Land Atmosphere Water Simulator

LAWS 2.0

RECLAMATION
Managing Water in the West

February 2009 – Revised August 2011

Land Atmosphere Water Simulator (LAWS)

Version 2.0

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LAWS V2 Users Manual

NOTE TO USERS: LAWS V2 Help File can also be used to access much of the information contained in this manual while running LAWS.

Table of Contents

Overview

This section provides background information about the structure and functionality included in the Land Atmosphere Water Simulator (LAWS) Version 2.0 model.

Introduction

The Land Atmosphere Water Simulator (LAWS) is a tool designed for the management of large-scale, multi-organizational water supply systems. LAWS differs from other water management models in several significant ways.

First, LAWS simulates daily, field-scale land, crop, and water management practices. It provides users with tools to simulate alternative methods for managing soil moisture on a daily basis during the irrigation season based on soil properties, crop type and growth stage. This approach permits LAWS to compute evapotranspiration, soil water content, surface water ponding, runoff, canal and drain losses, return flows to rivers, and deep percolation to groundwater at level of spatial and temporal resolution not present in existing planning and operations models. Although LAWS performs these calculations at the field scale, LAWS also provides users with ability to aggregate these results within larger user definable areas so that water budgets can be readily computed for arbitrary organizational regions.

Second, LAWS does not solve any governing flow equations except continuity nor is it an optimization model. However, LAWS V2 does offer several capabilities not typically found in most water resource system operations models. These features include the ability to simulate soil evaporation and crop transpiration as separate components of evapotranspiration, effects of soil moisture content on crop transpiration, crop rotations and root zone dynamics, effects of unsaturated flow on infiltration and runoff, effects of irrigation on water quality and effects of groundwater pumping on aquifer water levels and stream seepages. These effects are all simulated using analytical functions as opposed to numerical methods. This approach allows LAWS to be very computationally efficient but it requires the LAWS user to provide key input data from other sources of information such as field studies, remote sensing, GIS databases, physical process models, and expert judgment. In some instances such as for unsaturated flow soil properties and groundwater simulation, LAWS provides tools to assist the user in model parameterization. Although LAWS provides users with multiple methods for allocating water supplies and making priority based delivery decisions, LAWS does not employ any mathematical methods to determine what is the "best" allocation of water. In contrast, LAWS provides users with a powerful graphical user interface (GUI) that allows users to readily change water allocation and delivery priorities, land and crop management practices, and infrastructure characteristics to compare the effects of alternative system configurations on reservoir water supplies.

Third, LAWS has a native GIS capability built directly into the GUI. This GIS capability allows users to setup and analyze spatially accurate LAWS simulations across a span of scales ranging from large regional watersheds to sub-regions contained with individual fields. LAWS also provides users with the capability to import imagery, maps, and GIS information developed with commercially available software packages. Furthermore, LAWS has been developed from the Corp of Engineers Water Management System (CWMS) software from which it has inherited a powerful suite of tools to examine model outputs including side by side comparisons of outputs from multiple alternative simulations and animations of spatial and temporal time series results.

System Manager

LAWS captures both the spatial and hierarchical organization of a water supply system. In LAWS, the supply system is conceptualized as a series of nested spatial units that range in size from multi-regional watersheds to individual land units as small as fields. The largest scale land area is associated with a System Manger (SM). In a LAWS simulation, there may be one or more SMs. At the next smaller spatial scale, each Area Manager (AM) manages a particular region within the system. Within these regions, there are one or more Delivery Managers (DM). These DMs represent sub-regions within the AM region where water management is performed differently based on some unique characteristics of the land or the water supply associated with the sub-region. At the smallest scale, an individual land unit is represented by a Land Manager (LM). Each LM is located within a single DM sub-region. In LAWS, the geospatial locations of major reservoirs, rivers, canals and drains are explicitly located through its GIS capability down to the AM-scale. Although simulated mathematically, smaller scale conveyance infrastructure at the DM- and LM-scales is not explicitly geospatially referenced. The LAWS spatial organization is shown in Figure 1 below.

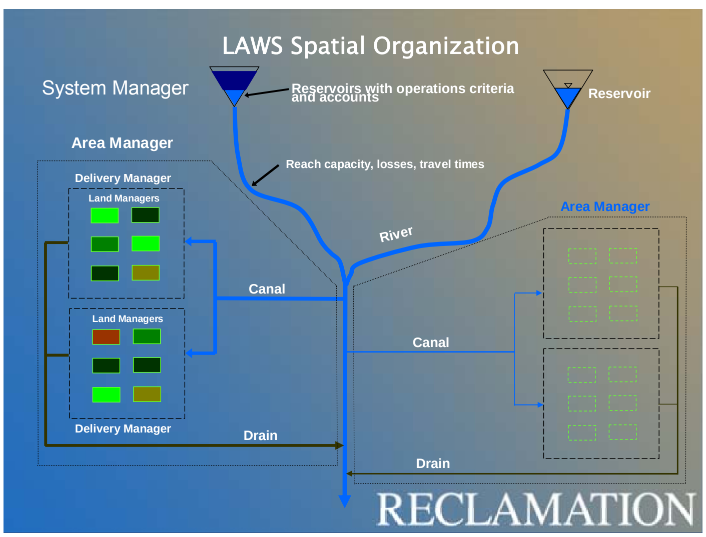


Figure 1. LAWS Spatial Organization

The LAWS hierarchical organization represents the basic structure for managing requests for water supplies and making management decisions necessary for determining the amounts of water to be released from reservoirs as well as the amounts of supply to be provided by groundwater pumping and drain water reuse by individual Land Managers. The LAWS hierarchical organization is presented on Figure 2 below.

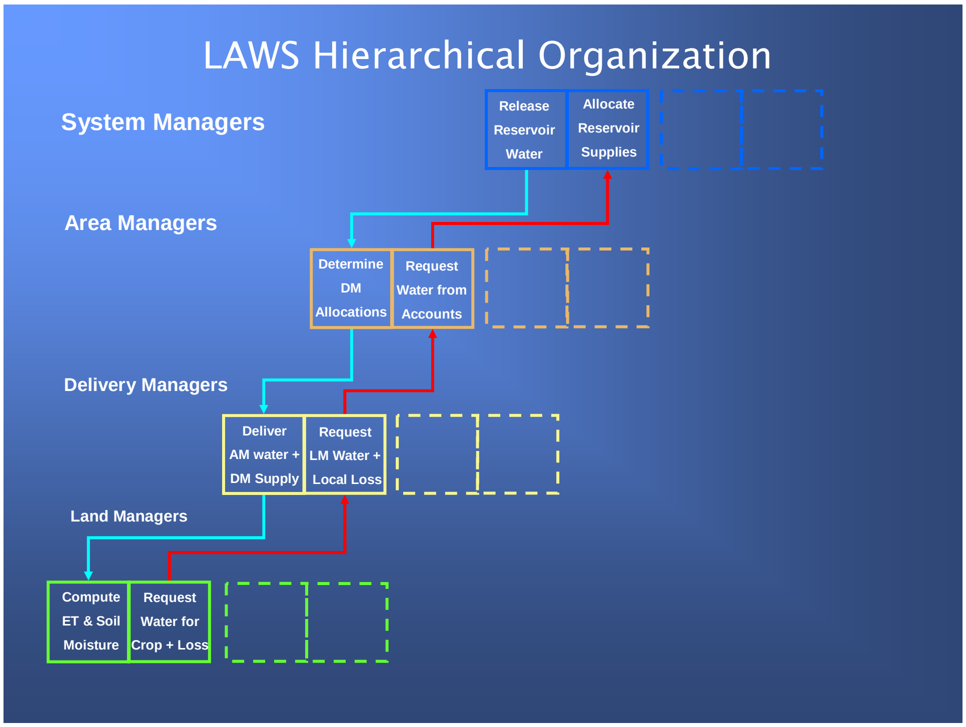


Figure 2. LAWS Hierarchical Organization

Each SM operates one of more reservoirs which may be located on different rivers systems within a regional watershed. Each reservoir consists of one or more accounts each of which is associated with a specific AM. The volume of water in each AM account is determined by a user specified percentage of the conservation pool. The amount of water in the conservation pool is reset on annual basis during the course of a multi-year simulation. The LAWS user has the option to allow an AM account to receive additional supply during a simulation in order to determine how much additional supply would be necessary to meet their water requirements over the simulation period.

At each daily time step, the SM can use either a sequential or balanced allocation method to determine how much water to release from each of the reservoirs it manages. In a sequential allocation the highest ranking account associated with a particular AM is fully depleted before the next highest ranking account is utilized. In a balanced allocation, water from each reservoir account associated with a particular AM is utilized simultaneously in a user specified proportion. If an account is completely utilized before the simulation is complete, the balance allocation ratios are recomputed to reflect the relative weighting of the accounts that still have remaining water supplies.

The total amount of the SM deliveries must be constrained by the available release capacity of the reservoir and the capacity of the downstream river channels to convey releases without causing flood damage. Since LAWS is intended to work in conjunction with other water management models, the reservoir release capacity can be specified at every time step. This approach permits LAWS reservoir releases to be constrained by other in-stream flow requirements that are not explicitly modeled in a LAWS simulation. This capability is accomplished by specifying a LAWS reservoir release capacity as the maximum physical release capacity minus the non-consumptive use flows that are released for other in-stream flow or water quality requirements. Typically, these regulatory releases would be simulated with another model and a daily time series of maximum reservoir release capacities would be computed for a LAWS simulation.

In LAWS, SM reservoir releases are delivered to AMs through an explicitly modeled network of rivers, canals, and drains. The hydraulic properties of these conveyance system features are represented explicitly at user defined reaches along the channels. The LAWS user specifies a maximum flow capacity for each reach and can simulate accretions and depletions in these reaches with simple gain/loss factors. The transit time for water flowing through reaches is also specified by the user.

It is important to recognize that LAWS does not solve the governing equations of flow in open channels. LAWS simulates flow hydraulics and surface-groundwater interactions by using user specified factors. Consequently, the LAWS user must develop this information from field studies, simulations using hydrodynamic and groundwater models, or expert judgment. This simplistic approach used throughout LAWS avoids the computational overhead and complex data requirements of numerical models. However, since LAWS is a mass conservative model, it can be used to determine water budgets from the regional-scale all the way down to the field-scale. Further, the simplicity of the approach permits the LAWS user to efficiently compare alternative land and water management practices, infrastructure characteristics and configurations as well as water delivery priorities explicitly established at each level of the multi-organizational hierarchy.

Area Manager

A LAWS Area Manger is one of the four levels in the LAWS hierarchical organization. An AM represents an organizational unit that manages of water supplies for a particular spatial region within the water supply system. In the LAWS hierarchy, an AM is the intermediary between a System Manager (SM) and the Delivery Managers (DM) which supplies water to individual Land Managers (LM).

The AM manages one or more water accounts. Each of these accounts is associated with a particular SM and has a specified maximum volume. An AM may have accounts with multiple SMs and more than one account with the same SM. The AM is responsible for managing the use of its accounts during a simulation. There are two account utilization mechanisms in LAWS. In a sequential utilization operation, the highest priority account is used completely before water from the next highest priority account is delivered from reservoir storage. In a balanced utilization operation, water from each account is utilized simultaneously in a user specified proportion. If an account is completely utilized before the simulation is complete, the balanced utilization ratios are recomputed to reflect the relative weighting of the accounts that still have remaining water supplies.

Although the SM determines the actual daily amounts of water released from an AM reservoir account, the AM is responsible for establishing the amounts of the groundwater pumping and drain water reuse to be used to meet consumptive use requirements within its DM sub-regions. In LAWS, the total volume of ground water use is not absolutely constrained to a specified amount. However, the amount of drain water recycling is limited to a user specified fraction of the total drain water inflow during each time step. These user specified factors represent the percentage of the total consumptive use requirement that is to be met from these sources of supply. The groundwater pumping and drain water reuse factors are set by the user for each DM in the AM region at each time step. In the event that the amount of drain water available for recycling is not sufficient to meet the AM target, groundwater pumping is automatically increased to make up for the deficit. Since the groundwater pumping and recycling factors may be set to zero by the user, alternative simulations using only reservoir supplies may be readily performed for comparison with various pumping and drain water recycling alternatives.

The AM is responsible for establishing the water delivery priorities that are to be implemented within its region. LAWS employs a user specified hierarchical system to determine how water is delivered to individual LM within a DM sub-region. The application delivery logic is designed to be user extensible so that multiple factors such as seniority of water rights, types of crop, growth stage, moisture stress or other user defined criteria could be employed in the delivery decision logic in future versions of the model.

The AM is responsible for managing the DMs within its region. At each time step, the AM must determine how much water to supply to each of its DMs. After receiving deliveries for each of its accounts from one or more SMs, the AM may use one of three different delivery priority mechanisms. In a sequential delivery operation, each DM is given a fixed priority relative to the others in the AM region and the highest priority DM's consumptive use requirement is completely satisfied before water from the next highest priority DM is delivered. In a balanced delivery operation, delivery is made to each DM in a user specified proportion. In hierarchical delivery operation, deliveries are to each DM based on the priority of individual LMs within the DM. This mechanism essentially treats all DMs with equal priority but insures that LMs meeting the highest ranking in the highest hierarchical level are completely satisfied before lower priority water deliveries are made. If a ranking is reached for which the remaining water supply is inadequate, a shortage delivery is made to the LMs in this ranking group.

At each daily time step, the AM is responsible for receiving and accumulating the requests for water supplies from each of its DMs. Using this request information, the

AM employs its account utilization methods to determine how much water to request from its various accounts. The amounts of requests are adjusted to account for conveyance depletions/accretions and forwarded to the SMs associated with each of its accounts.

Delivery Manager

Within the overall structure of LAWS, the Deliver Manager serves as an intermediary between the Land Manager (LM) whose function is to apply water to an individual land unit and the Area Manager (AM) that requests and distributes water received from the System Manager (SM). Each DM is associated with a single AM and operates to meet requests for water from multiple LMs.

At each time step, the DM is responsible for accumulating the amounts of water requested by each of its LMs. After all the LMs' application requests have been received, the DM has the responsibility for determining an appropriate amount of water to request from its AM to meet the needs of all the land units within its sub-region.

In order to determine the amount to request, the DM takes into account a number of physical and management factors impacting water use within its sub-region. The physical factors include conveyance losses from canals, inflows and outflows associated with adjacent DM sub-regions, deep percolation to groundwater, as well as various inflows and outflows from drains. Management factors include the desired amount of groundwater pumping and drain water reuse within the DM's sub-region. The water budget components of the DM system are shown on the Figure 3 below.

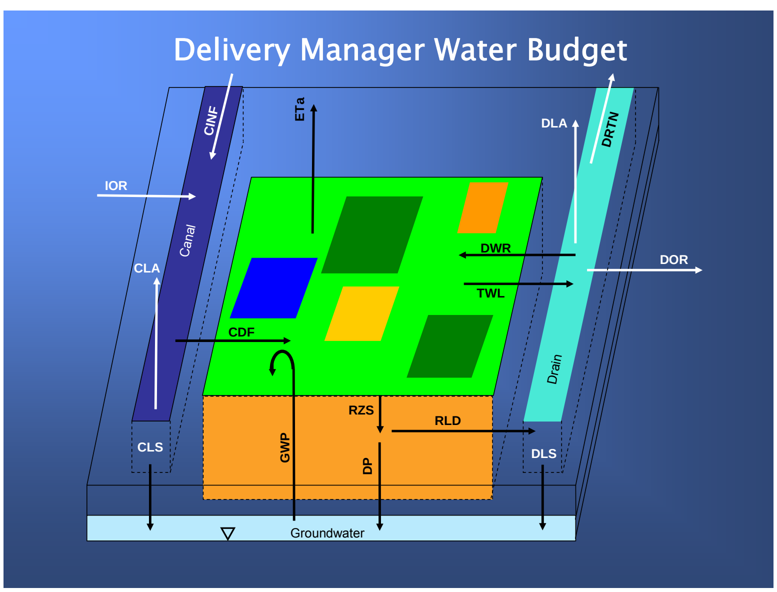


Figure 3 Delivery Manager Water Budget Components

It is important to recognize that the canals and drains within a DM sub-region are not explicitly represented as physical features within a LAWS model. The DM canals and drains represent the affect of field scale canals and drains on the overall water budget within the sub-region. This approach allows simulation of a sub-region's water balance without the difficult and time consuming task of explicitly accounting for all field-scale infrastructure typically found in a water delivery system. At the same time, this approach allows users ample flexibility to investigate the important effects these features exert on the amount the water needed to meet consumptive use requirements.

During each time step, the three major functions of a DM are to deliver to the LMs the water received from the AM, receive water application requests from LMs and determine an appropriate amount of water to request from the AM in the next time step. It is important to recognize that the actual amounts of water received from the AM for delivery to the LMs may be less than the amount requested.

At each time step, the AM establishes the deliver priorities within its region and notifies each DM of the supply available for delivery. The total amount consists of reservoir releases, groundwater pumping, and recycled drain water. Using the delivery priorities established by the AM, the DM delivers water to all the LMs for which sufficient supply is available.

As the DM delivers water, LMs inform the DM of any unmet water needs by making an application request for whatever amount is still required for consumptive use based on the final soil water content after delivery to the land unit. Once all the possible deliveries have been made, the DM queries the remaining LMs to determine their application requests. This process insures that every land unit is queried and results in the soil water content and other water budget components of every land unit being updated at every time step.

After the DM has completed the delivery process, the total amount of all LM application requests is known. The DM must now determine the total amount of water to request (DIV) for the entire sub-region. This process involves accounting for gains, losses and reuse of water within the sub-region. In addition to water supplied by the AM, other sources of supply to the DM sub-region include inflows into canals from adjacent sub-regions (IOR) and groundwater pumping (GWP). Other than consumptive use of applied water (CUAW), losses from the sub-region include canal seepage (CLS), drain seepage (DLS), and deep percolation (DP) to groundwater, evaporation from canals (CLA) and drains (DLA) to the atmosphere, outflows from drains to adjacent sub-regions (DOR) and return flow from DM drains to AM drains (DRTN). Tail water losses (TWL) and drain water reuse (DWR) within the DM's sub-region are other user defined management factors that affect the amount of water the DM requests from the AM.

Land Manager

Within the overall structure of LAWS, the role of the Land Manager (LM) is to apply water received from the Delivery Manager (DM) to the land, determine the soil moisture content after application and request an appropriate amount of water from the DM depending on the status of the soil water content.

In LAWS V2, soil water flow is simulated using a 1-dimensional 2 layer model to calculate bare soil evaporation, plant transpiration, surface water runoff, infiltration, groundwater table upflux, and deep percolation. Infiltration into the soil profile is simulated using a 1-dimensional unsaturated flow analytical equation. Soil evaporation and plant transpiration are computed using the well known dual crop coefficient method. Upflux and deep percolation are also computed by accounting for the effects of variable saturation in a dynamically changing root zone. These results are used to determine the soil moisture content at each daily time step. When the soil moisture is reduced to a user specified management allowable depletion, the LM notifies the DM that delivery of additional water is required. Since certain crops and management practices require ponding of water on the soil surface, a provision is made to manage water under both ponded and unponded conditions. The effects of irrigation on changes in a non-reactive, conservative constituent can also be simulated. The details of these calculations are provided in the Technical Reference section of this report.

Walkthrough

The following sections contain basic instructions on setting up, running, and viewing results of a LAWS Model. Use the Walkthrough to get familiar with the application and its components. The outline below is intended as a quick reference. The blue text indicates that there is more detailed information on a particular subject available in this document if needed. The use of the groundwater modeling capability in LAWS has been left out of this introductory discussion. Interested users are urged to read the detailed discussion provided in the **Technical Reference** section.

By design, the LAWS Project Tree reflects the dependencies and order in which data is usually created. Starting at the top of the tree is the Project node. This, is the starting point of the process. After a project is created, maps are added. Notice that Map node is directly under the Project node. The flow of data creation does not have to remain in this order. Although, it is the recommended order because there are dependencies between some objects which require a preceding object to be referenced by a subsequent object when it is created.

The following outline presents the steps in creating a LAWS model. More detailed information follows it.

Setting up the Initial Data:

- **Creating a Project**
- **Adding Maps**
- **Selecting model units**
- **Creating a Stream Alignment**
- **Entering Global Data**

Creating the Modules:

- **Land Module**
  - **Land Managers**
  - **Editing the Land Manager Data**
- **Crop Management Modules**
  - **Editing the Crop Management Module Data**
- **Flow Network Module**
  - **Creating a Reservoir**
  - **Editing a Reservoir**
  - **Creating a Reach**
  - **Editing a Reach**
- **Atmospheric Module**
  - **Creating a Met Station**
  - **Editing a Met Station**
- **Water Management Module**
  - **Creating an Area Manager**

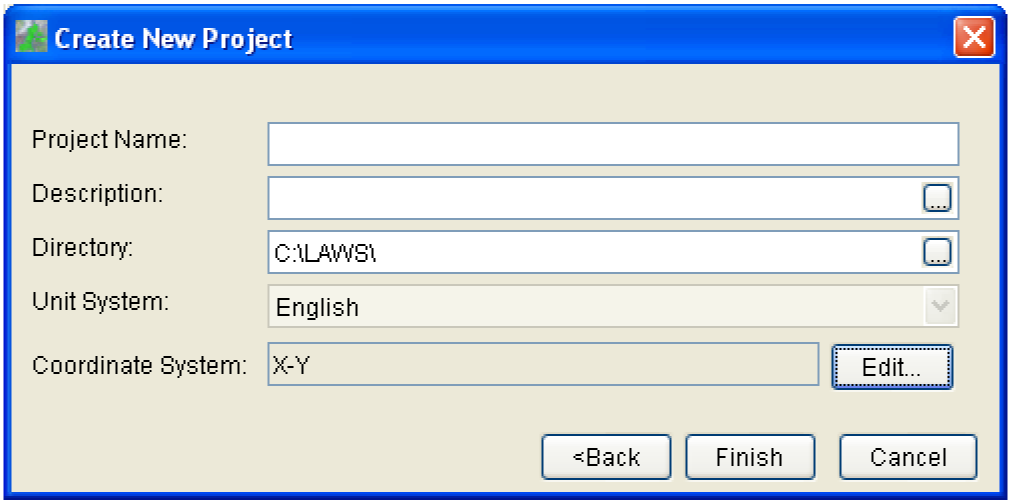
Bringing it all Together:

Initial Data

Creating a Project

The first step in starting the process of using LAWS is to create a new Project.

1. Select **New…** from the **File** menu.
2. In the **New…** dialog select **Project** from the list and click **Next.**
3. The **New Project** dialog will display like the one pictured below. Give the project a name and description. Select a directory you would like the project to reside in by clicking the ellipse button within the **Directory** text field. The **Unit System** will always be set to **English** and these are the units in which all calculations are made. However, there is the option to switch all input and output data to metric. This is discussed below. A Project directory will be created using the name given. All Project related files and directories will reside in this main directory. The Project's node will appear at the top of a Project Tree in the Project Tree Pane. The tree will also fill with data nodes and open an empty Map Schematic.



Adding a Map

Maps may be imported into the Project by adding them via the map context menu.

1. Right-click on the **Map** Node in the Project Tree and select **Add Maps**.
2. Traverse to the desired maps using the file browser.
3. Select the **Create Copy** check box located on the right side of the dialog to copy the map files to the Project's directory.
4. Click **OK**.

The Map Schematic window will expand by default to show the total map extents of the maps added. However the map extents can be changed manually through the Default Map Properties editor located in the Project menu. Use this editor to confirm that the proper map units are being used.

The following is a list of supported map types:

- DLG (USGS Digital Line Graphs)
- SHP (ArcView shapefiles)
- DXF (AutoCAD Digital Exchange Format)
- DEM (USGS Digital Elevation Models)
- IMG (Raster Image)
- ASC (ArcInfo ASCII grid)
- NET (ASCII NetTIN)

Next Step in the Walkthrough - Creating a Stream Alignment

Selecting Model Units

All LAWS calculations are made using English length units (feet), however, users wishing to use SI units for input and output data can do so. To change the system of units, the user should go to View - Unit System and select the preferred system.

