is identified. For these purposes, firm yield is defined as the minimum annual reservoir demand that can be sustained throughout the period of simulation. The model iterates until zero storage in the targeted reservoir account is exactly achieved during the simulated critical drought period. Firm yields are calculated for a specified reservoir user account and are a function of tributary flows, monthly demand patterns, reservoir evaporation rates, and higher priority demands (either upstream or downstream) in the simulated system.

Firm yield calculations can be performed in SWAM for multiple “alternative hydrology” input data sets. Users can prescribe multiple monthly timeseries sets of upstream tributary flows with the model calculating, in “batch” mode, firm yields for each hydrologic scenario. These alternative hydrologies might represent, for example, various climate change forecasts derived from Global Climate Model (GCM) projections. Two sets of hydrology projections can be prescribed, each with up to ten (10) different data sets. This format was implemented in recognition of a common approach to climate change modeling whereby separation is maintained between groups of projections specific to assumed greenhouse gas emission scenarios. For example, a user might prescribe a set of ten hydrologic projections developed for the A2 (worst case) greenhouse gas emission scenario and another ten for the B1 (best case) emission scenario. Model simulations are performed independently for each group. Output from the batch mode simulation are provided in the form of a table of firm yield values. Output can also be summarized by the model in probability (normal) distribution functions fitted to the output data. This type of summary provides quantification of the levels of model consensus across scenarios and is often useful for planning decision-making.

Section 3

Technical Documentation

This section provides detailed descriptions of the fundamental equations and algorithms employed by SWAM.

3.1 Diversions

For every timestep, t, diversions are calculated for each node as a function of physical availability, legal availability, net user demand, and physical diversion capacity. Within each timestep, these calculations are performed in order of node ranking by withdrawal permit (highest priority to lowest priority). The overall equation for calculating node diversions can be written as:

$$Q_{div} = \min\left(Q_{phys}, Q_{avail}, demand, capacity\right) \qquad (3\text{-}1)$$

Where Qphys = physically available water at point of diversion, Qavail = legally available water at point of diversion, demand = net demand on stream by node, and capacity = physical (ditch) capacity of diversion.

Physical availability at any given node is calculated as a function of upstream tributary flows, node diversions and return flows, and reservoir regulated releases. This calculation can be written as:

$$Q_{phys}^{i} = \sum_{j=i-1}^{j=0} Q_{HW}^{j} - Q_{div}^{j} + Q_{RF}^{j} + Q_{release}^{j} \qquad (3\text{-}2)$$

Where index i designates the relative downstream position of the node and j designates the upstream locations of tributary inflows, node diversions, node return flows, and reservoir releases.

Legal availability is calculated for each node, again in descending order of priority, as a function of monthly diversion right, annual storage right (if applicable), downstream priority demands, return flows, and downstream physical availability. This calculation follows the algorithm used in the State of Colorado's StateMod model ("Direct Solution Algorithm"). The first step in the algorithm is calculating the minimum flow left in the river at all downstream nodes after priority water users have diverted their allowable amount. This step can be written as:

$$Q_{avail'}^{i} = \min\left([Q_{phys}^{i+1} - Q_{div}^{i+1}], [Q_{phys}^{i+2} - Q_{div}^{i+2}], [Q_{phys}^{i+3} - Q_{div}^{i+3}], \dots [Q_{phys}^{i+n} - Q_{div}^{i+n}\right) \qquad (3\text{-}3)$$

Where i refers to the relative downstream position of the node and n = number of downstream nodes. Because of the order of node calculations, only higher priority downstream users will have non-zero Qdiv values in this equation.

The second step in the calculation of legally available flow is the recognition of the availability of return flow from the given node to downstream users. An adjustment is made to the previously calculated Qavail to account for these return flow "credits":

$$Q^{i}_{avail''} = \frac{Q^{i}_{avail'}}{1-\%RFi} \tag{3-4}$$

Where % RFi = percent return flow at node i. This step essentially allows for the diversion of additional water due to recognition of the return flows on that diversion that can then be used to satisfy downstream priority users.