Creating a Stream Alignment

A Stream Alignment is a visual representation of the stream system modeled. With or without a map, a **Stream Alignment** will need to be created or imported.

Create a New Stream Alignment

1. Right-click the Stream Alignment Node in the Project Tree and select **New...** from the popup menu.
2. In the **New Stream Alignment** dialog, enter a **Name** and **Description,** then click **OK**.

Stream Alignment Tools will be added to the current Map Schematic. A new Stream Alignment Node with the given name will appear under the main Stream Alignment node. If a Map Schematic is not opened, the creation of the stream alignment will open one automatically. Note that the newly created Stream Alignment name is shown in the Project Tree with **bold** type, indicating that it is displayed in the active Map Schematic window.

Drawing a Stream Alignment

1. Select the Stream Alignment Tool from the tool bar along the left side of the Map Schematic*.
2. Hold down the **Ctrl** key and click with the left mouse button to place successive points along the stream alignment.
3. To terminate the stream element, release the **Ctrl** key and click to place the last point of the stream.

Editing a Stream Alignment

1. To delete extra points on the stream alignment left-click on the point while holding down the **Ctrl** and **Shift** keys**. To add points, holding down the **Ctrl** and **Alt** keys and click on the Stream Alignment's line.

**The Stream Alignment must be created from upstream to downstream.*
***Be sure the Stream Alignment is selected. If it is selected, the points will be colored blue.*

Next Step in the Walkthrough - Creating Global Data

Creating Global Data

Global Data represents the collection of tangible information used to create the management components of the LAWS alternatives. They do not have graphic representations on the Map Schematics. The data are divided into five categories.

1. **Crop Types**
2. **Irrigation Types**
3. **Soil Types**
4. **Crop Schedules**

Next Step in the Walkthrough - Adding Crop Types

Adding Crop Types

1. Double click on the Crop Types Node in the Project Tree.
2. In the **Crop Types Editor** create a new **Plant Type** by selecting **New** in the **Crop Type** menu.
3. Give the new Crop Type a **Name** and **Description** and click **OK***.
4. The editor will fill with the new Crop Type.
5. Enter the **Early** and **Late Planting Dates** using the Calendar Tool accessed by the ellipse buttons in the text fields.
6. Fill out the **Growth Stage** table and click **OK**.

Repeat filling the editor for each Crop Type created. For more detailed descriptions see the LAWS Help section on Crop Types.

Next Step in the Walkthrough - Adding Irrigation Types

**It's recommended that you use names that clearly identify the crop type. For example, if the crop is corn, name the Crop Type "Corn". If more than one type of corn will be used, use names like "Dent Corn" and "Sweet Flint Corn".*

Adding Irrigation Types

1. Double click the Irrigation System Types Node in the Project Tree.
2. In the **Irrigation System Editor** click in the first empty row in the **Type** column.
3. The editor will be filled with default Irrigation Types. However, you can add additional Irrigation Types by first selecting the last row's **Type** column. This will automatically add a row to the table.
4. Fill in the table values for your new Irrigation Type.
5. Continue adding Irrigation System Types needed for the model.
6. Click **OK** to save the changes and close the editor.

For more information see the LAWS Help section on Irrigation System Types.

Next Step in the Walkthrough - Adding Soil Types

**Remember to use a meaningful name that describes the irrigation being represented, i.e., "Sprinkler", "Flood", "Furrow".*

Adding Soil Types

1. Double click on the Soil Type Node in the Project Tree.
2. In the **Soil Types Editor** create a new Soil Type by selecting **Soil Type** -> **New...**
3. Give the Soil Type a **Name*** and **Description,** then click **OK**.
4. In the editor, at a minimum enter the percent values for the soil's three texture types: **Sand Content**, **Silt Content**, and **Clay Content** and the evaporation layer thickness and the readily evaporable water (REW). The combined total of the texture percentages must equal 100. You can also add values for the **Bulk Density**, **Theta_s**, and **Ksat**, but these are not mandatory.
5. Once you have entered the data and the three content's values total 100, click the **Apply** button to calculate the van Genuchten parameter values.
6. When you are done adding Soil Types, click **OK** to close the editor and save the information.

For more detailed information on the Soil Type editor, see the Soil Types Help section.

Next Step in the Walkthrough - Adding Crop Schedules

** Try to use names that clearly identify the type of soil modeled, i.e., "Sand","Clay".*

Adding Crop Schedules

1. Double click the Crop Schedule Node in the Project Tree.
2. In the **[Crop Rotation Editor]** select **Crop Schedule** -> **New....**
3. Give the schedule a **Name** and **Description** then click **OK**.
4. In the **Crop Rotation Editor** fill in the table with planting events, choosing from the **Crop Types** created earlier.
5. Fill in the **Year** and planting **Date** for each event.
6. When you are done adding schedules, click the **OK** button.

If the time period of the schedule does not fully encompass a simulation period, the schedule is repeated (both into future and past as necessary).

See Crop Schedule for more information.

Creating Modules

Land Module

Creating a Land Module

1. To create a Land Module right-click the Land Modules Node in the Project Tree and select **New...** from the context menu.
2. A **New** dialog will appear. Give the Land Module a **Name** and **Description**, then click **OK**.

A new Land Module Node will appear under the Land Modules Node in the Project Tree. The Land Manager Tool will be added to the toolbar on the current Map Schematic. Use this tool to create graphical representations of Land Managers (fields) on the map.

Next Step in the Walkthrough - **Creating Land Managers**

Creating a Land Manager

1. First select the Land Manager Tool  in the Map Schematic*.
2. While holding down the **Ctrl** key, left click in the Map Schematic window were you would like to place the first point.
3. Continue creating the outline of the field shape by left clicking points on the map.

4. For the final point, release the **Ctrl** key and click**.
5. The outlined area will be filled in with yellow, indicating it is selected, otherwise it will appear green.

Next Step in the Walkthrough - **Editing Land Manager Data**

**A Land Module must be created first or set active in the Map Schematic.*
***Be sure to create an enclosed area and not overlap the outline on itself.*

Editing a Land Manager

1. Right click on a Land Manager  in the Map Schematic and select **Edit** from its context menu*.
2. The **Land Manager** editor will appear with the selected field information displayed.
3. Choose either **Calculate Area** or **Enter Area**. If **Calculate Area** is chosen LAWS calculates the Land Manager area using the geometry of the Land Manager polygon. LAWS can also be used to construct models that are not necessarily to scale by selecting the **Enter Area** option.
4. Select the **Land Use**. The choices are either **Irrigated Field** or **Other Demands**. Use the **Other Demands** option if a demand needs to specified as either a constant value or using a time series. The **Irrigated Field** option calculates a full root zone water balance.
5. If modeling water quality, enter the **Initial Water Quality** in ppm. This represents the concentration of the modeled constituent in the soil water at the beginning of the simulation period. This feature does not apply if **Other Demands** are being modeled.
6. Select the Field's **Irrigation System Type** from the drop down list of previously created Irrigation Systems.
7. Enter a value for the **Drain Inflow Factor**. This represents the portion of deep percolation that enters the drains. The remainder flows to the groundwater system.
8. Enter a value for the **Water Table Depth**. This value is used to calculate the amount of upflux from the water table. If the groundwater modeling option is used this value will be calculated by LAWS.

9. Soils information can be entered as **Soil Types** or **Soil Properties**. The Soil Types option utilizes information entered in the Soil Type Editor. The Soil Properties allows the direct entry of soil physical parameters. Select what entry form you would like to use and fill out the information accordingly.
    1. **Soil Types** - A table will be available that allows you to select the one or more Soil Types from a list of previously created Soil Types. Each Soil Type selected requires a percent value that represents the portion of the Land Manager that contains the chosen soil type. Once the percentages are entered, the Soil Property Input Values data and van Genuchten properties will be calculated.
    2. **Soil Properties** - The Soil Properties selection allows the manual entry of Soil Property Input Values or the Van Genuchten Parameters. Simply select which way you would like to enter the values using the radio buttons next to the input types listed. Then enter the values in the editable fields.

Next Step in the Walkthrough - Creating a Cropping Plan

**A Land Module must be open in the Map Schematic.*

Crop Management Module

Creating a Crop Management Module

1. Right click the Crop Management Modules Node in the Project Tree and select **New..** from the popup menu.
2. The **New** dialog will display. Enter a **Name** and **Description** for the Crop Management Module.
3. Select a Land Module for the Crop Management Module from the **Land Module** drop down list of previously created Land Modules.
4. Click **OK**.

A new node with the name of the created Crop Management Module, will appear under the Crop Management Modules Node.

Next Step in the Walkthrough - **Editing Crop Management Modules**

Editing a Crop Management Module

1. Right click the individual Crop Management Modules Node in the Project Tree and select **Edit** from the popup menu.
2. The Crop Management Module Editor will appear.

3. Select **Crop Schedules** for each Land Manager listed in the table.
4. Click **OK** to save the changes and close the editor.

Next Step in the Walkthrough - Creating a Flow Network Module

Flow Network Module

Creating a Flow Network

1. Right-click the Flow Network Module Node in the Project Tree and select **New...** from the popup menu.
2. In the **New** dialog enter a **Name** and **Description** for the new Flow Network.
3. Select a **Stream Alignment** for the Flow Network and click **OK**.

A new Flow Network Node will be created under the Flow Network Module Node. Flow Network tools will be added to the toolbar in the current Map Schematic.

Next Step in the Walkthrough - Creating Reservoirs

Creating a Reservoir

1. Select the Reservoir Tool in the Map Schematic*.
2. While holding down the **Ctrl** key, left-click the upstream area of the Stream Alignment you would like to place the starting point of the reservoir.
3. Release the **Ctrl** key and click the Stream Alignment were the Reservoir will end.

The cyan colored Reservoir will draw between the points. A triangle will be drawn at the downstream end. This triangle is the Reservoir's pool. The pool shape can be changed. To learn more, see Drawing Reservoirs.

Next Step in the Walkthrough - Editing the Reservoir Data

**A Flow Network must be opened in the current Map Schematic.*

Editing Reservoir Data

1. Right-click on the Reservoir in the current Map Schematic and select **Edit Reservoir** from the popup menu*.
2. In the **Reservoir Editor** enter values for **Maximum Conservation Storage** and **Instream Flow Requirement**. If the time series option is selected then a time series must be chosen in the Alternative Editor (see below).
3. Choose a **Release Capacity Option** from the option's dropdown list.
    1. If **Constant** is chosen for the release, enter a **Maximum Release Capacity**.
    2. If **Time Series** is chosen, a time series of release rates will need to be specified in the Alternative Editor. (See that section for more detail.)
4. Click **OK** to save the changes and close the dialog.

Next Step in the Walkthrough - Creating a Reach

**A Flow Network containing a Reservoir must be opened in the current Map Schematic.*

Creating a Reach

1. Select the Reach Tool  in the Map Schematic.
2. While holding down the **Ctrl** key, click where the Reach will begin on the Stream Alignment.
3. Release the **Ctrl** key and click the Stream Alignment to place the end point of the Reach.

The points will become red Junctions , unless the Reach was ended or started at a Junction. In this case the Reach will use the existing Junctions. The area between the points, along the stream alignment, will fill with the new Reach.

Next Step in the Walkthrough - Editing Reach Data

Editing Reach Data

1. Right-click the Reach and select **Edit Reach** from the popup menu.
2. The Reach Editor will appear. Within this editor the **Travel Time** and **Channel Losses** can be changed.

Next Step in the Walkthrough - Creating an Atmospheric Module

Atmospheric Module

Creating an Atmospheric Module

1. Right-click on the Atmospheric Modules Node in the Project Tree and selecting **New...** from the popup menu.
2. The **New Atmospheric Module** dialog appears.
3. Give the Module a **Name** and **Description.**
4. Click **OK**.

The new Atmospheric Module Node , with the given name, will appear under the Module's node. A Met Station Tool will be added to the current Map Schematic's Toolbar.

Next Step in the Walkthrough - Creating Met Stations

Creating a Met Station

1. Select the Met Station Tool in the Map Schematic*
2. Hold the **Ctrl** key down and click on the area you would like to place a Met station.

Next Step in the Walkthrough - Editing Met Station data

**An Atmospheric Module must be open in the current Map Schematic*

Editing a Met Station

1. Select the Met Station Tool in the Map Schematic*.
2. Right-click the Met Station and select **Edit Met Station**.
3. In the Met Station Editor, select the **Regional** type you need.
    1. If using Radial, a **Radius** value will need to be entered.
    2. To display the extent of Met station's influence, choose the Map tab on the Project pane and expand the Atmospheric Module branch. Check the Coverage Area to display the extent of the Met station's influence.
4. If water quality is being modeled, a rainfall water quality concentration will need to be entered. The user can select either a constant water quality value or a Time Series Water Quality which will need to be referenced in the alternative editor.

5. Click **OK** to save the changes and close the editor

Next Step in the Walkthrough - Creating a Water Management Module

**An Atmospheric Module must be open in the current Map Schematic*

Water Management Module

Creating a Water Management Module

1. Right-click the Water Management Node in the Project Tree and select **New...** from the popup menu.
2. The **New Water Mangement** dialog appears. Give the module a **Name** and **Descritpion**.
3. Click **OK**.

A new Water Management Node will appear under the module node. The **Delivery Manager Tool** will be added to the current Map Schematic window.

Next Step in the Walkthrough - Creating an System Manger

Creating a System Manager

1. Right-click on a Water Management Node and select **Edit** -> **System Manger** from the context menu.
2. The System Manager Editor will appear. In the **System Manager** menu select **New...**.
3. A **Create System Manger** dialog will appear.
4. Give the new System Manager a **Name** and **Description** then click **OK**.

The editor will fill with the new System Manager's information.

Next Step in the Walkthrough - Editing a System Manager

Editing a System Manager

1. Right-click on a Water Management Node  and select **Edit** -> **System Manger** from the context menu.
2. The System Manager Editor will appear. Select a **Flow Network** from the dropdown list of previously created Flow Networks.
3. Add Reservoir Accounts using Reservoirs contained in the Flow Network.
4. Select the **Add Account** button on the **Reservoir Account** tab. A **New Reservoir Account** dialog will display.
5. Give the Account a **Name** and **Description** then select the Reservoir from the **Reservoir** dropdown list.
6. Click **OK** to create the Account.
7. The new Account will appear in the Account table.
8. Enter the **% Conservation Storage**.
9. Select whether the reservoir storage will use **Balanced** or **Sequential Allocation** using the **Usage** radio buttons.
10. Click **OK** to save the changes and close the editor.

Next Step in the Walkthrough - Creating an Area Manager

Creating an Area Manager

1. Right-click the Water Manager Node  and select **Edit** -> **Area Manager** from the popup menu.
2. In the **Area Manager Editor** select **Area Manager -> New**. The New Area Manger dialog will display.
3. Give the new manager a **Name** and **Description** then click **OK**.
4. The editor will fill with the new Area Manger's default data.

Next Step in the Walkthrough - Editing an Area Manager

Editing an Area Manager

1. Right-click the Water Manager Node  and select **Edit** -> **Area Manager** from the popup menu.

Creating a Water Account

1. On the **Water Account** tab in the **Area Manager** **Editor,** create a new Water Account.
2. Select the **Add Account** button. The **New Water Account** dialog will display.
3. Give the Account a **Name** and **Description.**
4. Select the System Manager from the **System Manager** dropdown list.
5. Click **OK** to create the Account. The new Account will display in the Account table.

6. Enter a **Max Yearly Volume** for the Account.

Next Step in the Walkthrough - Creating a Delivery Manager

Creating a Delivery Manager

1. Select the Delivery Manager Tool  on the Map Schematic Toolbar*.
2. While holding down the **Ctrl** key, click in the Map Schematic where you would like to place the first point.**
3. Continue creating the outline of the polygon by clicking points on the map. Be sure to only encompass Land Mangers in only one Delivery Manager Area.
4. For the final point, release the **Ctrl** key and click near or on the first point. Be sure to create an enclosed area and not overlap the outline on itself.
5. A dialog will appear prompting you to give the Manager a **Name**, **Description**, and assign it an **Area Manager**.
6. Click **OK**.

The outlined area will be filled in with yellow, indicating it is selected, otherwise it will appear blue. Create as many Delivery Managers as needed for the Area Manager.

Next Step in the Walkthrough - Editing Delivery Managers

**A Water Management Module must be open in the current Map Schematic.*
<u>** Be careful not to overlap existing Delivery Managers!</u>

Editing a Delivery Manager

1. Select the Delivery Manager Tool  on the Map Schematic Toolbar*.
2. Right-click on a Delivery Manager and select **Edit Delivery Manager** from the popup menu.
3. The Delivery Manger Editor will appear.
4. Changes to the **Connectivity**, **Physical** and **Management Parameters** can be made.

Next Step in the Walkthrough - Creating an Alternative

**A Water Management Module must be open in the current Map Schematic.*

Bringing It All Together

Alternatives are where all the pieces of the LAWS model come together. The physical and biological characteristics, infrastructure and system management pieces previously created can be combined together in various combinations to evaluate their effects on system operations.

Alternatives

Creating an Alternative

1. Right-click the Alternative Node in the Project Tree and select **New...** from the popup menu. The **New Alternative** dialog will appear.
2. Give the Alternative a **Name** and **Description.** Then click **OK**.

The new Alternative's node will be created under the main Alternative Node.

Next Step in the Walkthrough - Editing the Alternative

Editing an Alternative

1. Right-click an Alternative Node and select **Edit** from the popup menu.

Selecting Modules

1. On the Module tab of the Alternative Editor select the **Modules** you would like the Alternative to use*.

If needed, New Modules can be made using their corresponding **New button.*

Run controls

1. On the **Run Controls** tab enter the **Start** and **End Date** for the Alternatives computation period.
2. Choose if water quality should be simulated. A description of the LAWS water quality algorithm is provided in the Technical References section.
3. Choose whether to **Write Land** and **Delivery Managers ASCII Output File****.

***This option is available because large numbers of Land Managers (Fields) can create large files.*

Initial conditions

1. Enter the required initial condition values.

Input Time-Series

1. On the **Time-Series** tab, DSS files need to be assigned to the Met Stations and any other options where DSS data inputs have been selected.
2. Click on a row in the table.
3. Select the **Browse DSS Paths** button.
4. A Time Series browser displays.
5. In the browser, select the dss path from the list
6. Click the Set Pathname button to assign the path to the selected Met Station row.
7. Close the Browser using the  button in the upper right-hand side of the dialog.
8. The Met Station row will display the selected pathnames chosen
9. Click **OK** to save the changes and close the Alternative Editor

Next Step in the Walkthrough - Running an Alternative

Running an Alternative

There are two ways to start the compute of an Alternative.

1. Select **Simulation** -> **Compute Alternative** from the main menu bar.
2. Right-click the Alternative's node and select **Compute** from the popup menu.

Once the Alternative starts computing, a compute progress bar will display. A compute message tab, using the Alternative's name, will be added to the Message Pane area.

Next Step in the Walkthrough - Viewing Results

View Results

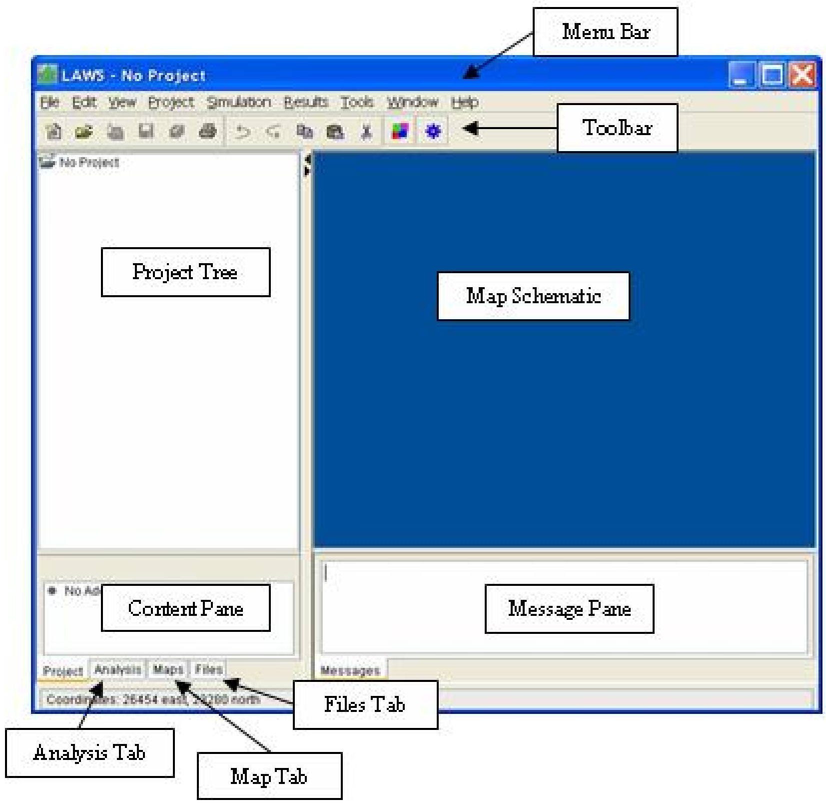
Results can be viewed using the following formats:

- Plots - Model output can be viewed by right-clicking on the object of interest and selecting the desired plot. These are available for Land Managers, Delivery Managers, Reservoirs, and Reaches. Within the plot window the Tabulate menu item can be selected to view the data in tabular format.

Interface

Main Window

When LAWS is opened for the first time, the Main Window below is displayed. The components of the Main Window are shown on the figure below and described in the subsections below.



Menu Bar

Along the top of the Main LAWS Window resides the Menu Bar. The Menu Bar allows for quick access to data information and editing additionally done through the Project Tree editors. It also gives access to viewing results, creating and saving information, and customizing the look and feel of the application. Helpful tools, such as DssVue and the LAWS Help documentation are available here as well. The Menu Bar includes the following options:

- File
- Edit
- View
- Project
- Simulation
- Results
- Tools
- Window
- Help

In the tables that follow, the functionality associated with each of these options is described and keyboard shortcuts are presented. Please note that some of the tables extend over several pages.

File Menu

File menu commands:

Name	Function	Keyboard Shortcut
New	**New** selector dialog. Within this dialog, depending on what is selected in the Project Tree, you can select to create the following: Project Stream Alignment Flow Network Module Land Module Atmospheric Module Alternative Water Management Module Cropping Plan	Ctrl + N

Open	**Open** selector dialog. Within this dialog, depending on what is selected in the Project Tree, you can select to open the following: Project Stream Alignment Flow Network Module Land Module Atmospheric Module Alternative Water Management Module Cropping Plan	Ctrl + O
Open Project	Open an existing Project	
Save Project	Save the current Project	
Save Project As	Copy and save the current project with a new name.	
Close Project	Close the current Project	
Open File in Project	Open a selected file within a Project by selecting the file using the file selector dialog shown above.	Ctrl + Shift + O
Save	Save a file in the current Project. Saves the file associated with the highlighted item in the Project Tree	
Save As	Copy and save the current file associated with the selected item in the Project Tree. A new name will be requested for the file. The new item will appear within the Project Tree	
Rename	Rename the current file associated with the selected item in the Project Tree	
Delete	Delete the current file associated with the selected item in the Project Tree and removes its tree node if applicable	
Save Map Image	Save the current Map Image within the Map Schematic	
Page Setup	*Currently not available.*	
Print	Print the file associated with the currently selected item within the Project Tree	

Reopen	Reopen a previously opened project from a provided list of Projects. The list of Projects to select from will appear in a menu to the right of the Reopen menu. If no Projects have been opened previously, the list will not appear	
Exit	Exit and close the LAWS Application	

Edit Menu

Edit menu commands:

Name	Function	Keyboard Shortcut
Undo	Undo the last editing change made	Ctrl + Z
Redo	Redo the last Undo change	Ctrl + Y
Cut	Remove selected information and store it to the clipboard.	Ctrl + X
Copy	Copy selected information and store it on the clipboard.	Ctrl + C
Paste	Paste information from the clipboard to the current cursor location.	Ctrl + V
Global Data	Displays an additional menu that contains a list of all Global Data types that can be edited in the current project. Each item in the list will display the corresponding editor for the following • Crop Types • Irrigation System • Crop Rotations • Water Rights	
Land Modules	Displays the Land Module Editor filled with the current project's Land Module data	

Crop Plan	Displays the Crop Plan Editor filled with the current project's Crop Plan data
Flow Network	Displays an additional menu option which contains a list of Flow Network. • Reservoir • Reach • Junction Each item in the list will display the corresponding editor.
Atmospheric Data	Displays the Atmospheric Data Editor filled with the current project's Atmospheric data
Water Management	Displays an additional menu option that contains a list of Water Management types in the current project. • Delivery Manager • Area Manager • System Manager Each item in the list will display the corresponding editor.
Alternative	Displays the Alternative Editor filled with the current projects alternatives.

View Menu

View menu commands:

Name	Function	Keyboard Shortcut
Toolbars	Allows you to display either the Standard tool bar, the Clipboard tool bar, or both just below the menu bar	
Project Pane	When checked, displays the Project Pane	
Messages	When checked, displays the Message Pane	
Status	When checked, displays the Status Pane	

Toggle Views	Toggle the view between displaying the Map Schematic at full screen or current screen view setting	Ctrl + T
Unit System	The unit system used within the Projects.	
Save Layout	Save the current layout	
Restore Layout	Restore a layout from a list of saved layouts	
Layout Manager	*Currently not available*	
Zoom to All	Zooms in to all open Map Schematics	

Project Menu

Project menu commands:

Name	Function	Keyboard Shortcut
Project Properties...	Displays the Project Properties dialog which contains information on the current project	
Default Map Properties	Displays the editor for the Default Map Properties.	
Archive Project	*Currently not available*	
Add Map	Add a map to the currently selected Map Schematic	
Import	Import Stream Alignments	
Export	Export a Stream Alignment	

Simulation Menu

Simulation menu commands:

Name	Function	Keyboard Shortcut
Compute Alternative	Starts the currently selected Alternative's compute	
Compute Manager	*Currently not available*	

Results Menu

Results menu commands:

Name	Function	Keyboard Shortcut
View Water Balance Summary	Display the Water Balance Summary for the currently selected Alternative	
View Account Volume Summary	Display the Account Volume Summary for the currently selected Alternative	
View Delivery Manager Output	Display the Delivery Manager output for the currently selected Alternative	
View Land Manager Output	Display the Land Manager output for the currently selected Alternative	
Land Module Display Properties	Display the properties editor for the current projects Land Modules	
Animate Results	Animates the computed data through the entire Alternative compute time window	

Tools Menu

Tool menu commands:

Name	Function	Keyboard Shortcut
Scripts...	Accesses a Jython Script editor. *Currently not* available	
HecDssVue	Displays the HEC application HecDssVue for viewing dss files	
Options...	Displays the Options dialog for the application	
Customize...	Displays the Customize dialog for the application	
Memory Monitor	Displays the Memory Monitor for the application	

Window Menu

Window menu commands:

Name	Function	Keyboard Shortcuts
New Map Window	Opens a new map window in the Map Schematic area	
Map Window Properties	Displays the properties dialog for the current map windows	
Tile	Display all open map windows in the form of tiles within the Map Schematic area	
Cascade	Display all open map windows in a cascade from left to right within the Map Schematic area	
Next Window	Brings the window behind the current window forward and to the front of all map windows in the Map Schematic Area	
Previous Window	Brings the previously viewed window forward and to the front of all map windows in the Map Schematic Area	
Window	Displays a dialog which allows you to select which window you	

Selector	would like to see display up front	
Window	Allows you to select the window to bring up front form a list of open windows in a menu	

Help Menu

Help menu commands:

Name	Function	Keyboard Shortcut
Help	Displays the main Help documentation for LAWS	
 What's This	Sets the cursor into a "What's This" mode. Any item the cursor clicks on will then display any relative Help documentation on that item	
LAWS Web Site	Displays your browser and loads the LAWS web site	
USBR Web Site	Displays your browser and loads the USBR web site	
About LAWS	Displays the About dialog on the LAWS application	

Toolbar

The Toolbar is located directly under the Menu bar. The Toolbar is initially set to display two sets of tools, the Standard and Clipboard tools. More tools can be added to the Toolbar through the **Customize** dialog accessed from the **Tools** menu. Below is a table of all tools available and their function:

Tool	Name	Function
	New	**New** selector dialog. Within this dialog, depending on what is selected in the Project Tree, you can select to create the following: Project Stream Alignment Flow Network Module Land Module Atmospheric Module Alternative Water Management Module Cropping Plan
	Open	**Open** selector dialog. Within this dialog, depending on what is selected in the Project Tree, you can select to open the following: Project Stream Alignment Flow Network Module Land Module Atmospheric Module Alternative Water Management Module Cropping Plan
	Close	Close the current project
	Save	Save the current project
	Save All	Save all changes made tot he current project
	Print	Print the associated data of the selected item in the current project
	Undo	Undo the last editing

	Redo	Redo the Undo
	Copy	Copy the selected item to the clipboard
	Paste	Paste item from clipboard to the cursor location
	Cut	Cut the selected item and copy it to the clipboard
	Land Module Display Properties	
	Animate Results	

Project Tree

The Project Tree is located on the upper left side pane of the Main LAWS Window. Each branch in the Project Tree is called a Node. Each Node represents different data components in the Project. The Nodes are named after the data types they contain. For instance, the Maps node will contain Manager Nodes for each map added to the Project. The Manager Nodes manage the data. From Manager Nodes, users may view and manipulate the Project's data and information.

Data are added to the Project following the Project Tree structure from top to bottom. For example, the first step in setting up a new Project is to add maps. The Maps Container Node resides at the top of the tree. The Nodes occur in the order that is recommended for building a LAWS model. For example, when a Stream Alignment is added its Node occurs below the Maps Node. And so on. The following is a list of available Nodes. A description of each Node follows the list.

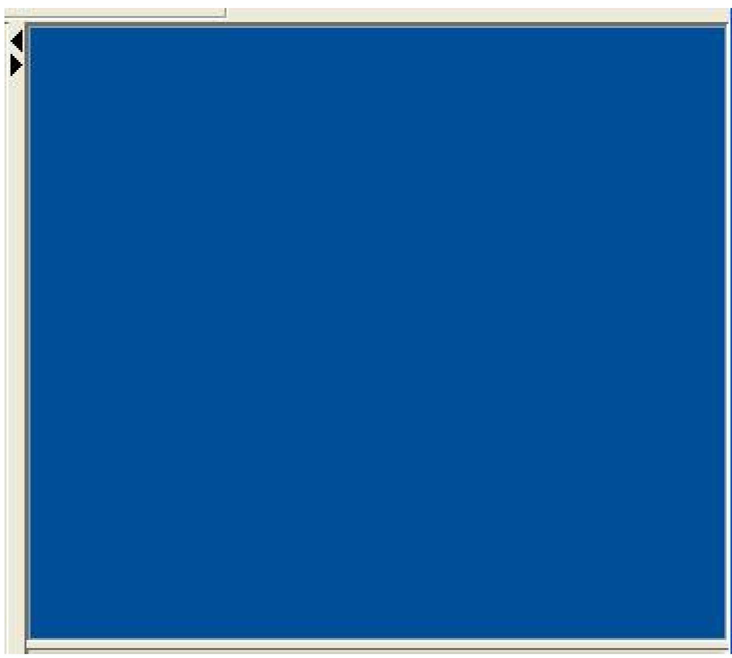
- Project
- Maps
- Stream Alignments

- Global Data
    - Crop Types
    - Irrigation System Types
    - Soil Types
    - Crop Schedules

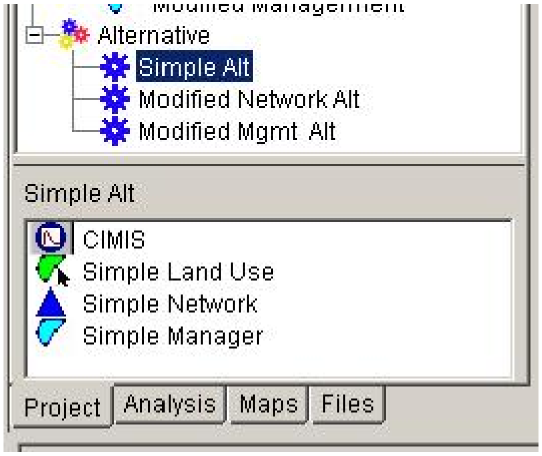
- Land Module
- Crop Management Module
- Flow Network Module
- Nonagricultural Land
- Atmospheric Modules
- Water Management Module
- Alternatives

Map Schematic Area

The Map Schematic Area is the area of the application where Map windows display. It is the large blue area located on the right side of the application window directly below the Toolbar. Multiple Map Schematic windows can be viewed within this area. The format for viewing Map Schematic windows can be changed through the Window menu. The Map Schematic area can be resized by selecting and dragging the panel's edges or by using the View menu Toggle View option.

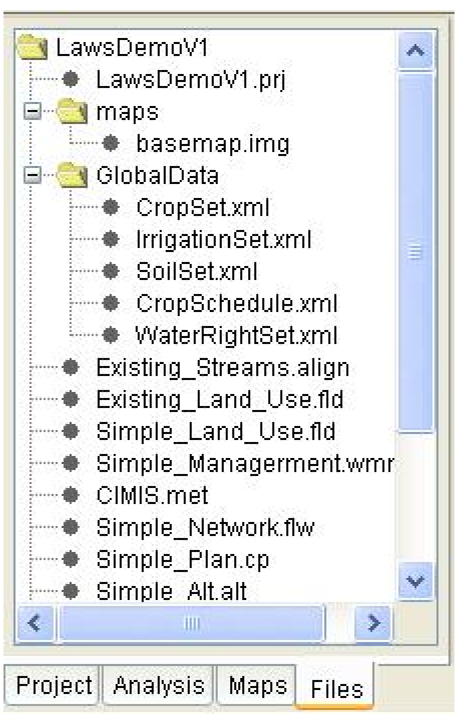


Content Pane



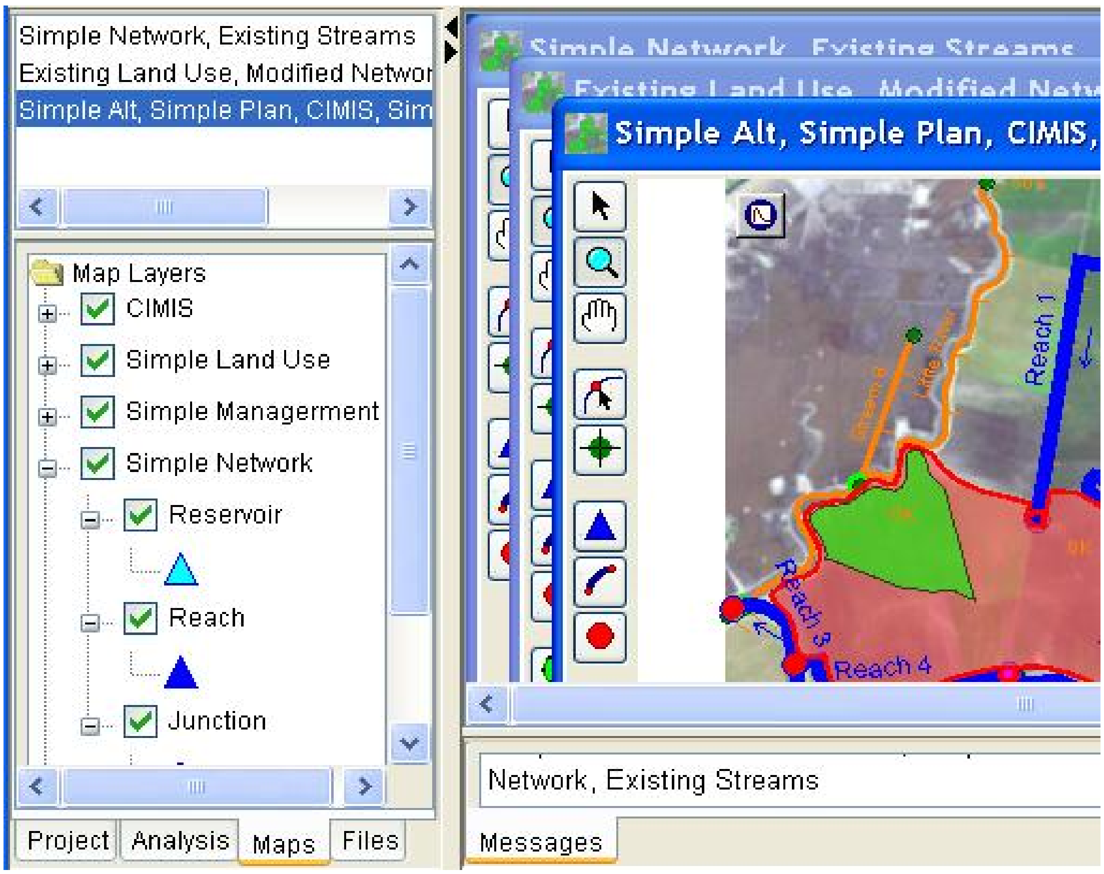
Located directly under the Project Tree area, the Content Pane displays information relating to the highlighted data object in the Project Tree. In the case below, the data object is the Alternative, "**Simple Alt**". The Content Pane displays information on that Alternative's data, which includes the Atmospheric Module (**CIMIS**), Land Module (**Simple Land Use**), Flow Network (**Simple Network**), and the Water Management Module (**Simple Manager**).

File Tab



The **Files tab** displays the open Project's files. The file tree layout is the same file structure you would see if you viewed the project files outside the application; for example if you used Windows Explorer. However, the files displayed do not include all files used or created by the application.

Map Tab



The **Map tab** lists all open Map Windows in the top pane. Selecting a particular Map Window from this list will display information on that Map Window's map layer data within the lower Content Pane.

Map Layers:

Map Layers are like transparencies laid one on top of the other, with static physical images such as roads, county and state boundaries, rivers, sub basins, etc., layered in the display as color pictures. Each of these images, along with its associated data, is a layer. The following are descriptions of the different Layers used in the LAWS application display. These layers are available for editing through the **Maps tab** under the Content Pane. To remove a layer from the Map Schematic remove the check mark next to the layer's data name in the Map Layers tree, pictured above.

- **Atmospheric Module -** Named "CIMIS" above, the Atmospheric Module layer displays Met Station Icons, in the Map Schematic Window.

- **Land Management Module -** The Land Management Module displays Land Manager polygons, as well as a legend.

- **Delivery Managers -** The Water Management Module, "Simple Management" above, displays the Delivery Manager Polygons .

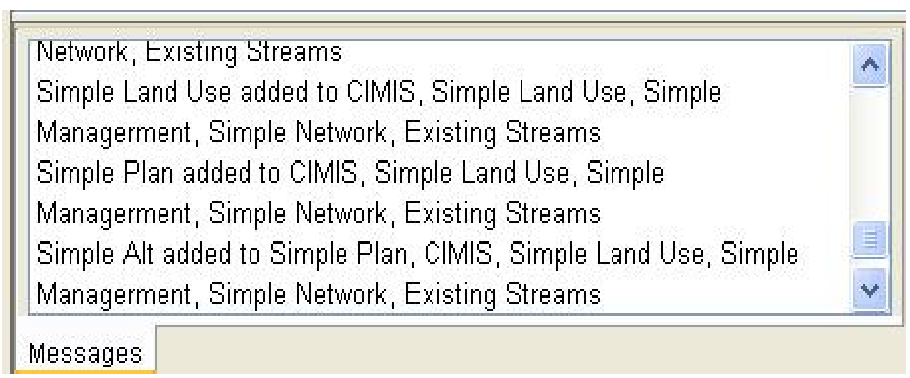
- **Flow Network -** The Flow Network Layer, "Simple Network" pictured above, contains the following layer data representations of the river system modeled in the watershed:
    - Reservoir
    - Reach
    - Junction
    - Groundwater

- **Stream Alignment -** The Stream Alignment Layer contains the Stream Alignment representing the river system in the watershed. The Stream Alignment layer includes three component layers:
    - Stream Junctions
    - Streams (also referred to as Stream Elements)
    - Stream Nodes
    -

- **Map -** This application can display various types of maps and elements in the geo-referenced map display area. These maps, displayed as map layers, are static physical images. Examples of map layers include roads, county and state boundaries, rivers, sub basins, etc. Some maps are static images, which display as color pictures in the display area. Map Layers are not interactive. Instead, you interact with data associated with Schematic Elements you place in your map display.

Message Pane

The Message Pane displays information on actions that occur within the application. These actions include, creating or loading data, computing an Alternative or displaying results. For instance, if an alternative was computed, the Message Pane will create a **Compute tab**, which will contain the output information for the alternative. If a new project was created, the Message Pane will display information about the project's creation on the **Messages tab**. The message would include the Project's file name, location, and whether it was created successfully. Problem or error messages also display within the pane's tabs.



Editors

The following is a list of Project Data Editors:

- **Global Data**
    - Crop Types
    - Irrigation System Types
    - Soil Types
    - Crop Rotation Types

- **Land Manager**

- **Crop Management**
    - Crop Schedule

- **Flow Network**
    - Reservoir
    - Reach
    - Junction

- **Atmospheric**
    - Met Station

- **Water Management**
    - System Manager
    - Area Manager
    - Delivery Manager

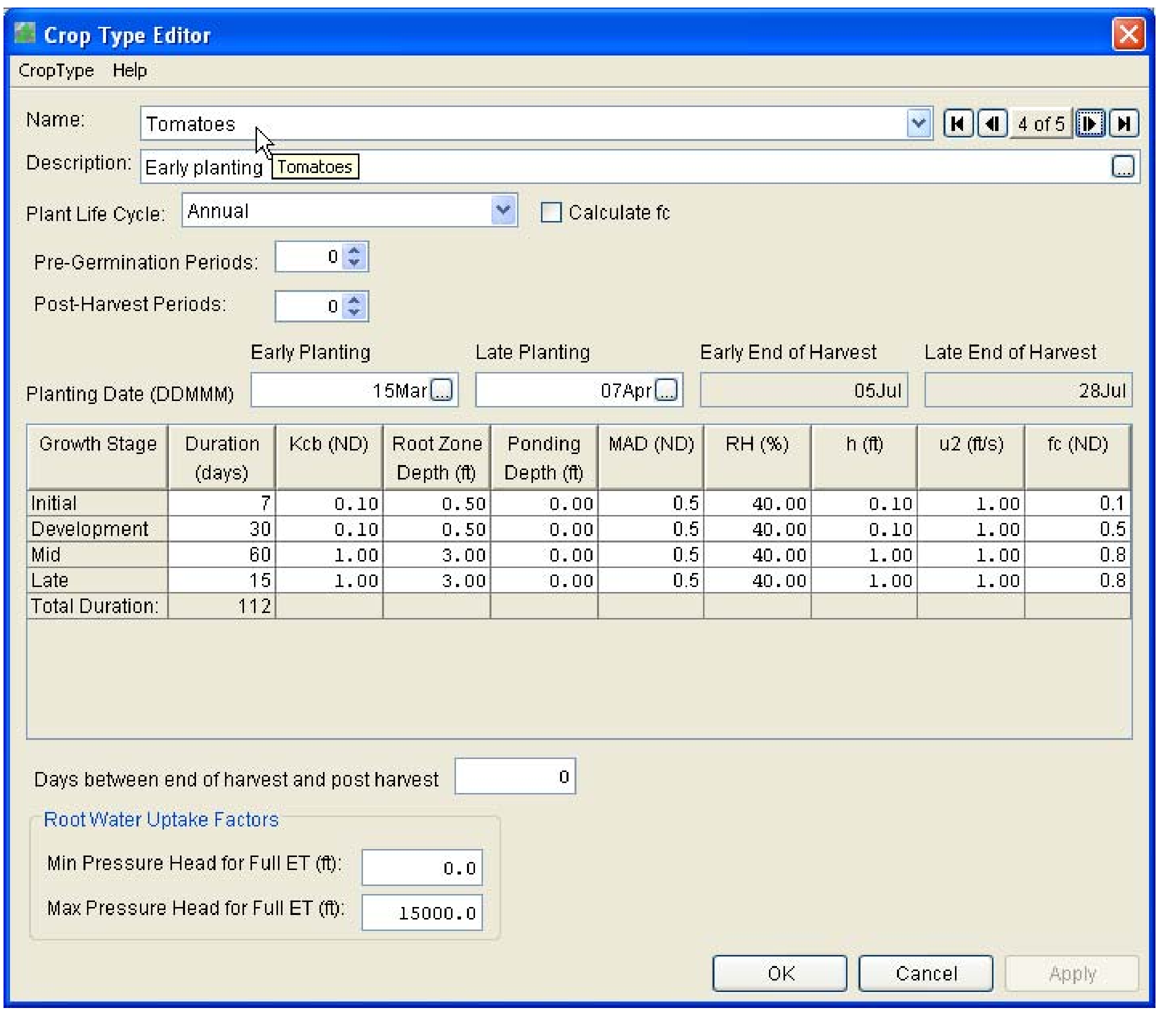
- **Alternatives**

Global Data

The Global Data Editors include:

- Crop Types
- Irrigation System Types
- Soil Types
- Crop Schedules

Crop Type Editor



Introduction

The Crop Type Editor was designed to enable the LAWS user to calculate evapotranspiration (ET) using the dual crop coefficient approach described in **"Crop evapotranspiration - Guidelines for computing crop water requirements - FAO Irrigation and drainage paper 56"** (Allen, et al., 1998), hereafter referred to as "FAO 56." Users of LAWS are urged to familiarize themselves with these calculations by reading the publication.

Basic Editor Functionality

Crop Type menu commands:

Name	Function	Keyboard Shortcut
New	Create a new Crop Type	Ctrl + N
Save	Save the changes made in the editor	Ctrl + S
Delete	Delete the Crop Type currently displayed in the editor from the current Project	
Rename	Rename the Crop Type current displayed in the editor	
Close	Close the editor dialog. If changes were made, a **Save Changes** dialog will display.	

Help menu commands:

Name	Function
Help	Displays the Crop Type Editor's help information in the LAWS online Help window

Crop Type Selection:

The **Crop Type Editor** allows you to browse through all the Crop Types created in the Project. The name of the current Crop Type appears in the **Name** field. To view other Crop Types, use the scroll buttons to the right of the **Name** field or select the Crop Type's name from the **Name** dropdown list. . The following is a table of the buttons and their functionality:

Button	Function
	View first record

	View previous record
1 of 4	Current record displayed out of total number of records
	View last record
	View next record in the list

Description:

The **Description** field displays the description for the current Crop Type. The description can be edited by typing in the field. A text window is available through the eclipse  button in the text-field.

Button Panel:

Button	Function
OK	Save the changes made and close the editor
Apply	Save the changes made
Cancel	Do not save the changes made and close the editor

Specific Editor Functionality

Plant Life Cycle:

The Plant Life Cycle combo box contains only one choice at this time:

- Annual

However, perennial vegetation may be simulated in LAWS as described below.

Calculate fc:

Checking this box will have LAWS calculate fc, the soil cover fraction, instead of requiring the user to enter it in the Growth Stage Table. When this option is selected the "fc" column in the Growth Stage Table will be replaced with the Kc min column. When this option is checked the following equation is solved:

$$fc = \left(\frac{Kcb - Kc\min}{Kc\max - Kc\min}\right)^{(1+0.5h)}$$

Kcb - basal crop coefficient
Kcmin - minimum value of Kc for a bare dry soil
Kcmax - maximum value for Kcb
h - plant height

Kcb and Kcmax are calculated by LAWS based on information entered in the Crop Type Editor

Pre-Germination Periods:

Enter the number of pre-germination periods. Pre-germination periods are periods of the year prior to planting in which crop transpiration does not occur but irrigation may occur in order to meet some management objective such as soil salt leaching or pre-irrigation. Entry of a non-zero number in this field will add a row(s) to the Growth Stage Table prior to the "Initial" stage.

Post-Harvest Periods:

Enter the number of post-harvest periods. Post-harvest periods are periods of the year after harvest during which crop transpiration does not occur but irrigation may be needed to meet some management objective such as rice straw decomposition. Entry of a non-zero number in this field will add a row(s) to the Growth Stage Table after to the "Late" stage.