The final steps in the calculation of legally available flow are checks against the node's monthly diversion right and annual storage right, both user input. The model constrains the legally available flow to the less of the monthly diversion right and the previously calculated Qavail. It also ensures that the total cumulative diversion for the given water year does not exceed the user-specified annual storage right (if applicable). This can be written as:

$$Q^{i}_{avail} = \min(Q^{i}_{avail''}, diversion\ right, \Delta storage\ right) \tag{3-5}$$

Where *Δstorage right* = the remaining "cap" space in the annual storage right allotment (annual storage right – total water year cumulative diversion to-date).

The demand at each node is calculated as a function of the available storage space in a reservoir account (if applicable) and the actual water usage for a given timestep. For a water user or agricultural user with a storage account, the model first attempts to meet water usage demands with stored water, then looks to the available stream water to make up the difference and replenish storage. This can be written as:

$$demand^{i} = storage\ gap + \Delta S^{i} \tag{3-6}$$

Where demand = the demand on source stream at given timestep for node i, storage gap = timestep demand - storage water withdrawal (see Section 3.2), and ΔS = available storage space (capacity – S) in account for node i after withdrawals.

Finally, as described in Equation 3-1, the model considers the physical capacity of the diversion structure, i.e. ditch or pipeline. This is simply a user-specified value that may or may not be constraining, depending on the other terms in the equation.

3.2 Water Users

The water user calculation module (WaterUserCalc) is called twice within each simulation timestep. The first call is prior to the calculation of diversions (described above). During this call, initial storage calculations are performed with all available storage used to meet node demands as needed. If there is not enough storage to meet the total demand, the "storage gap" is carried over to the calculation of stream diversion demands (Equation 3-6, above). The available storage space (ΔS) is also calculated in this first iteration and carried through to the stream diversion demand calculations. The second call to the water user calculation module incorporates the stream diversion and updates storage values, node shortages, and return flows. WaterUserCalc also includes calculation of various optional supply and demand management alternatives, including conservation, reuse, agricultural transfers, transbasin imports, and water exchanges.

Key equations associated with the water user object include calculations of storage, shortages, return flows, and the dynamics of multiple source accounts with a single water user (and single set of demands). Water user storage is calculated as a function of diversions, withdrawals, evaporation, and releases using the standard water balance equation:

$$\frac{dS}{dt} = inflow - outflow \qquad (3\text{-}7)$$

In SWAM, the numerical solution to this equation looks like:

$$S_i^t = S_i^{t-1} + diversion_i^t - demand_i^t - evap_i^t - release_i^t \qquad (3\text{-}8)$$

where Sit = storage volume at time t, diversion = stream diversion (= 0 for first call to WaterUserCalc), demand = demand for storage water to meet water user needs, evap = reservoir evaporation credited to storage account (see Section 3.4), and release = mandatory storage account release to fulfill reservoir release obligations or exchange program offset requirement.

In SWAM, Equation 3-8 is first applied using the full water user demand. If the demand exceeds the available storage (after mandatory releases and evaporation), then the result will be a negative storage value (Sit < 0). In this case, the model sets the storage to 0 and assigns the difference (the negative storage) to the "storage gap" variable used in Equation 3-6, for the 1st call to WaterUserCalc, or to the final node shortage, for the 2nd call to WaterUserCalc.

Water user return flows are calculated according to:

$$RF_i^t = (1 - \%CU) * demandMet \qquad (3\text{-}9)$$

Where RFit = return flow volume for given timestep, %CU = percent consumptive use associated with the water user demand, and demandMet = the actual demand met by storage water + diversion water.

When a water user includes multiple sources of water (see Section 2.2.3), SWAM calculates each account as if a stand-alone water user object. These calculations proceed in order of source account preference. SWAM attempts to meet all water user demands using the 1st preference source account, before moving to the 2nd, and so-on. Residual demands (shortages) are carried over from one account to the next account by setting the demand variable of the next preferred account to the residual demand (shortage) of the previous account. Timestep iterations are performed with these adjusted demands until either the total original demand is met, or all sources of supply are exhausted. An illustrative example is provided below.