Planting Dates:

The **Planting Date** section contains entry fields for **Early Planting** and the **Late Planting**. The date (DDMMM format) can be entered manually into the two fields or selected using the Calendar Tool accessed through the eclipse button in each field. The **Early End of Harvest** and **Late End of Harvest** field data are calculated by the editor using the **Total Duration** in the Growth Stage Table. The Total Duration is added to the Early Planting date to get the Early End of Harvest date and added to the Late Planting date to acquire the Late End of Harvest. The actual planting date will be entered in the Crop Schedules data screen.

Growth Stage Table:

Within this table, each stage of the plant's growing cycle requires additional information.

- **Initial** - This stage runs from planting to approximately 10% ground cover. For perennial crops this stage starts with "greenup."

- **Development** - This stage runs from 10% crop cover to effective full cover (when soil shading is complete).
- **Mid** - This stage runs from effective full cover to the start of maturity.
- **Late** - This stage runs from the start of maturity to harvest or full senescence.

The sum of the total number of days in the growth period is calculated and displayed in the **Total Duration** row of the table. Each growth period requires the following information:

1. **Duration in days** - The number of days in the growth period.
2. **Kcb** - The basal crop coefficient (dimensionless).

The basal crop coefficient varies over the growing season with its values specified as shown in Figure 1 and Table 1 below. **Please note that to have the Kcb values properly interpolated, the user needs to enter the "initial" Kcb value in both the "Initial" and "Dev" rows of the table.** Representative values of Kcb for many crops can be found in Table 17 of FAO 56 (Allen, et al., 1998)

Growth Stage	Dur - ation	Kcb	Root Zone Depth	Ponding Depth	MAD	RH	h	u2	fc[1]	Kc min[1]
Initial		**Kcb_i**	**RD_i**	PD_i	MAD_i	RH_i	**h_i**	$u2_i$	fc_i	$Kcmin_i$
Dev		**Kcb_i**	**RD_i**	PD_d	MAD_d	RH_d	**h_i**	$u2_d$	fc_d	$Kcmin_d$
Mid		Kcb_m	RD_m	PD_m	MAD_m	RH_m	**h_m**	$u2_m$	fc_m	$Kcmin_m$
Late		Kcb_l	RD_m	PD_l	MAD_l	RH_l	**h_m**	$u2_l$	fc_l	$Kcmin_l$

Table 1. Growth Stage Table Variables.

1. See discussion in subsection 9 below for information on how to enter these values. Note **bold** values in Table indicate variables that are remain the same in than one Growth Stage.

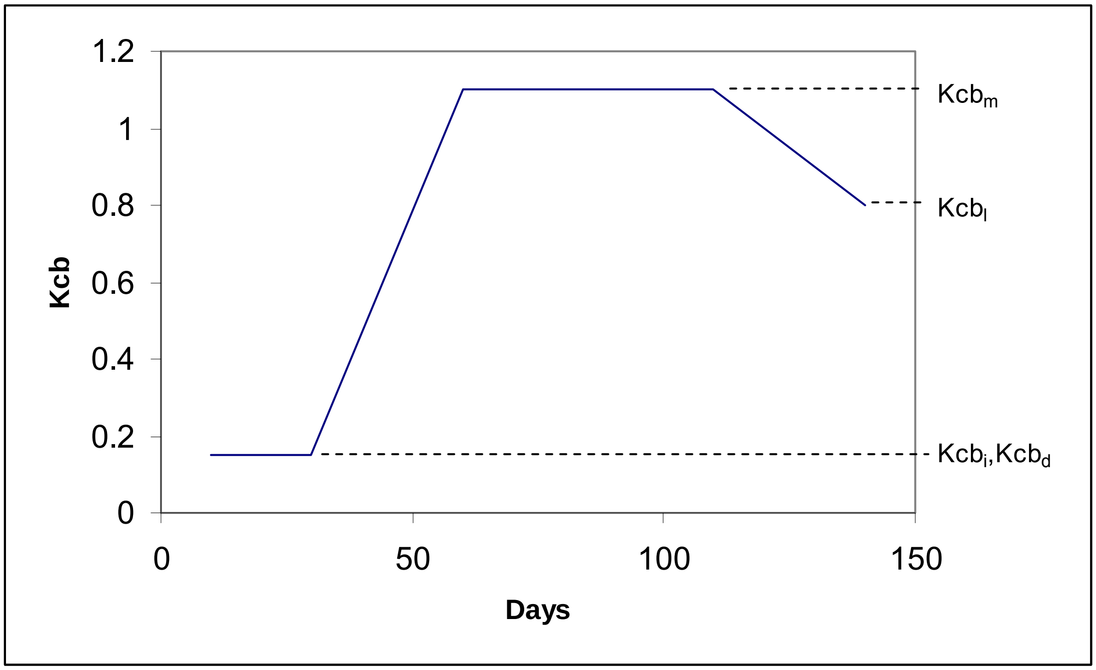


Figure 1. Example of time varying Kcb values based on values specified in the Growth Stage Table.

3. Root Zone Depth (**RD)** - the depth of the plant root zone (ft or m).

Consistent with FAO 56, root zone depth increases from the initial value to the maximum value during the development stage. **Therefore, values of root zone depth for the "Initial" and "Dev" rows of the table should be identical as should the "Mid" and "Late"** (Figure 2 and Table 1). Representative values for rooting depth can be found in Table 22 of FAO 56.

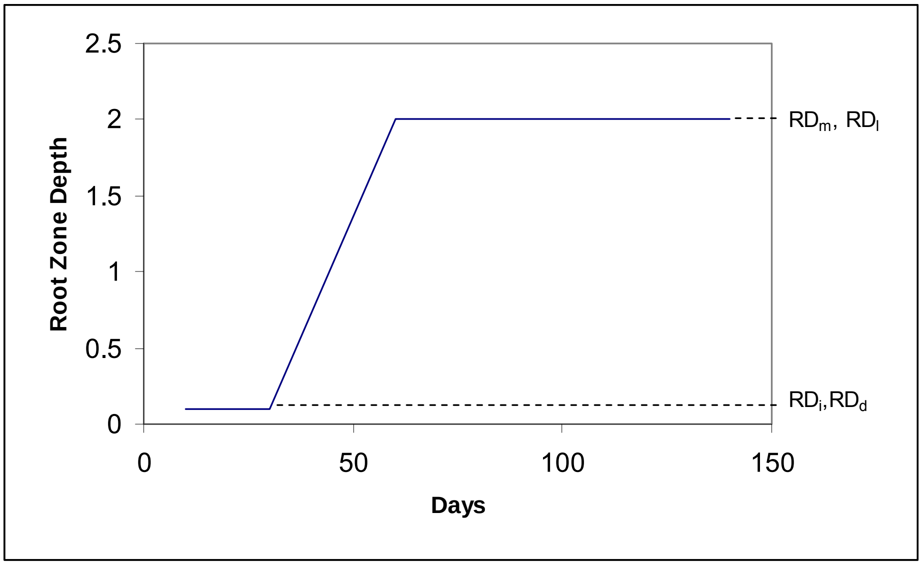


Figure 2. Example of time varying root zone depth as specified in the Growth Stage Table.

4. Ponding Depth (PD) - depth of ponding is required for certain crops (e.g. for rice) (ft or m). For most crops ponding depth is 0.

The ponding depth is specified for each growth stage (Figure 3,Table 1).

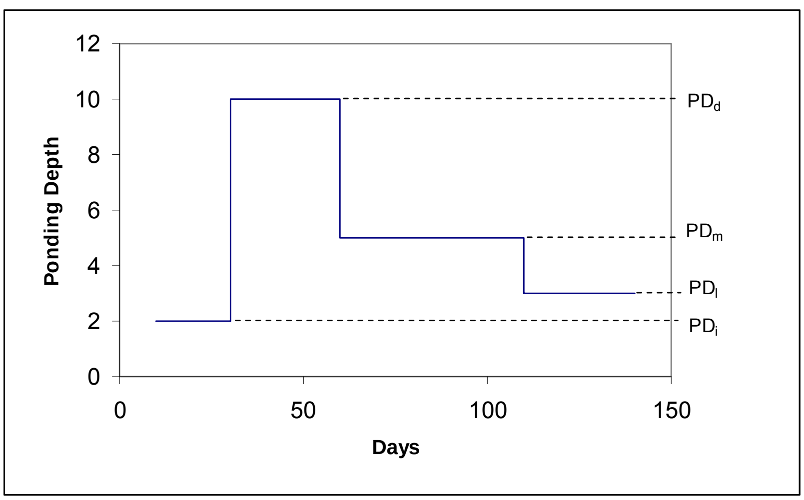


Figure 3. Example of time varying ponding depth as specified in the Growth Stage Table.

5. Management Allowable Depletion (MAD) - management allowable depletion (dimensionless) is the fraction of the plant available water holding capacity that the crop can utilize before irrigation is requested. Available water capacity is defined as the difference between the water content at field capacity and the water content at permanent wilting point. For example, a MAD value of 0.4 means that plants can transpire 40% of the plant available water holding capacity before an irrigation is requested. Values of MAD are specified for each growth stage (Figure 4, Table 1). Representative values of the depletion fraction, or MAD, can be found in Table 22 of FAO 56.

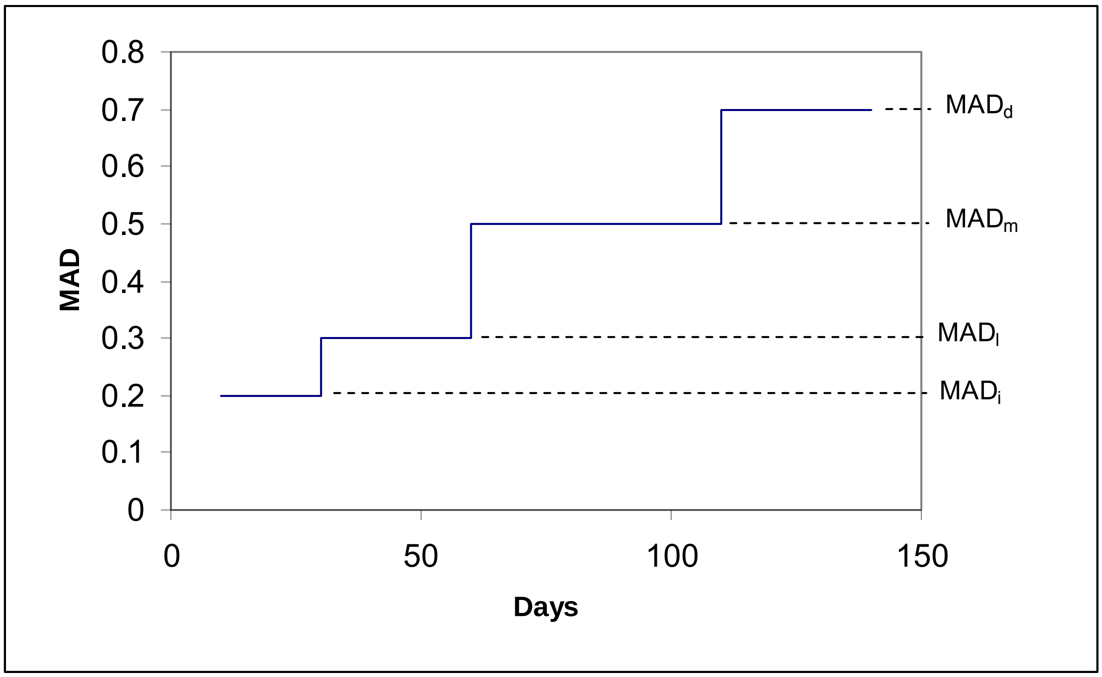


Figure 4. Example of time varying MAD as specified in the Growth Stage Table.

6. Relative humidity (%) (RH) - The mean value for daily minimum relative humidity during the mid- or late season growth stage. Values are specified for each growth stage (Figure 5, Table 1). This information is used by LAWS to compute the value of KCmax used in the dual crop coefficent method. See **Technical Reference** Section.

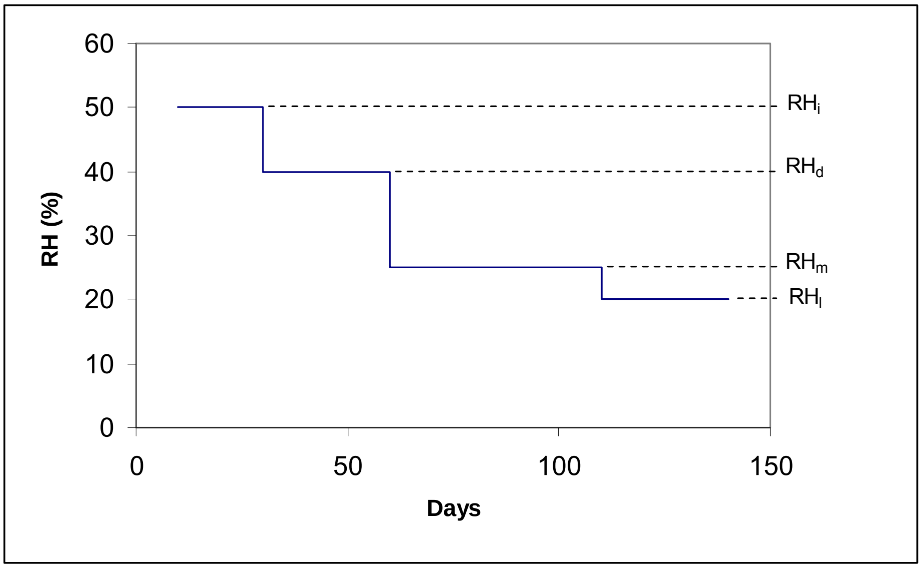


Figure 5. Example of time varying minimum daily relative humidity as specified in the Growth Stage Table.

7. Plant height (h) - maximum plant height during the growth stage period of calculation (ft or m). Values are specified for each growth stage (Figure 6, Table 1). **Note that the same values are used for the Ini-Dev stages and Mid-Late stages.** This information is used by LAWS to compute the value of KCmax used in the dual crop coefficient method. See **Technical Reference** Section.

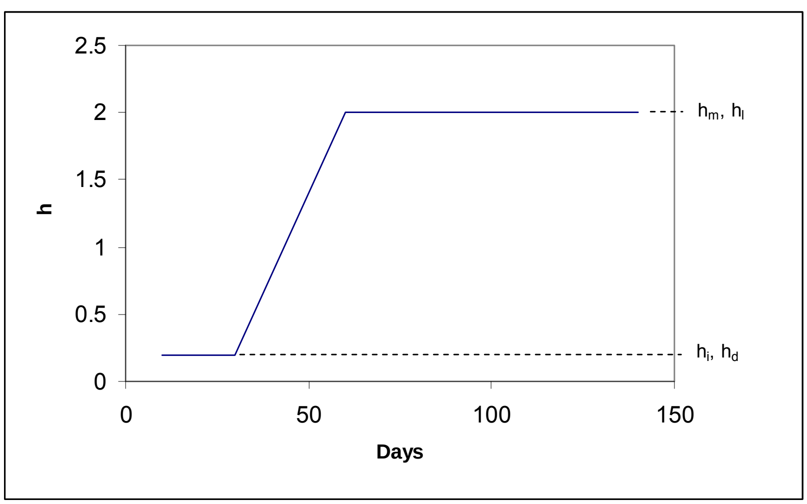


Figure 6. Example of time varying mean maximum plant height as specified in the Growth Stage Table.

8. Wind speed (u_2) - mean value of daily wind speed at 2 m height (ft/s or m/s). Values are specified for each growth stage (Figure 7, Table 1). This information is used by LAWS to compute the value of KCmax used in the dual crop coefficent method. See **Technical Reference** Section.

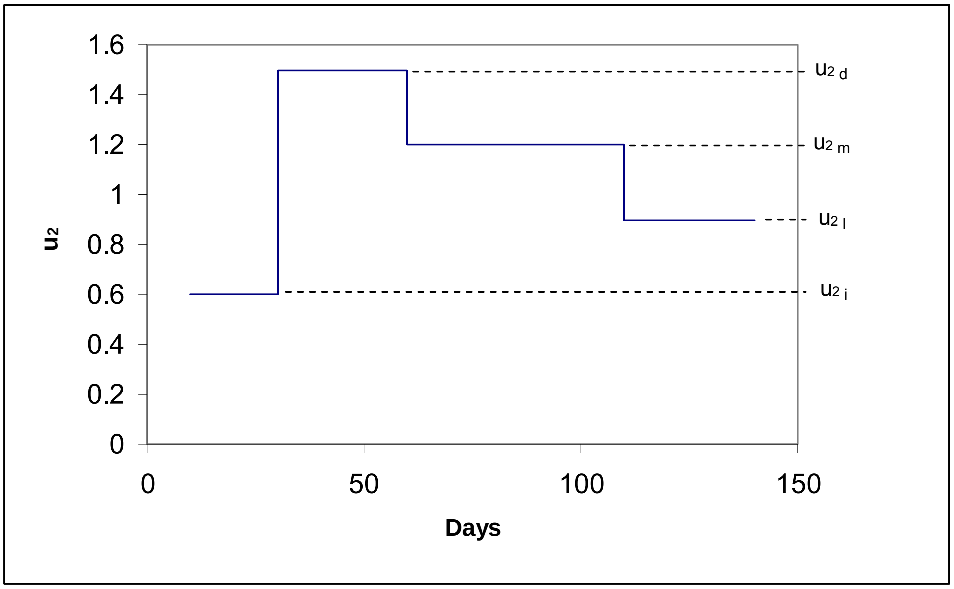


Figure 7. Example of time varying mean daily wind speed as specified in the Growth Stage Table.

9. Soil cover fraction / Kc minimum (fc / Kc_{min}) - fc is the soil cover fraction (dimensionless), Kc_{min} is the minimum Kc for dry bare soil with no ground cover (dimensionless). If fc is to be specified then the user enters a value for each growth stage. If fc is to be calculated by LAWS then this column changes to Kc_{min} and a value should be entered for each growth stage (Figure 8, Table 1). Representative values of fc can be found in Table 21 of FAO 56.

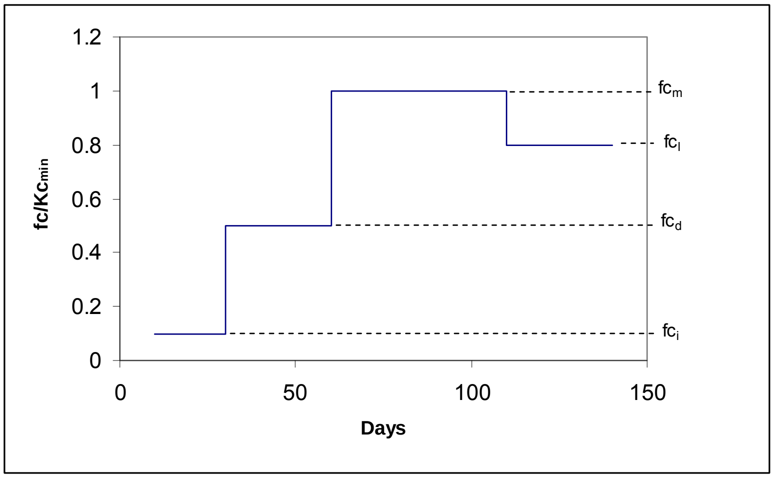


Figure 8. Example of time varying fc (or Kc_{min}) as specified in the Growth Stage Table.

Root Water Uptake Factors

Plant transpiration can be limited using a function that is equal to 1.0 for a range of optimal pressure heads (PH) and less than 1.0 for anoxic (very wet) and very dry conditions (Feddes, 1974) (Figure 9). Transpiration is limited for |PH|> PHmax and |PH|<PHmin. It is assumed transpiration ceases at |PH| = 15,0000 cm.

- **Min Pressure Head for Full ET (PHmin)** - pressure head value at which anoxic conditions start to limit plant transpiration (PHmin on Figure 9).
- **Max Pressure Head for Full ET (PHmax)** - pressure head at which transpiration starts to be limited by a lack of soil moisture (PHmax on Figure 9).

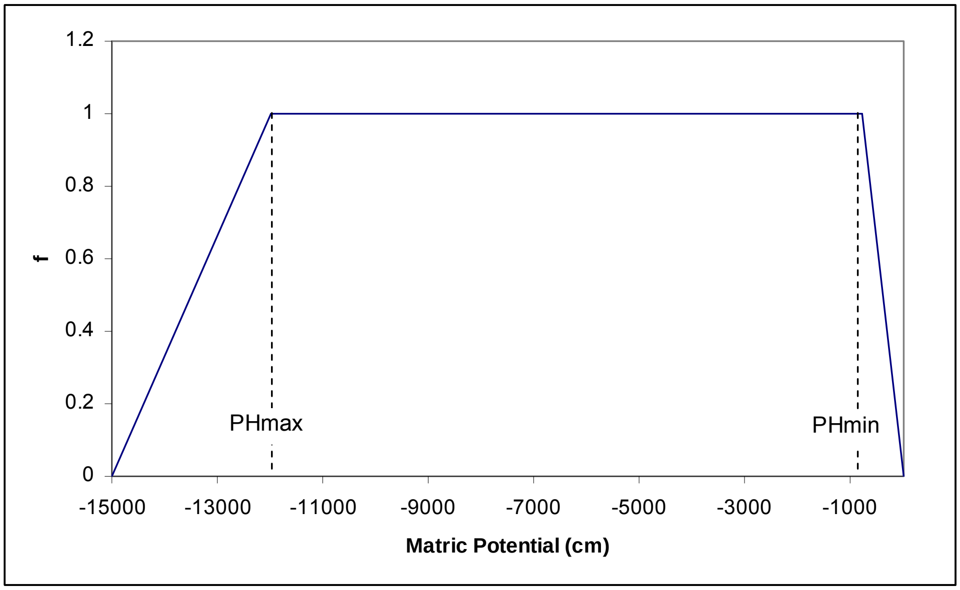
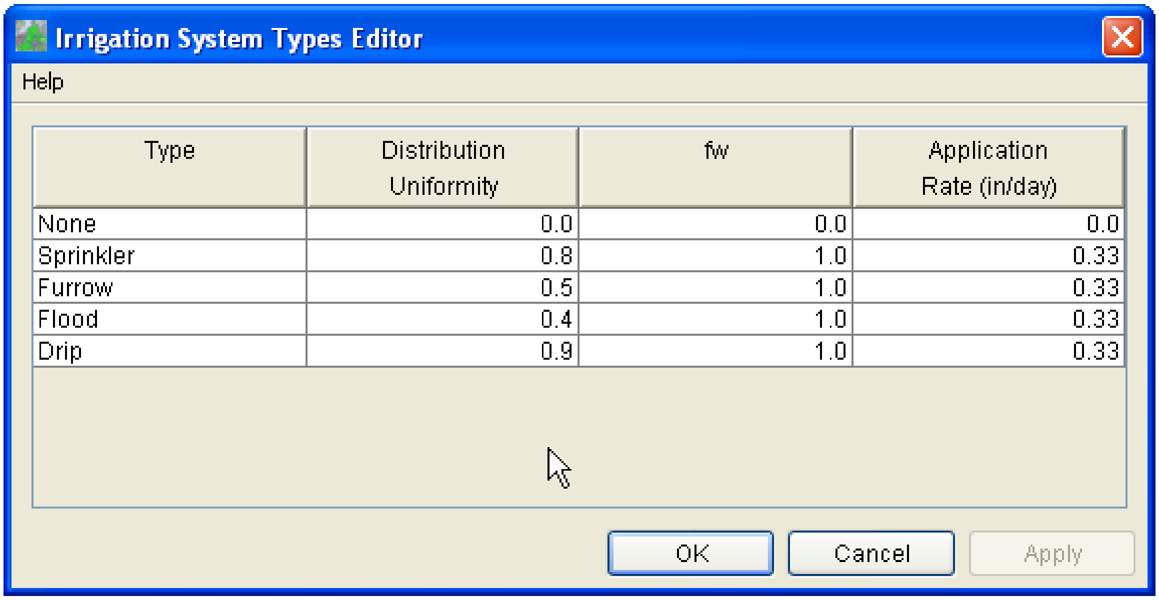


Figure 9. Example of the transpiration limiting function.

Additional Information:

- Crop Types
- Adding Crop Types

Irrigation System Type Editor



Basic Editor Functionality

Help menu commands:

Name	Function	Keyboard Shortcut
Help	Displays the Irrigation System Editor's help information in the LAWS online Help window	

Button Panel:

Button	Function
OK	Save the changes made and close the editor
Apply	Save the changes made
Cancel	Do not save the changes made and close the editor

Specific Editor Functionality

Irrigation Table:

The Irrigation System Types Editor lists the available irrigation systems. Each row in the table represents a different irrigation system type. There are four default irrigation system types initially provided: sprinkler, furrow, flood, and drip. However, additional irrigation system types can be added. Below is a description of the requirements:

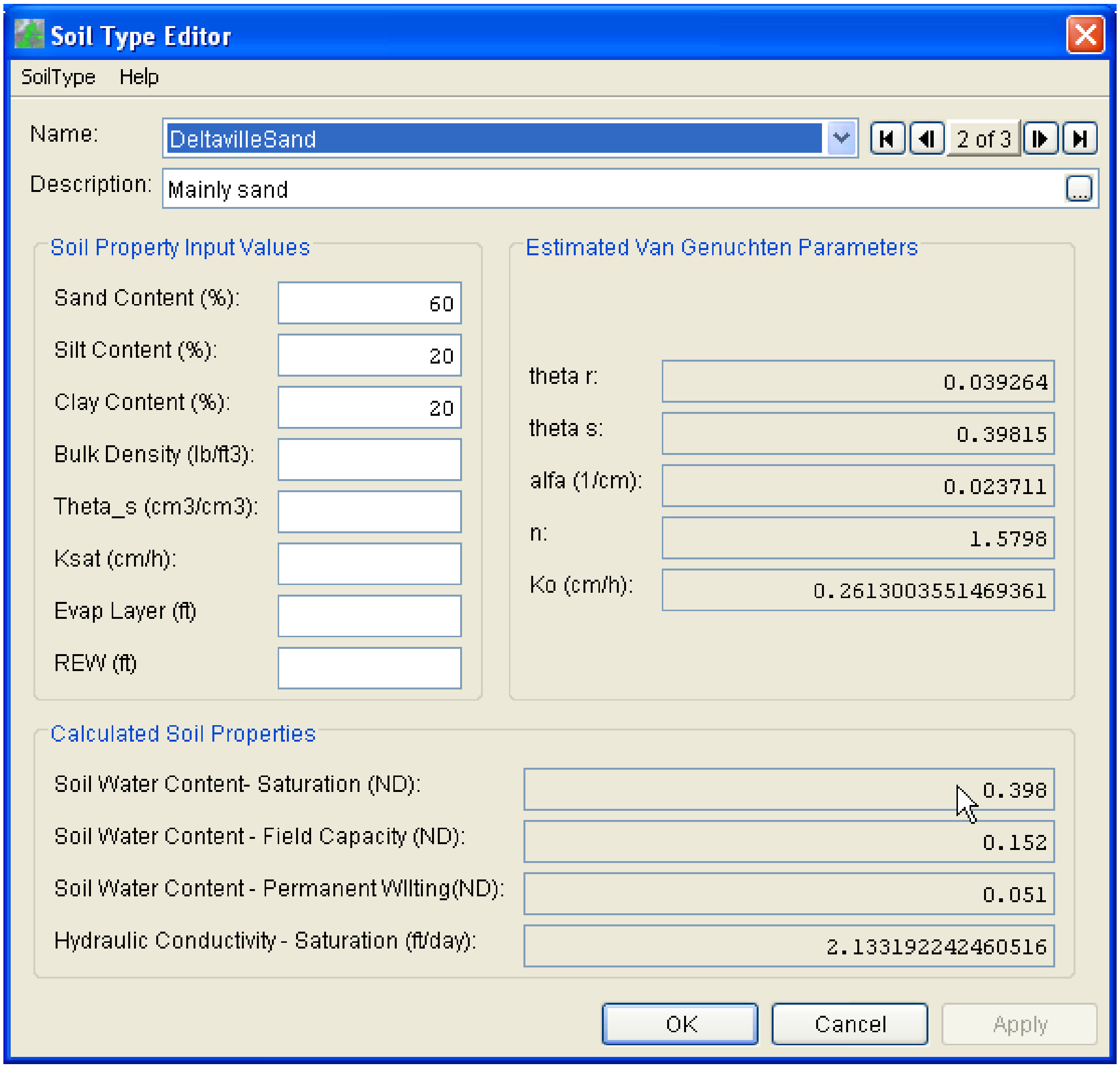
- **Type** - Name of the irrigation system type.
- **Distribution Uniformity** - Determines the amount of additional irrigation water delivered to account for the non-uniformity of the irrigation application. The distribution uniformity is typically expressed as the ratio of the average depth of water applied to the quarter of the field receiving the least water over the average depth of water applied to the entire field.
- **fw** - The fraction of the irrigated area that is wetted by the irrigation and therefore the field may potentially have bare soil evaporation. For instance, sprinklers usually have an fw = 1.0 while drip irrigation may have an fw of 0.4. Table 20 in FAO 56 provides representative values of fw.
- **Application Rate** - The water application rate of the irrigation system type (ft/d or m/d).

To enter any information in the table, simply click the cell and type.

Additional Information:

- Adding Irrigation Types
- Irrigation Types

Soil Types Editor



Introduction

The **Soil Types Editor** allows the user to enter various soil physical properties including percent sand, silt, and clay, bulk density, and saturated hydraulic so that unsaturated flow parameters can estimated using the Neuro Multi-Step pedo-transfer program created by Minasny, et al. (2004) (Soil Sci. Soc., Am. J. 68:417-429) to estimate the van Genuchten parameters. Soil water content at saturation, field capacity, permanent wilting point and saturated hydraulic conductivity are then estimated using these van Genuchten parameters. These parameters are also used to simulate unsaturated flow conditions during infiltration events.

At a minimum, the user is required to enter representative values for the percentages of sand, silt and clay associated with each soil type. Additional information such as the bulk density, saturated water content, and saturated hydraulic conductivity can be entered if available.

If the saturated hydraulic conductivity is not specified by the user then LAWS calculates the hydraulic conductivity at saturation using the pedo-transfer function of Cosby, et al. (1984) found in Water Resources Research. 20:682-690.

The user must also enter values for the thickness of the evaporation layer and the readily evaporable water (REW) for use in the bare soil evaporation calculations made using the approach outlined in FAO 56 (see the Crop Type Editor for more information). Representative values for the REW can be found in Table 19 of FAO 56.

Basic Editor Functionality

Soil Type menu commands:

Name	Function	Keyboard Shortcut
New	Create a new Soil Type	Ctrl + N
Save	Save the changes made in the editor	Ctrl + S
Rename	Rename the Soil Type current displayed in the editor	
Delete	Delete the Soil Type currently displayed in the editor from the current Project	
Close	Close the editor dialog. If changes were made, a **Save Changes** dialog will display.	

Help menu commands:

Name	Function	Keyboard Shortcut
Help	Displays the Soil Type Editor's help information in the LAWS online Help window	

Soil Type Selection:

The **Soil Type Editor** allows you to browse through all the Soil Types created in the Project. The name of the current Soil Type appears in the **Name** field. To view other Soil Types, use the scroll buttons to the right of the name field or select the Soil Type's name from the **Name** dropdown list. The following is a table of their functionality:

Button	Function
	View first record
	View previous record
1 of 4	Current record displayed out of total number of records
	View last record
	View next record in the list

Description:

The **Description** field displays the description for the current Soil Type. The description can be edited by typing in the field. A text window is available through the eclipse  button in the text-field.

Button Panel:

Button	Function
OK	Save the changes made and close the editor
Apply	Save the changes made
Cancel	Do not save the changes made and close the editor

Specific Editor Functionality

Soil Property Input Values:

Below are descriptions for the editable entry fields for the soil properties:

- **Sand Content (%)** - Percentage of sand found in the soil **(required).**
- **Silt Content (%)** - Percentage of silt found in the soil **(required).**
- **Clay Content (%)** - Percentage of clay found in the soil **(required).**
- **Bulk Density (g/cm)** - Bulk density of soil (optional).
- **Theta_s (cm3/cm3)** - Water content at saturation (optional).
- **Ksat (cm/h) -** Hydraulic conductivity at saturation (optional).
- **Evap Layer (cm)** - Thickness of the evaporation layer used in the dual crop coefficient approach for calculating crop evapotranspiration described in FAO 56. Typical values range from 10 to 15 cm **(required)**.

- **REW** - Readily Evaporable Water. This is the water that can be evaporated from the soil during Stage 1 of the drying process. During Stage 1, the soil is wet enough that bare soil evaporation is only limited by the evaporative energy available at the soil surface. Table 19 in FAO 56 provides typical values for REW **(required)**.

Estimated Van Genuchten Parameters:

The following describes the estimated van Genuchten parameter properties of the soil:

- **Theta r -** residual water content.
- **Theta s -** water content at saturation**.**
- **Alfa (1/cm) -** van Genuchten parameter.
- **n -** van Genuchten parameter.
- **Ko (cm/h) -** van Genuchten parameter.

NOTE: The sand, silt, and clay percentages combined total must equal 100% in order for the editor to close.

Calculated Soil Properties:

The following describes the calculated soil properties in the editor:

- Soil Water Content at Saturation (ND)

- Soil Water Content at Field Capacity (ND)
    - Field Capacity assumed to be at 333 cm (1/3 bar) of pressure head.
- Soil Water Content at Permanent Wilting (ND)
    - Permanent Wilting assumed to be 15,000 cm (15 bars) of pressure head.

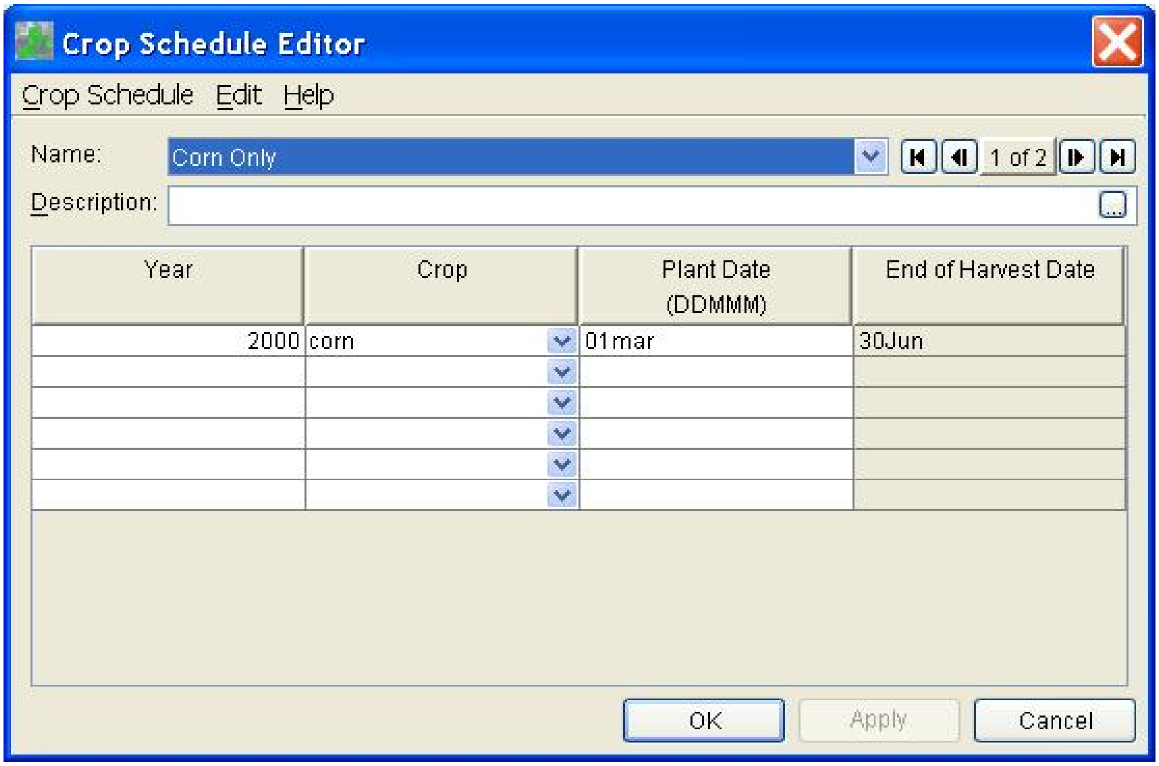
- Hydraulic Conductivity at Saturation (L/T)

The hydraulic conductivity at saturation is either specified by the user or if it is not specified, it is automatically calculated using the pedo-transfer function of Cosby, et al. (1984) found in Water Resour. Res. 20:682-690. This function predicts hydraulic conductivity as a function of the percent sand and clay in the soil.

Additional Information:

- Soil Types
- Adding Soil Types

Crop Schedule Editor



Introduction

The **Crop Schedule Editor** allows users to browse through all the Crop Schedules created in the Project. The name of the current Crop Schedule appears in the **Name** field. To view other Crop Schedules, use the scroll buttons to the right of the name field or select the Crop Schedule's name from the **Name** dropdown list. The following is a table of their functionality:

Basic Editor Functionality

Crop Schedule menu commands:

Name	Function	Keyboard Shortcut
New	Create a new Crop Schedule	Ctrl + N
Save	Save the changes made in the editor	Ctrl + S
Delete	Delete the Crop Schedule currently displayed in the editor from the current Project	
Close	Close the editor dialog. If changes were made, a **Save Changes** dialog will display.	

Edit menu commands:

Name	Function	Keyboard Shortcut
Crop Type	Displays the Crop Type Editor.	

Help menu commands:

Name	Function	Keyboard Shortcut
Help	Displays the Crop Schedule Editor's help information in the LAWS online Help window	

Crop Schedule Selection:

Button	Function
	View first record
	View previous record
1 of 4	Current record displayed out of total number of records
	View last record
	View next record in the list

Description:

The **Description** field displays the description for the current Crop Schedule. The description can be edited by typing in the field. A text window is available through the eclipse  button in the text-field.

Button Panel:

Button	Function
OK	Save the changes made and close the editor
Apply	Save the changes made
Cancel	Do not save the changes made and close the editor

Specific Editor Functionality

Schedule Table:

Each row in the Schedule table represents a new planting event. Below is a description of each column:

Year - Represents the year the crop will be planted.

Crop - Select the crop to be planted from the dropdown list filled with previously created **Crop Types** in the Crop column*.

If you need to edit or add a Crop Type access to the Crop Type Editor is available through the menu bar. Select **Edit then the **Crop Type** menu option.*

Plant Date - This field defaults to the selected Crop Types Early Planting date. However, this date can be changed, as long as the date entered falls within the range of the Early and Late Planting dates predefined by the Crop Type. If you would like to use a date outside the Crop Type range either edit the Crop Type dates or create a new Crop Type that best describes the dates needed. For example: You may have two types of corn, Late and Early Corn. They are both corn, but their planting dates differ.

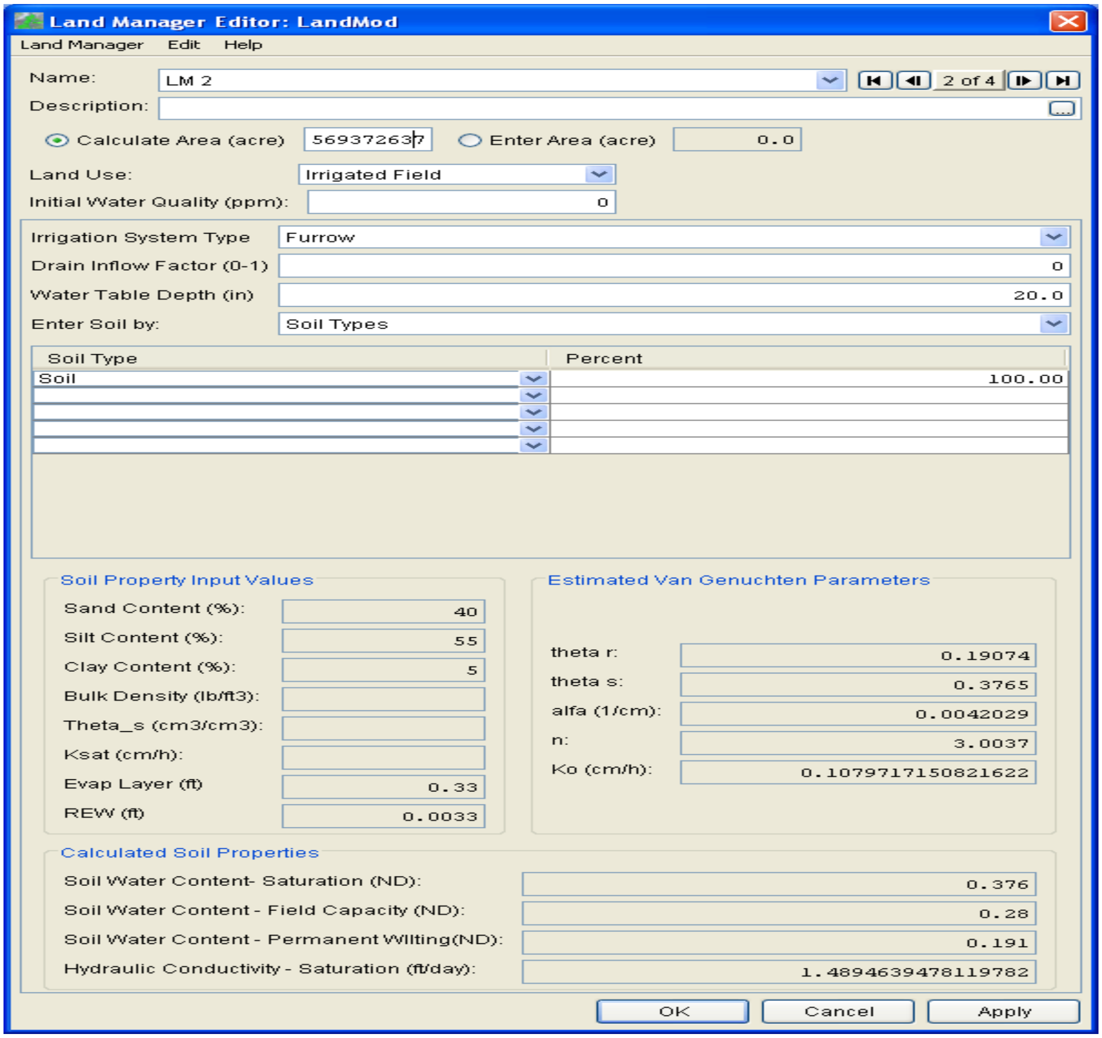
Harvest Date - The **Harvest Date** will be calculated by the editor using the **Total Duration** time of the selected Crop Type's growth stage from the time of the Plant Date.

NOTE: During the Alternative's compute, if the year indicated by the Crop Schedule is not included in the time range of an Alternative computation, then the Crop Schedule will automatically determine the appropriate start crop and proceed to rotate the crops throughout the simulation. However, the user needs to check whether the Crop Schedule is appropriate for their purposes.

Additional Information:

- Crop Schedules
- Adding Crop Schedules

Land Manager



Introduction

The Land Manager is the fundamental calculation unit within LAWS. It is at this scale that the interactions between soils, vegetation, and the atmosphere are calculated. Outputs from these calculations include surface runoff, infiltration, bare soil evaporation, plant transpiration, deep percolation, upflux from a shallow water table, soil moisture storage, and drain flows. It is also within the Land Manager that irrigation demands are calculated as a function of the user specified management parameters (MAD and irrigation system characteristics).

In addition to the water balance calculations described above, the Land Manager can be used to calculate demands based on a user specified constant demand or time series of demands. This functionality is useful for representing demands outside of the LAWS project area that nonetheless have an impact of reservoir storage or stream flow within the geographic area of the project.

Basic Editor Functionality

Land Manager menu commands:

Name	Function	Keyboard Shortcut
 Save	Save the changes made in the editor	Ctrl + S
Rename	Rename the Land Manager current displayed in the editor	
 Delete	Delete the Land Manager currently displayed in the editor from the current Project	
Close	Close the editor dialog. If changes were made, a **Save Changes** dialog will display.	

Edit menu commands:

Name	Function	Keyboard Shortcut
Soil Type	Displays the Soil Type Editor	
Irrigation Type	Displays the Irrigation Type Editor	

Help menu commands:

Name	Function	Keyboard Shortcut
Help	Displays the Land Manager Editor's help information in the LAWS online Help window	

Land Manager Selection:

The Land Manager Editor allows you to browse through all the Land Managers created in the Project. The name of the current Land manager appears in the **Name** field. To view other Land Managers, use the scroll buttons to the right of the name field or select the Land Manager's name from the **Name** dropdown list. The following is a table of their functionality:

Button	Function
	View first record
	View previous record

1 of 4	Current record displayed out of total number of records
	View last record
	View next record in the list

Description:

The **Description** field displays the description for the current Land Manager. The description can be edited by typing in the field. A text window is available through the eclipse button in the text-field.

Button Panel:

Button	Function
OK	Save the changes made and close the editor
Apply	Save the changes made
Cancel	Do not save the changes made and close the editor

Specific Editor Functionality

Land Use -This variable determines the method used to calculate water demand. The choices are **Irrigated Field** and **Other Demand**. If the **Irrigated Field** option is chosen then a full root zone water balance is calculated for each day of the simulation and irrigation water is ordered if the water content in the root zone reaches the Management Allowable Depletion and a crop is active. If the **Other Demand** option in chosen then no root zone water balance is calculated and the user simply enters a constant water use rate or a time series of water use rates.

The remainder of this section is describes data entries required for the **Irrigated Field** option.

Calculate Area - If this option is chosen the area of the Land Manager is calculated by LAWS using the geometry of the polygon that represents it.

Enter Area - If this option is chosen the user can enter a value for the Land Manager area. This option should be used if a more abstract representation of a water resources system is required. This allows the user to develop a model in which a Land Manager may represent a very large area with similar crop and soil properties yet the Land Manager polygon on the LAWS schematic does not exactly coincide with the boundaries of the modeled area.

Irrigation System Type - The Irrigation System Type drop down list is populated with previously created Irrigation System Types. The selected Irrigation Type will represent the irrigation system used primarily in the Land Manager. If an Irrigation System Type needs to be edited or created, the Irrigation System Types Editor can be accessed via the Edit -> Irrigation Type menu option within this editor.

Drain Inflow Factor (0-1) - The Drain Inflow Factor field allows entry of a value ranging from 0 to 1. This value represents the fraction of the deep percolation that will go into the drainage system of the Delivery Manager and is made available to other Delivery Managers as a function of the settings in the Delivery Manager Editor.

Water Table Depth - This value is used to calculate the amount of groundwater upflux that can be used to meet plant water demand. If the **groundwater modeling option** is being used this value is calculated by LAWS. If the water table is deep enough that no plant transpiration demand is met by the water table source then this number should be large (>20 ft or 6 m)

Enter Soil By - The soil information for the Land Manger may be entered in two ways, by Soil Types or Soil Properties. Both are available through the Enter Soil By dropdown list. The following is a description for each selection:

- **Soil Types** (default)

Soil Type	Percent
Clay Loam	64.00
Loamy Sand	36.00

Enter Soil by Soil Types uses a table for data entry (see above figure). Previously defined soil types described by the user in the Soil Type Editor are chosen. With this approach the user selects the soil types present in the Land Manager and assigns a percentage of each type to represent the portion of the Land Manager covered by a particular soil type. LAWS then uses these percentages to calculate a weighted average value for percent sand, silt, and clay. If present, a weighted average of bulk density, Theta_S and Ksat are also calculated. These average values are then used as input for the Neuro Multi-Step pedo-transfer program created by Minasny, et al. (2004) (Soil Sci. Soc., Am. J. 68:417-429) which estimates the van Genuchten parameters. Soil water content and saturation, field capacity, and permanent wilting point are then calculated using the van Genuchten parameters.

If the hydraulic conductivity at saturation is not provided by the user then LAWS calculates the hydraulic conductivity at saturation using the pedo-transfer function of

Cosby, et al. (1984) found in Water Resources Research. 20:682-690. This pedo-transfer function uses as inputs the percent sand and clay.