<u>Example of Multiple Source Account Distribution of Demands, For Timestep t:</u>

Original total demand = 100 AF

Iteration 1:

Account #1 demand = 100 AF

Account #2 demand = 0 AF

Account #3 demand = 0 AF

Account #1 supply (storage + diversion) = 50 AF

Total Shortage = 50 AF

Iteration 2:

Account #1 demand = 50 AF

Account #2 demand = 50 AF

Account #3 demand = 0 AF

Account #2 supply (storage + diversion) = 25 AF

Total Shortage = 25 AF

Iteration 3:

Account #1 demand = 50 AF

Account #2 demand = 25 AF

Account #3 demand = 25 AF

Account #3 supply (storage + diversion) = 20 AF

Total Final Shortage = 5 AF

End Iterations.

3.3 Agricultural Users

Agricultural users are handled as water users in SWAM and utilize the same code. Differences compared to standard (M&I) water users are:

- Ag User return flow percentages are used directly within the WaterUserCalc module, rather than percent consumptive use (see Equation 3-9). As described in Section 2.2.4, these percentages are either user-defined or calculated within the user-interface as a function of irrigation efficiency and ditch losses.
- Demands can either be user-specified (full timeseries) or calculated within the user-interface according to the Blaney-Criddle equation (modified or original) for crop ET.

Return flow calculation:

$$\%RF = \%ditchLoss + (100 - \%ditchLoss) * \%irrEffic \qquad (3\text{-}10)$$

where *%ditchLoss* = ditch loss percentage and *%irrEffic* = irrigation efficiency.

Ag demand calculation (Blaney Criddle):

$$u = kt * kc * f \qquad (3\text{-}11)$$

$$kt = \max(0.0173 * T - 0.314, 0.3);\ Modified\ Blaney\ Criddle \qquad (3\text{-}12)$$

or

$kt = 1;\ Original\ Blaney - Criddle$

kc = $WF_1 * kc_1(t) + WF_2 * kc_2(t) + WF_3 * kc_3(t) + \ldots..$ (3-13)

$$WF_i = \frac{A_i}{A} \quad (3\text{-}14)$$

and

$$demand = \frac{u}{12} * A - \frac{P_{eff}}{12} * A \quad (3\text{-}15)$$

where u = crop ET (inches), kt = climate factor for modified Blaney-Criddle equation, kc = aggregate crop factor that is calculated as a weighted average of user-defined crop-specific factors that vary according to growing season stage, T = mean air temperature, f = temperature and daylight factor, A = total irrigated acreage, A_i = irrigated acreage for crop type i, and P_{eff} = effective precipitation (inches).

3.4 Reservoirs

Reservoir objects are comprised of single or multiple water user storage accounts. The primary purposes of the Reservoir object calculations are to aggregate account storage values for outputting and to calculate reservoir evaporation and releases and distribute these losses across appropriate user accounts. Specific account storage calculations are described in Section 2.2. Reservoir object calculations are performed at the start of each simulation timestep (in the sub-routine "ResCalc"). Start of month total reservoir storage is calculated as the sum of all relevant user account storage values calculated in the previous timestep (see Equations 3-7 and 3-8). Evaporation and release calculations are linearized in SWAM by formulating as a function of start-of-month reservoir storage only. This is an approximation, but is deemed adequate for this planning level model.

Evaporation losses are calculated as a function of user-defined monthly rates (in mo-1) and start-of-month surface area, or as a function of user-defined monthly percent volumetric losses and start-of-month storage. Alternatively a timeseries of monthly evaporation losses (AFM) can be prescribed by the user. As an example, the former can be written as:

$$evap^t = evapRate^t * area^{t-1} \quad , \quad (3\text{-}16)$$

where evapt = evaporation loss (AFM) at timestep t, evapRatet = prescribed monthly loss rate corresponding to timestep t, and areat-1 = reservoir surface area at start of timestep t (or end of timestep t-1).

As described previously (Section 2.2), calculated evaporative losses are distributed to individual accounts based on relative volumes of storage in each account at the given timestep. In other words, accounts with larger stored water will realize a greater evaporative loss than accounts with less stored water. This distribution occurs within the Reservoir object module at the start of the given timestep.

Similar to evaporation losses, reservoir releases are either calculated as a function of start-of-month hydrologic conditions or are prescribed by the user as mandatory monthly release volumes. For the latter, the model releases the prescribed amount as available in storage (after evaporation losses). For the former, "advanced" reservoir release rules, the model calculates release requirements as a function of downstream hydrologic conditions. These conditions equate to those calculated in the previous timestep (start-of-month storage or previous month flow).

Reservoir releases are distributed across individual accounts based on storage permit priority (lowest to highest priority). SWAM attempts to assign all of a regulated release to the lowest priority account. If this account is unable to meet the total release volume required (due to lack of physical availability), the model moves on to the next lowest priority account, and so on.

Since allocation of evaporation and release losses to individual user accounts is performed at the start of each timestep, these values are incorporated into subsequent water user water balance calculations.

For online reservoirs, flood control pool outflows are calculated as a function of start-of-month reservoir storage and user-defined outflow-capacity tables. Like releases, flood control pool outflows are calculated after evaporation calculations for each timestep. Therefore storage volumes used to calculate outflows equate to start-of-month values minus evaporation losses for the current month. Note that flood control pool outflows are included in the total release volume required to satisfy prescribed monthly release requirements. In other words, if a prescribed mandatory monthly release is 10,000 AFM, and 5000 AFM is calculated for the flood control pool outflow, then only an additional 5000 AFM is required to satisfy the release requirement.

3.5 Instream Flow Objects

Instream flow objects are handled as non-consumptive water user objects (Section 3.2) in the model. Instream flow objects impart a monthly demand on the system, parameterized according to a permit and priority date, but all allocated flows are 100% immediately returned to the system and no water storage occurs. In this way, no flow depletions occur while still imparting a flow demand. Internally, calculations follow those described for water user objects above but with storage set to zero, return flow percentages set to 100%, and return flow location set to the same as the point of diversion.

3.6 Recreation Pools

As above, recreation pools are included in the model calculations as non-consumptive water user objects. Reservoir recreation pool object demands are calculated as the difference between the specified rec pool target volume and the actual pool volume at the start of the timestep. Water usage for the rec pool object is set to zero. Consequently, the only losses of water for a rec pool object are evaporation. As with any water user object, rec pools are parameterized with a storage permit priority date. The rec pool permitted withdrawal volume is set internally so that it is non-limiting (106 AFY). Water therefore gets allocated to a rec pool based on its priority date and the pool demand (difference between target and beginning of timestep volume).

3.7 Aquifer Objects

Aquifer storage is calculated via a standard storage water balance:

$$\frac{dS}{dt} = inflow - outflow \qquad (3\text{-}7)$$

In SWAM, the numerical solution to this equation looks like:

$$S_i^t = S_i^{t-1} + recharge_i^t - \sum_{j=1}^{n} GWpumping^t$$

where i = aquifer index, S = storage at end of given timestep, recharge = monthly aquifer recharge rate, j = index for all water users that pump from aquifer i, n = number of water users that pump from aquifer i. Groundwater pumping rates are calculated internally for each water user or ag user object as a function of demands and availability and priority of other sources of supply.

Aquifer drawdown is calculated using a polynomial expansion of the Theis equation. The Theis equation can be written as:

$$s = \frac{Q}{4\pi T} W(u)$$

$$u = \frac{r^2 S}{4Tt}$$

where s = drawdown (change in hydraulic head at a point in space as a function of cumulative impacts from pumping since the start of pumping), u = dimensionless time parameter, Q = pumping rate, T = aquifer transmissivity (L^2/t), S = aquifer storativity (unitless), r = distance from the pumping well to the drawdown observation point, t = time since pumping began, and W(u) is the well function. In SWAM, the well function (W(u)) is approximated by a multi-term polynomial presented in Abramowtz and Stegun (1968). SWAM applies convolution principles to calculate the combined impacts of multiple pumping wells, in different locations, with time-variable pumping rates.