Weighted averages for the thickness of the evaporation layer and the readily evaporable water (REW) are also calculated using the soil type percentages

Note: If a Soil Type needs to be edited or created, the Soil Type Editor is available via the Edit->Soil Type menu option on the editor.

Enter Soil By - This is an alternative way to specify Land Manager soil properties.

- **Soil Properties**

If this option is selected then the user has the choice of entering either the Soil Property Input Values and having the Neuro Multistep pedo-transfer program calculate the van Genuchten parameters or directly entering the van Genuchten parameters. The following Land Manager soil property values can be entered.

Soil Property Input Values:

- **Sand Content (%)** - Representative percentage of sand found in the Land Manager **(required)**.
- **Silt Content (%)** - Representative percentage of sand found in the Land Manager **(required)**.
- **Clay Content (%)** - Representative percentage of sand found in the Land Manager **(required)**.
- **Bulk Density (g/cm)** - Representative percentage of sand found in the Land Manager.
- **Theta_s (cm3/cm3)** - Representative percentage of sand found in the Land Manager.
- **Ksat (cm/h) -** Representative percentage of sand found in the Land Manager.
- **Evap Layer (cm)** - Representative thickness of the evaporation layer found in Land Manager used in the dual crop coefficient approach for calculating crop evapotranspiration described in FAO 56. Typical values range from 10 to 15 cm **(required)**.
- **REW** - Representative amount of Readily Evaporable Water found in Land Manager that can be evaporated from the soil during Stage 1 of the drying process. During Stage 1, the soil is wet enough that bare soil evaporation is only limited by the evaporative energy available at the soil surface. Table 19 in FAO 56 provides typical values for REW **(required)**.
-

Calculated Soil Properties:

The following describes the calculated Soil Properties in the editor:

- Soil Water Content at Saturation (ND)

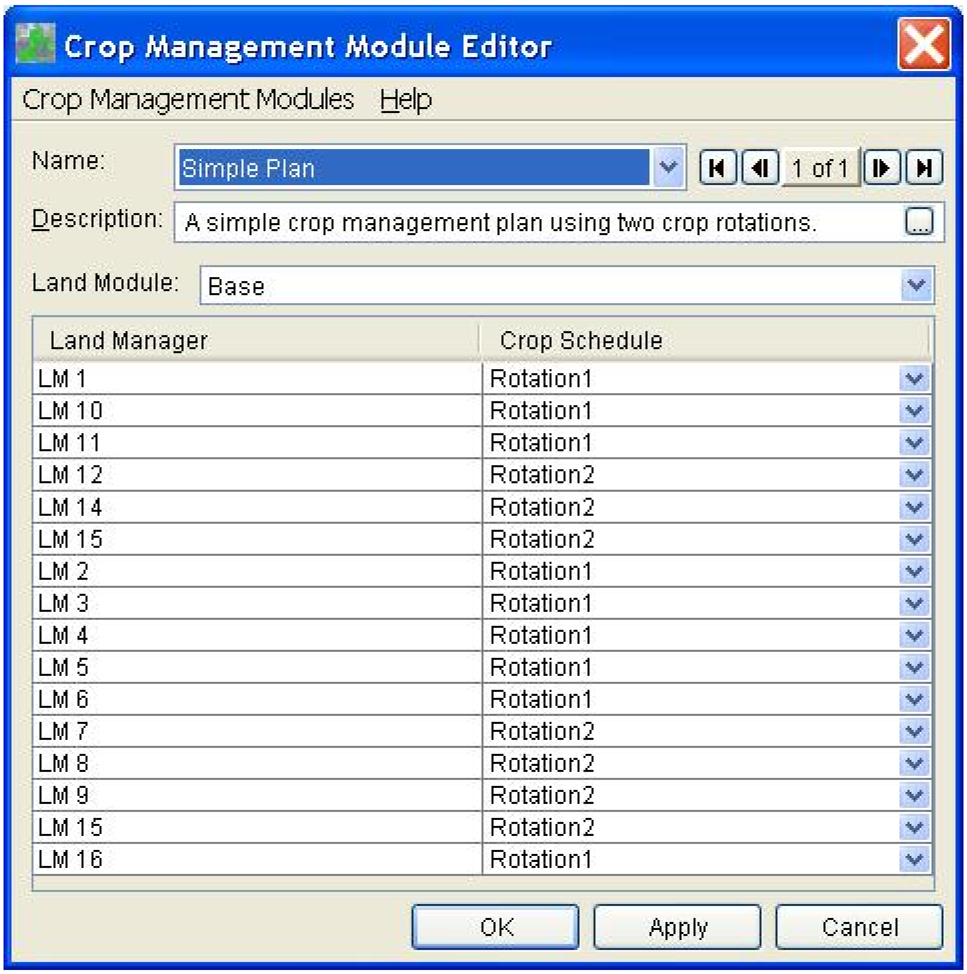
- Soil Water Content at Field Capacity (ND)
    - Field Capacity assumed to be at 333 cm (1/3 bar) of matric potential.
- Soil Water Content at Permanent Wilting (ND)
    - Permanent Wilting assumed to be 15,000 cm (15 bars) of matric potential.

- Hydraulic Conductivity at Saturation (L/t)

Additional information:

- Creating a Land Manager
- Land Manager
- Land Manager Summary
- Technical information of the Land Manager

Crop Management



Introduction

The Crop Management Module editor is used to specify crop schedules that are used by Land Mangers during the LAWS simulation.

Basic Editor Functionality

Crop Management Module menu commands:

Name	Function	Keyboard Shortcut
Save	Save the changes made in the editor	Ctrl + S
Rename	Rename the Crop Management Module current displayed in the editor	
Delete	Delete the Crop Management Module currently displayed in the editor from the current Project	

Close	Close the editor dialog. If changes were made, a **Save Changes** dialog will display.

Help menu commands:

Name	Function	Keyboard Shortcut
Help	Displays the Crop Management Module Editor's help information in the LAWS online Help window	

Crop Management Module Selection:

The **Crop Management Module Editor** allows a user to browse through all the Crop Management Modules created in the Project. The name of the current Crop Management Module appears in the **Name** field. To view other Crop Management Modules, use the scroll buttons to the right of the name field or select the Crop Management Module's name from the **Name** dropdown list. The following is a table of their functionality:

Button	Function
	View first record
	View previous record
1 of 4	Current record displayed out of total number of records
	View last record
	View next record in the list

Description:

The **Description** field displays the description for the current Crop Management Module. The description can be edited by typing in the field. A text window is available through the eclipse  button in the text-field.

Button Panel:

Button	Function
OK	Save the changes made and close the editor
Apply	Save the changes made

Cancel	Do not save the changes made and close the editor

Specific Editor Functionality

- **Land Module:**

The **Land Module** dropdown list includes all Land Modules created in the Project. Select a Land Module to use in the Crop Management Module.

- **Land Module Table:**

Once a Land Module is selected the collection of Land Managers that populate the Module will be listed in a table. Each row in the table represents a crop event. For each Land Manager a Crop Schedule is assigned. The Crop Schedules are listed in the **Crop Schedule** column's dropdown menu. All previously created Crop Schedules are available for selection.

Additional Information:

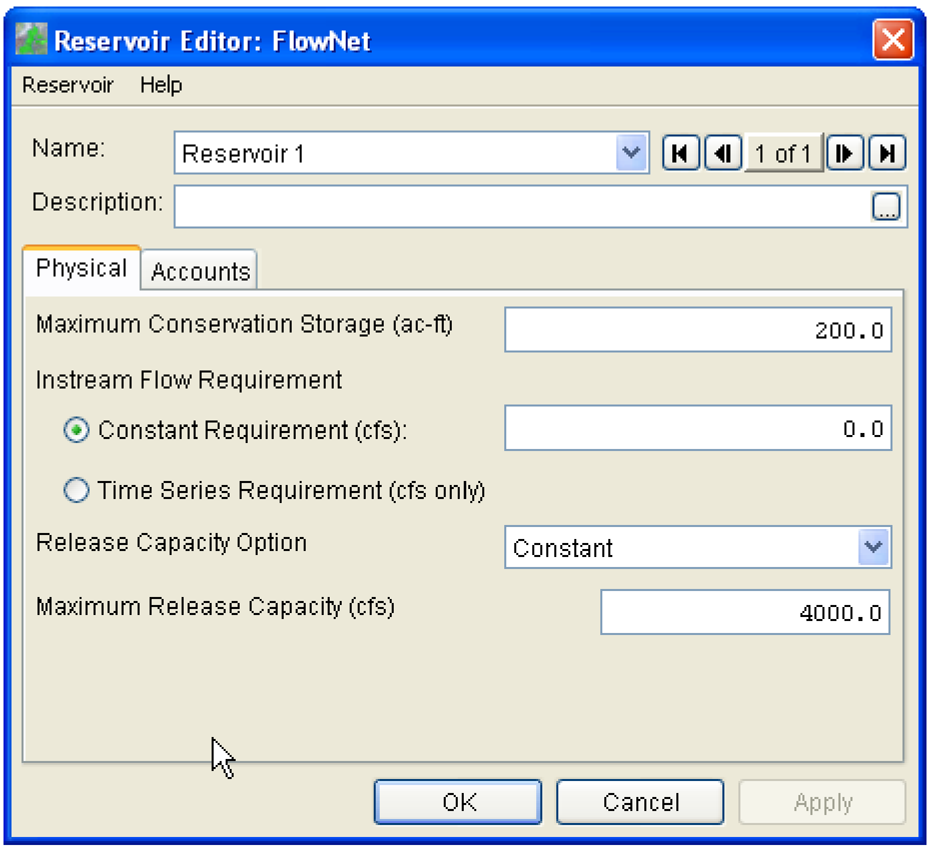
- Land Modules
- Creating Land Modules

Flow Network Module

The Flow Network Editors include:

- Reservoir
- Reach
- Junction

Reservoir Editor



Introduction

The Reservoir Editor allows the user to provide information about the physical characteristics and water management operations associated with it.

Basic Editor Functionality

Reservoir menu commands:

Name	Function	Keyboard Shortcut
New	Create a new Reservoir	Ctrl + N
Save	Save the changes made in the editor	Ctrl + S
Rename	Rename the Reservoir currently displayed in the editor	
Delete	Delete the Reservoir currently displayed in the editor from the current Project	
Close	Close the editor dialog. If changes were made, a **Save Changes** dialog will display.	

Help menu commands:

Name	Function	Keyboard Shortcut
Help	Displays the Reservoir Editor's help information in the LAWS online Help window	

Reservoir Selection:

The Reservoir Editor allows you to browse through all the Reservoirs created in the Project. The name of the current Reservoir appears in the **Name** field. To view other Reservoirs, use the scroll buttons to the right of the name field or select the Reservoir's name from the **Name** dropdown list. The following table describes their functionality:

Button	Function
	View first record
	View previous record
1 of 4	Current record displayed out of total number of records
	View last record
	View next record in the list

Description:

The **Description** field displays the description for the current Reservoir. The description can be edited by typing in the field. A text window is available through the eclipse button in the text-field.

Button Panel:

Button	Function
OK	Save the changes made and close the editor
Apply	Save the changes made
Cancel	Do not save the changes made and close the editor

Specific Editor Functionality

Maximum Conservation Storage:

The Maximum Conservation Storage is the volume of the reservoir's total maximum storage that can be delivered to downstream users.

Instream Flow Requirement:

The Instream Flow Requirement specifies the reservoir release rate needed to meet downstream flow requirements. For example, this could be a release required for maintaining favorable in-stream aquatic habitat conditions. It can be specified as a constant value or as a time series of daily releases if varying flow requirements are needed. If the time series option is selected, a time series data file must be selected in the Alternatives Editor, Input Time Series tab.

Release Capacity Option:

The **Release Capacity Option** represents the physically constrained maximum release for the reservoir. There are currently two options.

- **Constant**
  Using a Constant release rate requires only that the **Maximum Release Capacity** be entered once. This value is the maximum rate the reservoir can release water at any time.

- **Time Series**

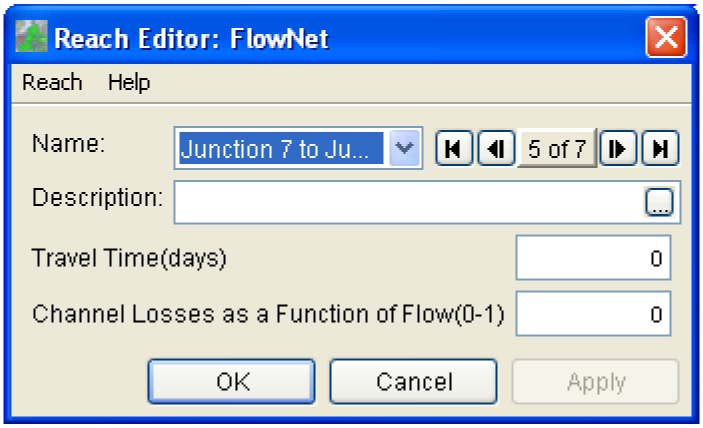
The **Time Series** option allows for a DSS record to be used to set the maximum release capacity for the reservoir. The DSS record specifies the day, month, and year of the release. A variable name for the Time Series must be given in the **Time Series Name** text field. This variable will need to have a DSS file and record assigned to it in the Alternatives Editor's Time Series tab. There, the variable name will be displayed along with the Reservoir's name.

See the Area Manager Accounts tab

Additional Information:

- Reservoirs
- Creating a Reservoir
- Editing a Reservoir
- Drawing Reservoirs

Reach Editor



Introduction

The Reach editor allows the user to specific physical characteristics are associated with flows traveling through the reach.

Basic Editor Functionality

Reach menu commands:

Name	Function	Keyboard Shortcut
New	Create a new Reach	Ctrl + N
Save	Save the changes made in the editor	Ctrl + S
Rename	Rename the Reach currently displayed in the editor	
Delete	Delete the Reach currently displayed in the editor from the current Project	
Close	Close the editor dialog. If changes were made, a **Save Changes** dialog will display.	

Help menu commands:

Name	Function	Keyboard Shortcut
Help	Displays the Reach Editor's help information in the LAWS online Help window	

Reach Selection:

The **Reach Editor** allows you to browse through all the Reaches created in the Project. The name of the current Reach appears in the **Name** field. To view other Reaches, use the scroll buttons to the right of the name field or select the Reach's name from the **Name** dropdown list. The following is a table of their functionality:

Button	Function
	View first record
	View previous record
1 of 4	Current record displayed out of total number of records
	View last record
	View next record in the list

Description:

The **Description** field displays the description for the current Reach. The description can be edited by typing in the field. A text window is available through the eclipse  button in the text-field.

Button Panel:

Button	Function
OK	Save the changes made and close the editor
Apply	Save the changes made
Cancel	Do not save the changes made and close the editor

Specific Editor Functionality

By default, Reaches have no effect on the water that passes through them. However, if you have specifications for the Reach, the Reach's information can be changed through this editor.

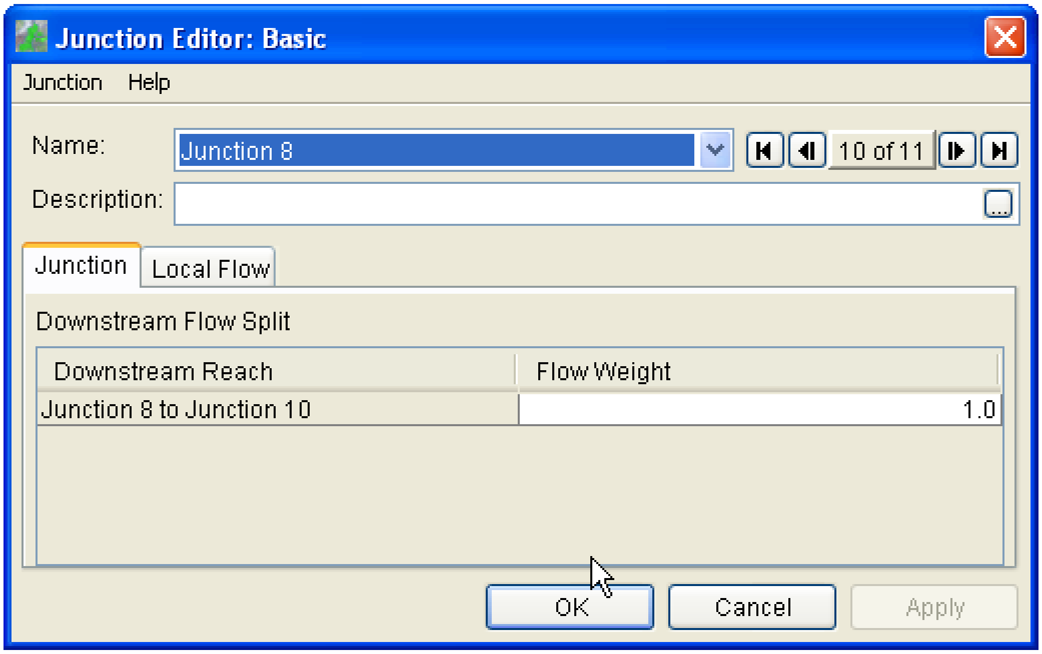
- **Travel Time -** Travel Time represents the number of days it takes for water to travel the length of the reach. The numerical value can be represented as a fraction. For example, if it takes only a half a day (12 hours) for water to pass through the reach, 0.5 can be entered as the Travel Time.

- **Channel Losses as a Function of Flow -** Channel Losses can be specified as a function of flow. The value represents the ratio of the water lost to the amount of water that entered the reach. This value will never exceed 1. For instance: If 1000 cfs enters the reach and 150 cfs of that 1000 cfs is lost, the value to enter would be .15 (150/1000 = .15). If a negative value is entered then the channel will gain water. Use this to represent cases in which the channel is gaining water from the groundwater system. If the groundwater functionality is being used then losses or gains from/to the reach are calculated by the groundwater model and the user value is ignored.

Additional Information:

- Reaches
- Creating a Reach
- Moving Reaches
- Editing Reach Data

Junction Editor



Introduction

The Junction Editor allows the user to specify how flow is divided when reaches converge or diverge.

Basic Editor Functionality

Junction menu commands:

Name	Function	Keyboard Shortcut
Save	Save the changes made in the editor	Ctrl + S
Rename	Rename the Junction currently displayed in the editor	
Delete	Delete the Junction currently displayed in the editor from the current Project	
Close	Close the editor dialog. If changes were made, a **Save Changes** dialog will display.	

Help menu commands:

Name	Function	Keyboard Shortcut
Help	Displays the Junction Editor's help information in the LAWS online Help window	

Junction Selection:

The Junction Editor allows users to browse through all the Junctions created in the Project. The name of the current Junction appears in the **Name** field. To view other Junction, use the scroll buttons to the right of the name field or select the Junction's name from the **Name** dropdown list. The following is a table of their functionality:

Button	Function
	View first record
	View previous record
1 of 4	Current record displayed out of total number of records
	View last record
	View next record in the list

Description:

The **Description** field displays the description for the current Junction. The description can be edited by typing in the field. A text window is available through the eclipse  button in the text-field.

Button Panel:

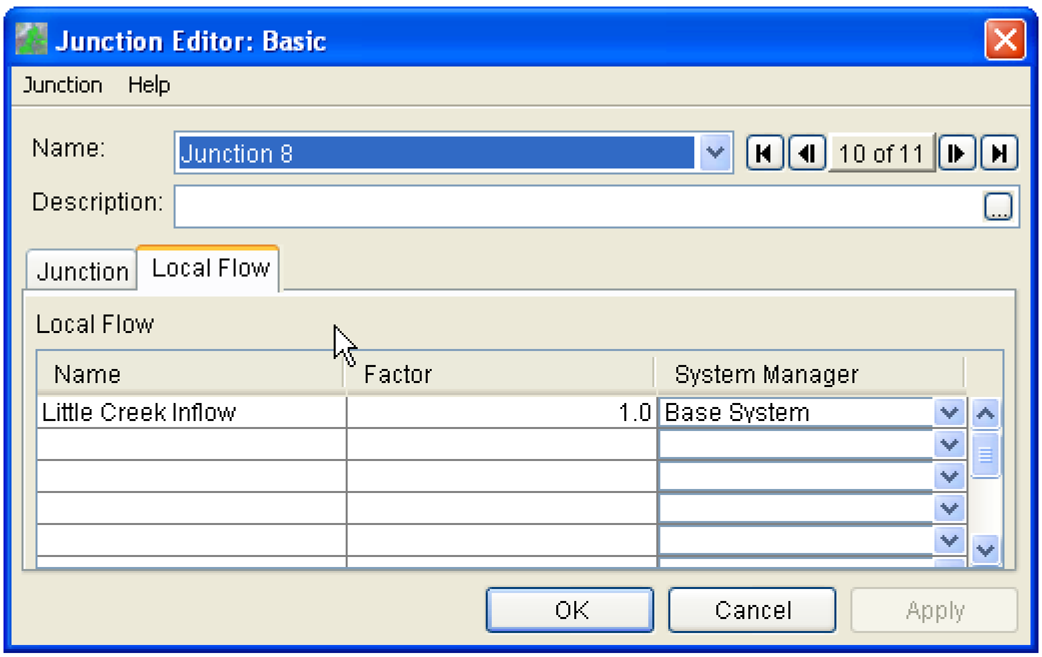
Button	Function
OK	Save the changes made and close the editor
Apply	Save the changes made
Cancel	Do not save the changes made and close the editor

Specific Editor Functionality

Junctions are automatically created when Reservoir and Reaches are produced. However, the weights can be changed through this editor.

Downstream Flow Spill:

The **Downstream Flow Spill** table lists all **Downstream Reaches** connected to the current Junction. If there is more than one downstream reach a **Flow Weight** value is required. The **Flow Weight** represents how the Junction distributes its outgoing flow to multiple reaches. For example: A Junction may split the outflow 40/60 between two downstream reaches. The first reach's **Flow Weight** would then be 0 .4 and the second reach, 0.6. If only one reach is downstream, the Flow Weight will be 1.0 regardless of what is entered in the editor.



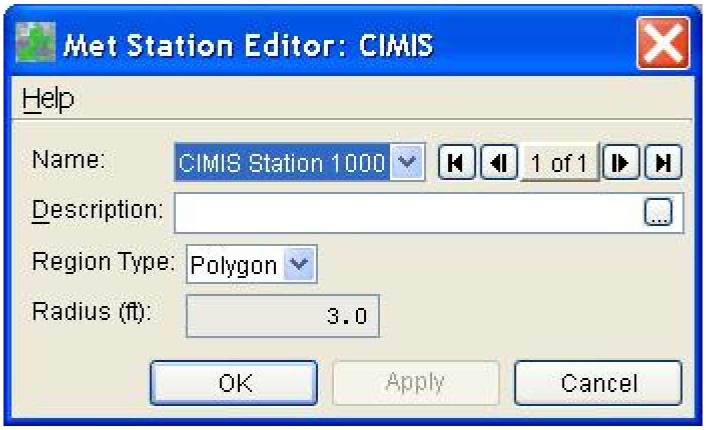
The **Local Flow tab** allows for the specification of inflows to a junction. This feature should be used for junction nodes that are upstream of a reservoir. Currently, LAWS does not manage water that is freely flowing in a stream. In order for water to be managed (used for irrigation) it must first flow into a reservoir. The **System Manager** field specifies to which System Manager account in the receiving reservoir the water will accrue.

Additional Information:

- Junctions
- Moving a Junction
- Editing a Junction

Atmospheric

Met Station Editor



Introduction

A Met Station provides daily a time series of precipitation (Prcp) and reference crop evapotranspiration (ETo) values to be used in computing the water budget of **Land Managers** within its area of influence. The station location is represented by an icon on the LAWS project map and in the LAWS Project tree. The influence that each Met Station has on a particular Land Manager is a function of the Met Station's area of influence and the distance between the Met Station and the Land Manager. If a Land Manager falls within the Met Station area of influence then the ETo and Prcp values for the Land Manager will be obtained from the Met Station. If the Land Manager falls within more than one Met Station's area of influence then the ETo and Prcp values will be interpolated based on the relative distance between the Land Manager and each of Met Stations.

Basic Editor Functionality

Help menu commands:

Name	Function	Keyboard Shortcut
Help	Displays the Met Station Editor's help information in the LAWS online Help window	

Met Station Selection:

The Met Station Editor allows a user to browse through all the Met Stations created in the Project. The name of the current Met Station appears in the **Name** field. To view other Met Stations, use the scroll buttons to the right of the name field or select the Met

Station's name from the **Name** dropdown list. The following table describes their functionality:

Button	Function
	View first record
	View previous record
1 of 4	Current record displayed out of total number of records
	View last record
	View next record in the list

Description:

The **Description** field displays the description for the current Met Station. The description can be edited by typing in the field. A text window is available through the eclipse  button in the text-field.

Button Panel:

Button	Function
OK	Save the changes made and close the editor
Apply	Save the changes made
Cancel	Do not save the changes made and close the editor

Specific Editor Functionality

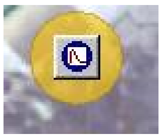
Region Type:

The **Region Type** represents the type of shape drawn for the Met Station's area of influence. **The user must make certain that at least one Met Station's area of influence surrounds each Land Manager.** If multiple Met Station's area of influence surround a Land Manager, the ETo and Prcp values will be interpolated between them by inverse distance square weighting. The shapes are not visible in the Map Schematic by default. (See Viewing Met Station Shapes) . The two shape types available in the dropdown list are discussed below:

- **Polygon**

The **Polygon** shape can be configured into any shape through the **Map Schematic**. The initial shape is a square. Points can be moved and added to increase the area and change the shape. If **Polygon** is selected as the **Region Type**, the **Radius** field will not be available for editing.

- **Radius**



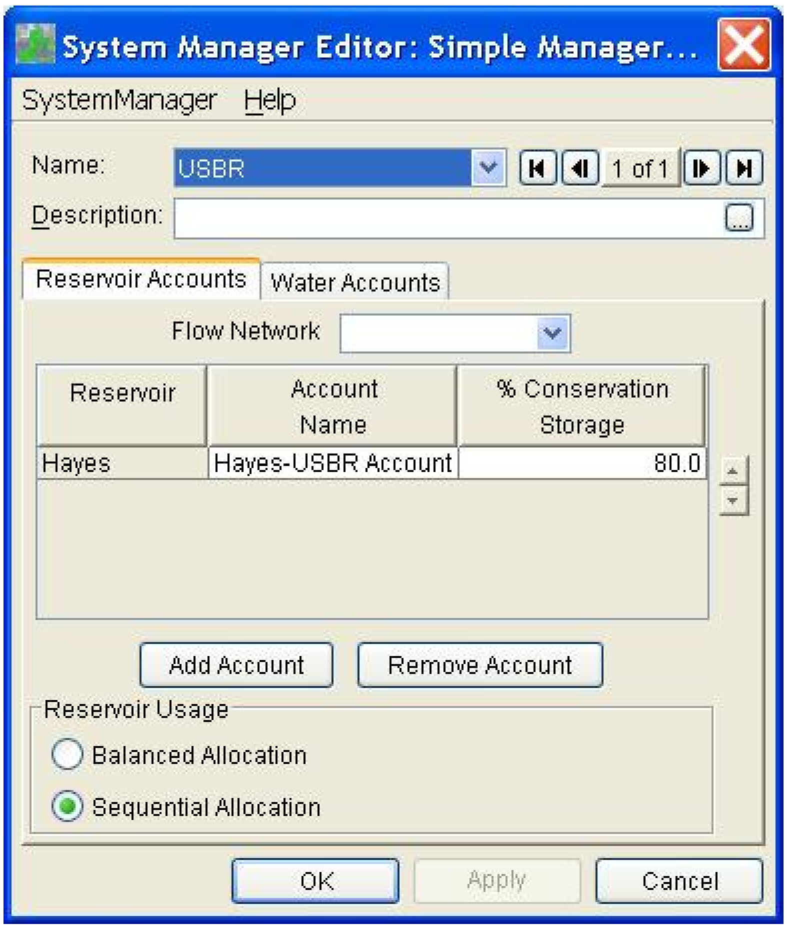
The **Radius** shape is a circle centered on the Met Station. The radius of this circle is determined by the value in the **Radius** field. The circle is calculated and draws using the value. There is no user interaction with the circle in the **Map Schematic**.

Water Management

The Water Management Module contains the following editors:

- System Manager Editor
- Area Manager Editor
- Delivery Manager Editor

System Manager Editor



Introduction

The System Manager Editor allows the user to specify what reservoirs are managed by each System Manager and how the System manager interacts with each of the Area Managers having Water Accounts with it.

Basic Editor Functionality

System Manager menu commands:

Name	Function	Keyboard Shortcut
New	Create a new System Manager	Ctrl + N
Save	Save the changes made in the editor	Ctrl + S
Rename	Rename the System Manager current displayed in the editor	
Delete	Delete the System Manager currently displayed in the editor from the current Project	
Close	Close the editor dialog. If changes were made, a **Save Changes** dialog will display.	

Help menu commands:

Name	Function	Keyboard Shortcut
Help	Displays the System Manager Editor's help information in the LAWS online Help window	

System Manager Selection:

The System Manager Editor allows a user to browse through all the System Managers created in the Project. The name of the current System Manager appears in the **Name** field. To view other System Managers, use the scroll buttons to the right of the name field or select the System Manager's name from the **Name** dropdown list. The following table describes their functionality:

Button	Function
	View first record
	View previous record
	Current record displayed out of total number of records
	View last record
	View next record in the list

Description:

The **Description** field displays the description for the current System Manager. The description can be edited by typing in the field. A text window is available through the eclipse button in the text-field.

Button Panel:

Button	Function
OK	Save the changes made and close the editor
Apply	Save the changes made
Cancel	Do not save the changes made and close the editor

Specific Editor Functionality

Reservoir Accounts Tab:

- **Flow Network -** The Flow Network contains a dropdown list of previously created Flow Networks in the current Project. The reservoirs in the selected Flow Network will be used to create Reservoir Accounts.

- **Reservoir Account Table -** The Reservoir Account Table displays existing Reservoir Accounts. The Reservoir Accounts name can be changed within the table by double clicking in the Reservoir Account Name cell. Each Reservoir Account will need a % Conservation Storage entered. This storage represents the percentage of the conservation pool that can be used for the Reservoir Account. To change or add a storage value, double-click in the % Conservation Storage cell of the Reservoir Account then type in the value.

- **Add Account -** Use the **Add Account** button to add a Reservoir Account to the Reservoir Account table. Clicking the button displays the **New Reservoir Account** dialog pictured below. Assign the new Reservoir Account to a Reservoir using the **Reservoir** dropdown list of previously created Reservoirs.

- **Remove Account -** The Remove Account button will remove the selected Reservoir Account in the Reservoir Account Table. A conformation message will display to verify the removal of the Reservoir Account.

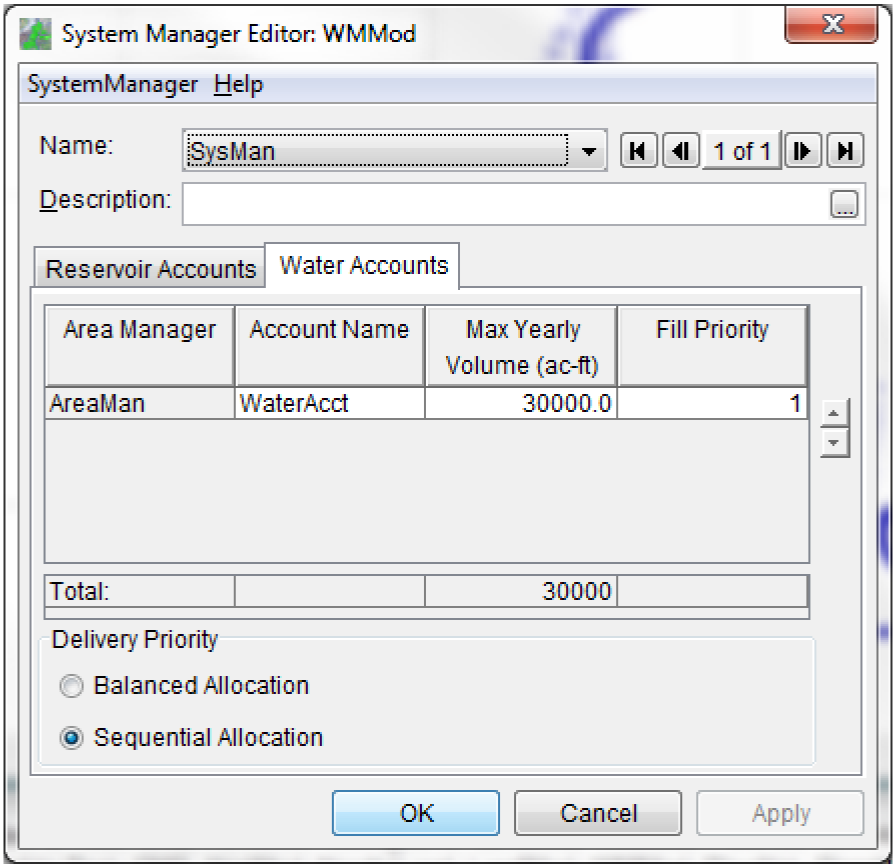
- **Reservoir Usage -** Reservoir Usage describes the allocation or distribution of the Reservoir Accounts. There two types of Allocation represented:

  - **Balance Allocation** removes total volume of water to be delivered in equal amounts from each Reservoir Account.

  - **Sequential Allocation** removes the total volume of water to be delivered from each Reservoir Account sequentially, starting with the first Reservoir Account in the Table. Once that Reservoir Account's maximum release is reached, the next Reservoir Account in the table will be used and so forth.

Use the radio buttons to select which Allocation one you would like to use.

Water Accounts Tab:



NOTE: An Area Manager should be created before using this tab. Water Accounts are shared by System and Area Managers. Area Managers are needed before creating the Water Accounts.

- **Water Account Table -** The Water Account Table displays existing Water Accounts. The Water Accounts name can be changed within the table by double clicking in the Water Account Name cell. Each Water Account will need a Fill Priority and Maximum Yearly Volume. The volume is the maximum amount of water that can be used for the Water Account. To change or add a volume or priority, double-click in the cell under the corresponding column to set the cell editable. Each Account has a maximum annual volume of water associated with it. The Fill Priority can be used to determine the order that Accounts are receive water as reservoir inflows occur. The total volume for the collection of Water Accounts is displayed at the bottom of the table.

- **Remove Account -** The **Remove Account** button will remove the selected Water Account in the Water Account Table. A conformation message will display to verify the removal of the Water Account.

- **Delivery Priority -** sets the manner in which multiple water accounts are managed by LAWS. There are two types of Delivery Priorities.

    - **Balance Allocation** removes total volume of water to be delivered in equal amounts from each Reservoir Account.

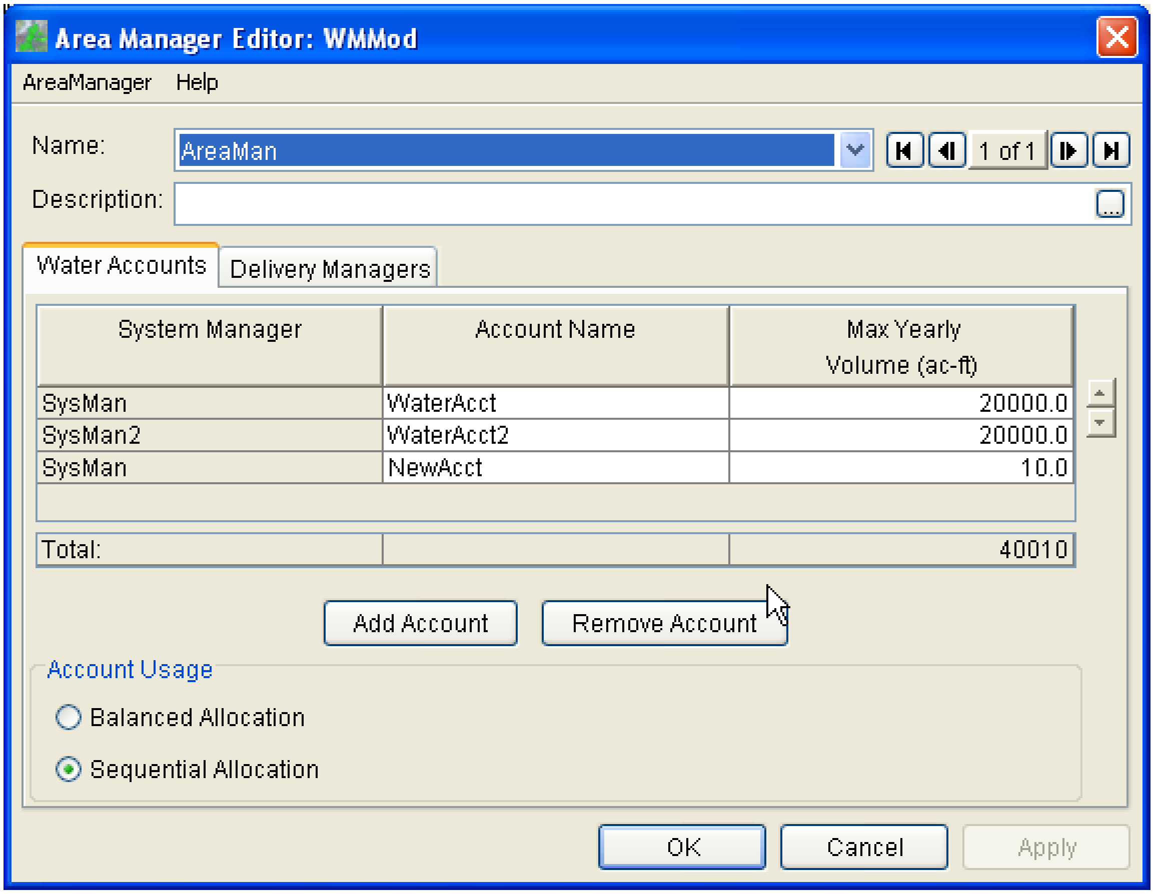
    - **Sequential Allocation** removes the total volume of water to be delivered from each Reservoir Account sequentially, starting with the first Reservoir Account in the Table. Once that Reservoir Account's maximum release is reached, the next Reservoir Account in the table will be used and so forth.

  Use the radio buttons to select which Allocation one you would like to use.

Additional Information:

- Technical Design on System Managers
- System Manager
- Creating a System Manager
- Editing a System Manager

Area Manager Editor



Introduction

The Area Manager Editor allows the user to specify the characteristics of its Water Accounts and how they are managed as well as its relationship with its Deliver Managers.

Basic Editor Functionality

System Manager menu commands:

Name	Function	Keyboard Shortcut
New	Create a new Area Manager	Ctrl + N
Save	Save the changes made in the editor	Ctrl + S
Rename	Rename the Area Manager current displayed in the editor	
Delete	Delete the Area Manager currently displayed in the editor from the current Project	

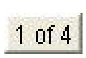
Close	Close the editor dialog. If changes were made, a **Save Changes** dialog will display.	

Help menu commands:

Name	Function	Keyboard Shortcut
Help	Displays the Area Manager Editor's help information in the LAWS online Help window	

Area Manager Selection:

The Area Manager Editor allows a user to browse through all the Area Managers created in the Project. The name of the current Area Manager appears in the **Name** field. To view other Area Managers, use the scroll buttons to the right of the name field or select the Area Manager's name from the **Name** dropdown list. The following table describes their functionality:

Button	Function
	View first record
	View previous record
	Current record displayed out of total number of records
	View last record
	View next record in the list

Description:

The **Description** field displays the description for the current System Manager. The description can be edited by typing in the field. A text window is available through the eclipse  button in the text-field.

Button Panel:

Button	Function
OK	Save the changes made and close the editor
Apply	Save the changes made
Cancel	Do not save the changes made and close the editor

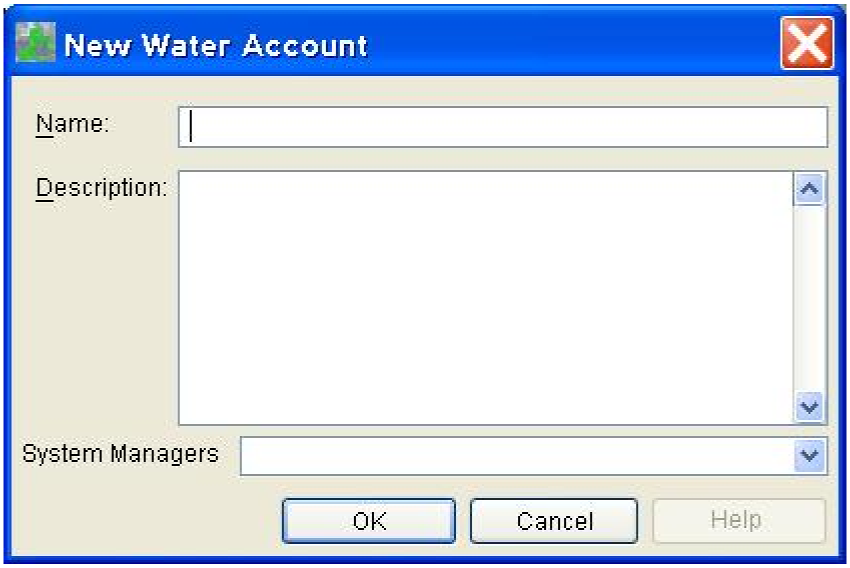
Specific Editor Functionality

Water Accounts Tab:

Note: A System Manager should be created before using this tab. Water Accounts are shared by System and Area Managers. System Managers are needed when creating the Water Accounts.

- **Water Account Table -** The Water Account Table displays existing Water Accounts. The Water Accounts name can be changed within the table by double clicking in the **Water Account Name** cell. Each Water Account requires a **Maximum Yearly Volume**. This volume is the maximum amount of water that can be used from the Water Account. To change or add a volume, double-click in the **Maximum Yearly Volume** cell to set it editable. The **Total Maximum Yearly Volume** for the collection of Water Accounts is displayed at the bottom of the table.

- **Add Account -** To add a Water Account use the **Add Account** button. Clicking the button displays the **New Water Account** dialog displayed below. Assign the new Water Account a previously created System Manager using the **System Managers** dropdown list.



- **Remove Account -** The **Remove Account** button will remove the selected Water Account in the Water Account Table. A conformation message will display to verify the removal of the Water Account.

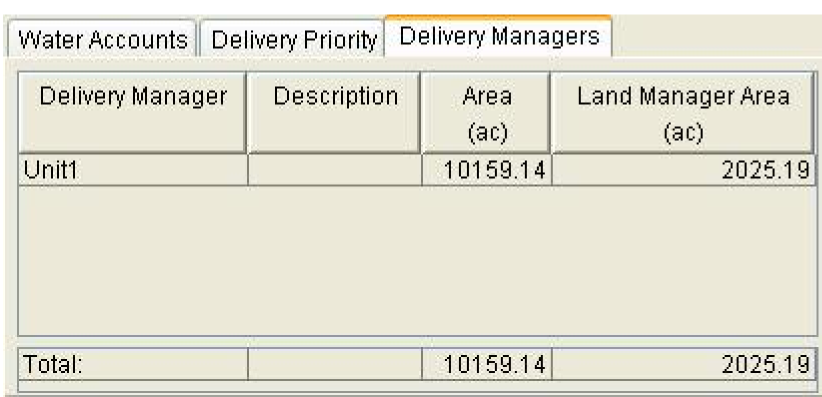
- **Account Usage -** Account Usage describes the allocation or distribution of the Water Accounts. There two types of Allocation represented:

- **Balance Allocation removes total volume of water to be delivered in equal amounts from each Reservoir Account.**

- **Sequential Allocation** removes the total volume of water to be delivered from each Reservoir Account sequentially, starting with the first Reservoir Account in the Table. Once that Reservoir Account's maximum release is reached, the next Reservoir Account in the table will be used and so forth.

Use the radio buttons to select the Allocation method you would like to use.

Delivery Managers Tab:


Water Accounts | Delivery Priority | Delivery Managers

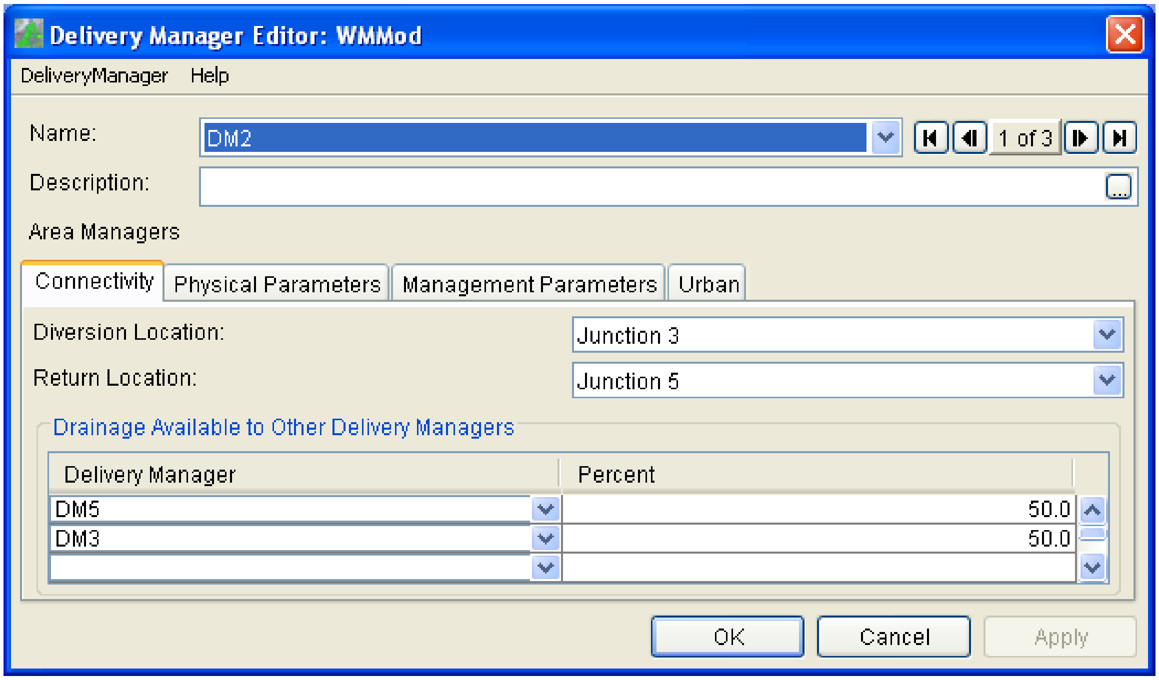
Delivery Manager	Description	Area (ac)	Land Manager Area (ac)
Unit1		10159.14	2025.19
Total:		10159.14	2025.19

The **Delivery Managers tab** displays a list of existing Delivery Managers within the Area Manager. Each Delivery Manager listed displays the total area for the Land Managers to which it delivers water. The total area for all the Delivery Managers and their associated Land Managers is displayed at the bottom of the Table.

Additional Information:

- Technical Design of Area Managers
- Area Manager
- Creating an Area Manager
- Editing an Area Manager

Delivery Manager Editor



Introduction

The Delivery Manager Editor allows users to specify which Land Managers receiving water delivery, the physical characteristics the infrastructure; the sources of water used to meet demands and what non-agricultural uses may be served within the delivery area.

Basic Editor Functionality

Delivery Manager menu commands:

Name	Function	Keyboard Shortcut
New	Create a new Delivery Manager	Ctrl + N
Save	Save the changes made in the editor	Ctrl + S
Rename	Rename the Delivery Manager current displayed in the editor	
Delete	Delete the Delivery Manager currently displayed in the editor from the current Project	
Close	Close the editor dialog. If changes were made, a **Save Changes** dialog will display.	

Help menu commands:

Name	Function	Keyboard Shortcut
Help	Displays the Delivery Manager Editor's help information in the LAWS online Help window	

Delivery Manager Selection:

The Delivery Manager Editor allows a user to browse through all the Delivery Managers created in the Project. The name of the current Delivery Manager appears in the **Name** field. To view other Delivery Managers, use the scroll buttons to the right of the **Name** field or select the Delivery Manager's name from the **Name** dropdown list. The following table describes their functionality:

Button	Function
	View first record
	View previous record
1 of 4	Current record displayed out of total number of records
	View last record
	View next record in the list

Description:

The **Description** field displays the description for the current Delivery Manager. The description can be edited by typing in the field. A text window is available through the eclipse  button in the text-field.