3.8 Reuse

Reuse is a demand management option for water user objects. In SWAM, the only form of reuse explicitly available under this option is direct recapture of indoor usage return flows (wastewater treatment plant effluent). When this option is selected by the user, net monthly water demand is adjusted at each timestep according to:

$$demand^t = total\_usage^t - total\_indoor\_usage^t * (1 - \%CU) * \%reuse$$

where %reuse = a user-specified percentage of indoor return flows that gets recaptured for reuse and %CU = percent consumptive use associated with the indoor usage. Return flows from a water user implementing reuse are also reduced accordingly.

3.9 Conservation

A net monthly conservation percentage is calculated at each timestep as parameterized by the model user. This percentage corresponds to a percent reduction in water usage. Different percentages are calculated for indoor use versus outdoor use. The percentages are applied according to:

$$totalUsage^t = indoor\_usage^t * \left(1 - \%Cons^{in}\right) + outdoor\_usage^t * (1 - \%Cons^{out})$$

where %Consin = monthly percent conservation reduction in indoor water usage at timestep t, and %Consout = monthly percent conservation reduction in outdoor water usage at timestep t.

3.10 Transbasin Imports

Transbasin import water gets added to the total supply portfolio of a water user at each timestep. Import water is calculated as a function of specified transbasin delivery targets, source water availability, and conveyance losses (if any). In SWAM, transbasin water automatically gets added to the total supply of the assigned water user, regardless of demand. If a surplus in supply in a given month results, the surplus is returned to the river. In other words, transbasin import water, if designated by the water user, represents a continuous additional water source for a modeled basin.

3.11 Agricultural Transfers

As with transbasin imports, agricultural transfers are simulated in SWAM as supplemental sources of supply for a given water user. Ag transfer water deliveries are calculated as a function of user-defined irrigated acreage that gets retired, the irrigation consumptive use associated with the acreage, irrigation efficiency, and a monthly distribution of irrigation demands. As above, ag transfer water, when selected by the user, represents a continuous source of supply to the water user, and ultimately the modeled surface water basin, independent of demand.

3.12 Groundwater Pumping

Groundwater pumping is available as a source of supply for water user and agricultural user objects in SWAM. Groundwater supply is calculated in the model as a function of user-specified target pumping rates, net demand for groundwater, and aquifer storage availability. A key difference between groundwater as a source of supply and the supplemental supplies described above is that groundwater pumping is constrained by demand at each timestep. In other words, groundwater will not be pumped if there is not a need for it in a given simulation month.

Groundwater pumping return flows are included in the calculation of total surface water returns from a given water user.

3.13 Water Exchanges

Water exchange programs can be established between two water user supply accounts. Because it requires two supply accounts acting in concert, water exchanges are only available if the "multiple sources of supply" checkbox is selected. A water exchange is defined in SWAM as an agreement whereby an upstream diversion account can only divert water if a downstream partner account releases water from storage of the same amount and in the same timestep. Practically, this allows for diversion and storage to occur at the downstream location during wet periods and direct diversion to occur at the upstream location during dry periods, with no impact on downstream users (since the diversion is offset by releases from the downstream stored water). In SWAM, the downstream storage account in an exchange program can only store and release water to the stream. Water can't be used for consumption from this storage account. Diversion to the downstream storage account can only occur in timesteps where there is no release requirement (i.e. no upstream diversion) and as allowed according to standard water user supply account calculations of physically and legally available flow. For the upstream direct diversion in an exchange program, the model calculates legally and physically available flow at the node following the standard algorithms but then constrains the legally available flow to less than or equal to the total available for release from the downstream partner account. When the seasonality flag is selected (under "Water Exchange" tab), the user can specify the months in which the exchange program is active. For the selected months, upstream diversions and downstream releases can occur as described above. For months when the exchange program is not active (un-selected checkboxes), no diversions to the upstream account are allowed even if downstream storage is available for releases. Note that the downstream account in an exchange program must be assigned to the #5 preference supply account and thus is forced to be the less preferred account in the exchange partnership.

Section 4

References

Abramowtz and Stegun 1968. Handbook of Mathematical Functions with Formulas, Graphs, and Mathematical Tables. 7th Edition. United States Department of Commerce.

CDM Smith