Button Panel:

Button	Function
OK	Save the changes made and close the editor
Apply	Save the changes made
Cancel	Do not save the changes made and close the editor

Specific Editor Functionality

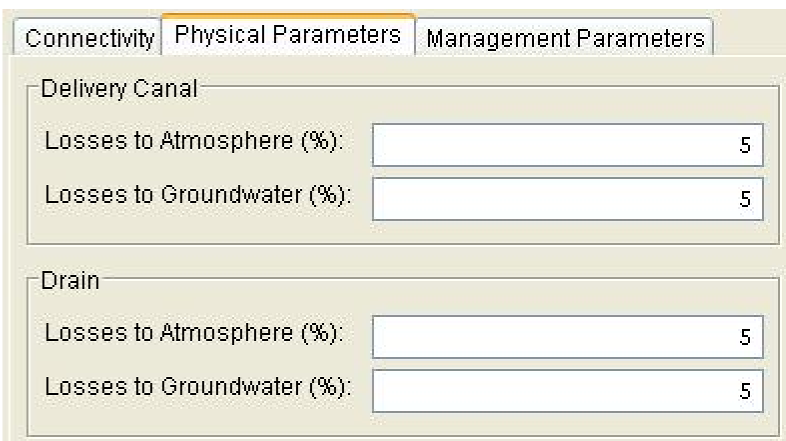
Connectivity Tab:

- **Diversion Location -** The **Diversion Location** is the location where the water enters the Delivery Manager. The Diversion Location is populated with a list of Junctions in the Flow Network.

- **Return Location -** The Return Location is the location where the water leaves the Delivery Manager. The Return Location is populated with a list of Junctions in the Flow Network.

- **Drainage Available to Other Delivery Managers Table -** This Table allows the assignment of drainage produced by the current Delivery Manager to flow to other Delivery Managers. The Percent field represents the portion of the total drainage produced by all the Land Managers within the current Delivery Manager that can be used by the target Delivery Manager. The sum of the values in the Percent field should be 100%. The drainage produced by the current Delivery Manager is available to the target Delivery Managers on the following day.

Physical Parameters Tab:



- **Delivery Canal -** The **Delivery Canal** represents the water delivery system within the Delivery Manager. This network is not explicitly modeled in LAWS. However, losses to evaporation and groundwater can be specified.

  - **Losses to Atmosphere -** Percentage of water delivered that is lost to the atmosphere while traversing the canals located within the current Delivery Manager.
  - **Losses to Groundwater -** Percentage of the water delivered that is lost to or gained from the groundwater system while be conveyed in within the current Delivery Manager.

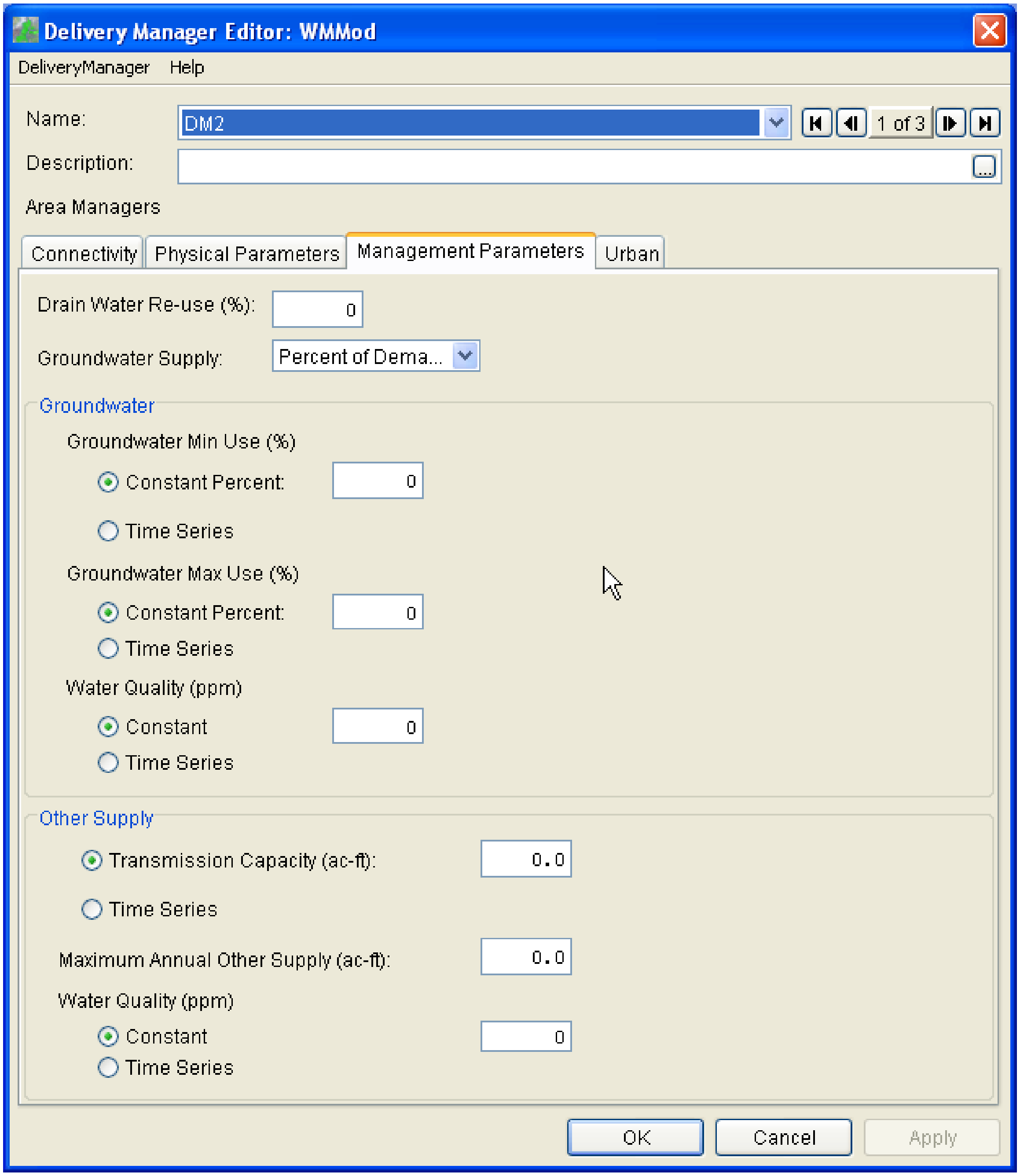
- **Drain -** The **Drain** represents the drainage system losses or gains (if present) in the Delivery Manager. This network is not explicitly modeled in LAWS. However, losses to evaporation and groundwater can be specified.

    - **Losses to Atmosphere -** Percentage of drainage water lost to the atmosphere while traversing the drainage system located within the current Delivery Manager.
    - **Losses to Groundwater -** Percentage of water lost/gained to/from the groundwater system while traversing the drainage system within the current Delivery Manager.

Management Parameters Tab:

- **Drain Water Re-use (%) -** This value represents the percentage of the total drain water in the current time step that can be used to meet irrigation demands within the current Delivery Manager. Drain water may also be available to the current Delivery Manager if other Delivery Managers have set the current Delivery Manager as a recipient target on their **Connectivity tab**.

- **Groundwater Water Supply -** The settings in this portion of the **Management Parameters tab** determine how much, if any, of irrigation demand will be met by groundwater. The user can choose between either limiting groundwater pumping to a fixed percentage of overall irrigation demand or to a fixed volume. If **Percent of Demand** is specified in the **Groundwater Supply** dropdown list then the following screen will appear.



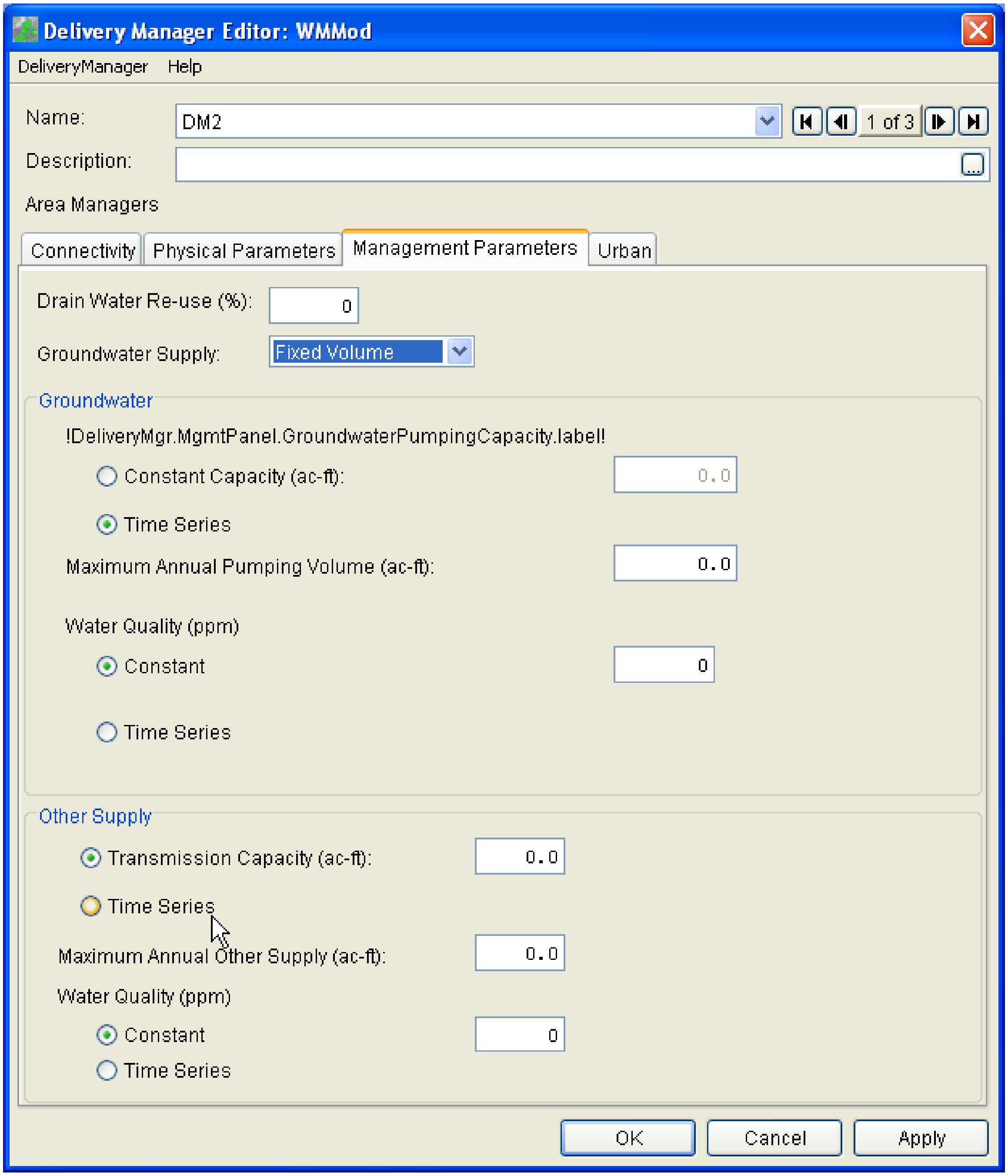
The specification of a **Groundwater Min Use** will result in LAWS supplying a percentage of the irrigation demand from groundwater. The **Groundwater Max Use** will result LAWS supplying groundwater up to the specified maximum percentage of groundwater to meet irrigation demands. In these situations, the assumed preference is to use surface water. If there is a shortage of surface water, then groundwater will be used up to the specified maximum percentage of irrigation demand.

- **Groundwater Min Use (%) -** This value represents the minimum percentage of the Land Manager's irrigation demand that will be met using groundwater. For example, if this value is 15%, then 15% of all irrigation demands in the current Delivery Manager will be met by groundwater. To force a Delivery Manager to provide only groundwater to its Land Managers enter a value of 100%.

- **Groundwater Max Use (%) -** This value represents the maximum percentage of the Land Manager's irrigation demand that can be met using groundwater. For example, if this value is set to 80%, up to 80% of the irrigation demand can be met using groundwater.

NOTE: The percentages of **Groundwater Supply** can be specified as either constant values or time series inputs. If the time series option is selected, then a time series path must be entered in the Alternative Editor.

If the user wishes to limit the overall total volume of groundwater pumping (perhaps due to infrastructure constraints) then the **Fixed Volume option** can be chosen in the **Groundwater Supply** dropdown menu. When this option is selected the following screen will appear.



If the **Constant Capacity option** is selected then the groundwater supply rate is limited by the capacity. The user can select to use a constant capacity or a time series capacity. If the **Time Series** option is selected then a time series path must be entered in the Alternative Editor.

- **Maximum Annual Pumping Volume** - the maximum volume that can be pumped during a year.

Water Quality

The concentration of a modeled non-reactive, conservative constituent may be specified as either a **Constant** or a **Time Series**. If the Time Series option is selected then a Time Series path must be specified in the **Alternative Editor**.

Other Supply

The **Other Supply option** on the **Management Parameters tab** provides an option to model the use of a water supply that is neither groundwater nor surface water from the explicitly modeled surface water supply system. This type of supply could include out of service area transferred water that was purchased and "wheeled" through the system. The data input requirements are similar to the Fixed Volume groundwater case. The transmission capacity can be specified as either a fixed rate or a time series. A maximum annual volume can be also be specified and its water quality can be assigned to the supply.

Urban Tab:

Urban water users can be modeled using the Urban Tab in the Delivery Manager Editor.

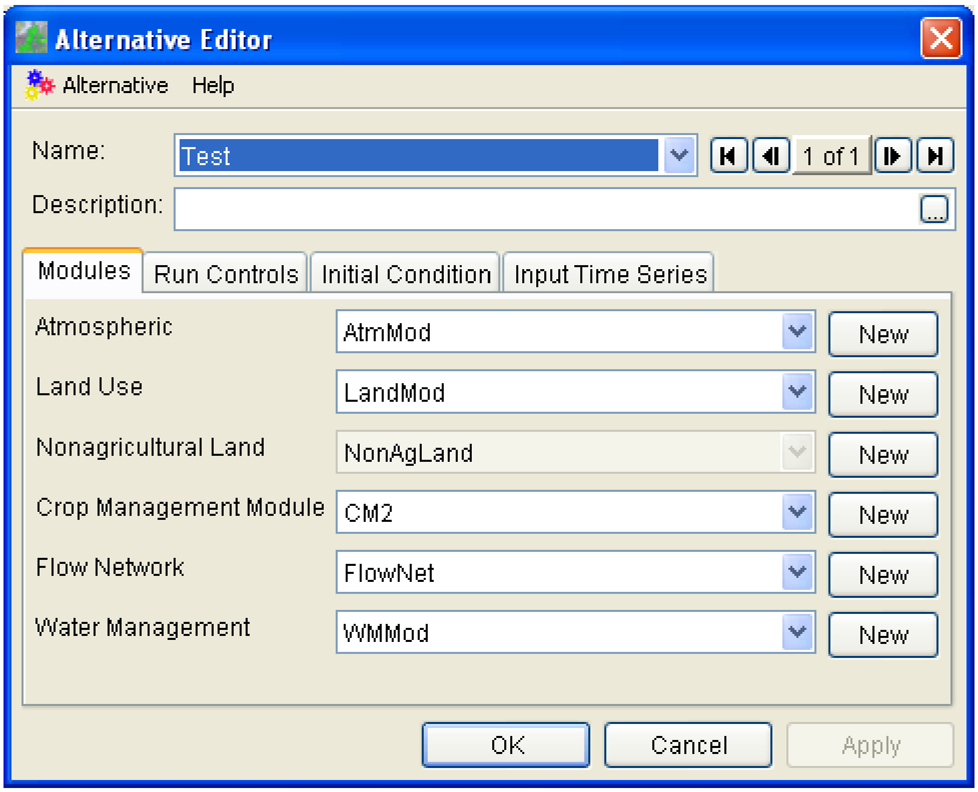
- **Use -** This is a text descriptor of the urban water use type.
- **Annual per Unit Use -** This is the total amount of water used by each demand unit. A demand unit may be a person (per capita use), a store, a factory, etc.
- **Number of Units -** This is the total number of units. This could be the number of people in the urban area, the number of stores, number of factories, etc.
- **Consumptive Percent -** This is the percentage of the delivered water that is consumptively used and cannot re-enter the water distribution system.
- **Surface Runoff Percent -** This is the percentage of the non-consumptively used water that ends up as surface runoff. The sum of surface runoff and the Deep Percolation Percent must be 100%.
- **Deep Percolation Percent -** This is the percentage of the non-consumptively used water that ends up as deep percolation. The sum of this and the surface Runoff Percent must be 100%.

Additional Information:

- Technical Design of Delivery Managers

- [Delivery Managers]
- [Creating Delivery Managers]
- [Editing Delivery Managers]

Alternative Editor



Introduction

The Alternative Editor allows the user to specify which instances of LAWS Modules will used in a particular Alternative. This feature also allows to user to easily create new Alternatives for comparisons.

Basic Editor Functionality

Alternative menu commands:

Name	Function	Keyboard Shortcut
New	Create a new Alternative	Ctrl + N
Save	Save the changes made in the editor	Ctrl + S
Rename	Rename the Alternative current displayed in the editor	
Delete	Delete the Alternative currently displayed in the editor from the current Project	
Close	Close the editor dialog. If changes were made, a **Save Changes** dialog will display.	

Help menu commands:

Name	Function	Keyboard Shortcut
Help	Displays the Alternative Editor's help information in the LAWS online Help window	

Alternative Selection:

The Alternative Editor allows a user to browse through all the Alternatives created in the Project. The name of the current Alternative appears in the **Name** field. To view other Alternatives, use the scroll buttons to the right of the name field or select the Alternative's name from the **Name** dropdown list. The following table describes their functionality:

Button	Function
	View first record
	View previous record
1 of 4	Current record displayed out of total number of records
	View last record
	View next record in the list

Description:

The **Description** field displays the description for the current Alternative. The description can be edited by typing in the field. A text window is available through the eclipse  button in the text-field.

Button Panel:

Button	Function
OK	Save the changes made and close the editor
Apply	Save the changes made
Cancel	Do not save the changes made and close the editor

Specific Editor Functionality

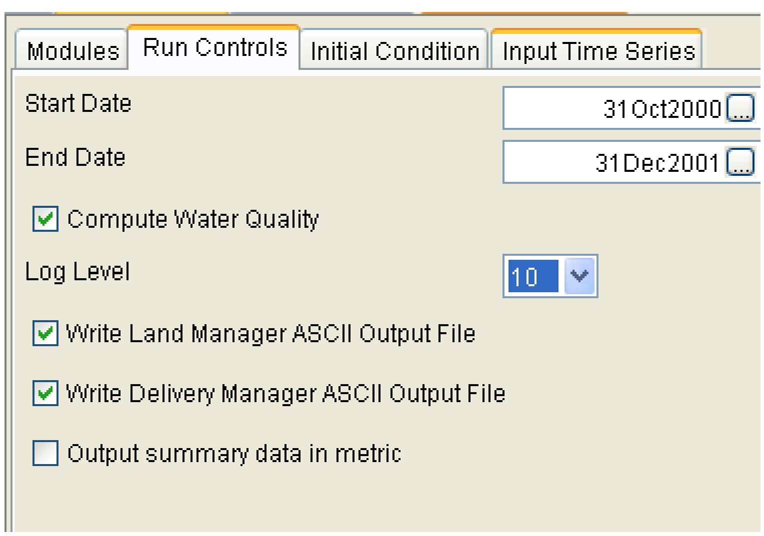
Modules Tab:

On the Module tab of the **Alternative Editor** select the **Modules** you would like the Alternative to use. Currently the following Modules are needed to create a complete Alternative:

- Land Module
- Non-agricultural Land Module
- Crop Management Module
- Flow Network
- Atmospheric Module
- Water Management Module

Each Module contains a dropdown list of their previously created types. If needed, New Modules can be created using the corresponding **New** button. The Non-agricultural Land Module is an optional module that only has to be used if groundwater is being modeled.

Run Controls Tab:



Start Date and End Date:

The **Run Controls tab** contains editable information on the model's run commands. The time window for the Alternative run is entered in the **Start Date** and **End Date**. The date fields require the DDMMMYYYY date format; for example, 01JUN1999. The dates may be entered manually or using a **Calendar Tool** accessed through the ellipse  buttons in the **Start Date** and **End Date** text fields.

Compute Water Quality:

Checking this box enables the water quality calculations in LAWS. For a complete description of the water quality calculations please see the **Technical References section** documentation.

Log Level:

The **Log Level** represents the detail and quantity of error messages reported by the compute engine. This can be very useful when trying to debug an unsuccessful run. The higher the **Log Level** number, the more messages will be logged during the compute. Messages are written to the Compute's **Message Pane** and the application log file. The Default **Log Level** is 0.

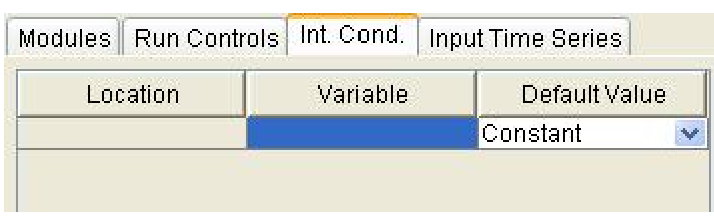
Write Land Manager ASCII Output File:

The LAWS output to this ASCII file for Land Managers can become extremely large if there are multiple Land Managers in the Land Module assigned to the Alternative. If the Land Manager Summary is not needed, this option can be turned off by unselecting the checkbox. Then the Land Manager output file will not be written during the compute. This option is unchecked by default.

Write Delivery Manager ASCII Output File:

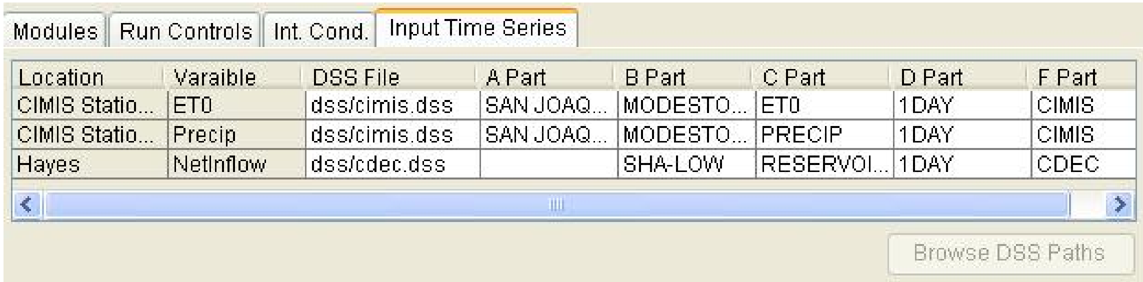
The LAWS output to this ASCII file for the Delivery Managers can become extremely large if there are multiple Delivery Managers in the Water Management Module assigned to the Alternative. If the Delivery Manager Summary is not needed, this option can be turned off by unselecting the checkbox. Then the Delivery Manager output file will not be written during the compute. This option is checked by default.

Initial Condition Tab:



The **Initial Condition tab** displays a table of model variables that require an initial condition. These include reservoir storage and reservoir water quality if the Compute Water Quality option is selected.

Input Time Series Tab:



The **Input Time Series tab** displays a table of variables for which input time series must be specified. These time series inputs use the U.S. Army Corps of Engineer's HEC DSS data format. For more information on this data format see http://www.hec.usace.army.mil/software/hec-dss/hecdss-dss.html. LAWS includes the HEC DSSVue tool which can be accessed from in the Tools menu, It can be used to import spreadsheet and text data and output the data in the HEC DSS data format.

The following is a description of each column in the Table:

Location - The **Location** refers to the data component that references the variable. For example: The Precip variable, in the second row of the table displayed above, belongs to the Atmospheric Module CIMIS's Met Station.

- **Variable** - The name of the variable.
- **DSS File** - Either the full path name to the dss file assigned to the variable or the relative path to the project's directory.
- **A Part** - The A Part or first part, of the dss record's pathname. Normally named after the general location were the data was collected. For example: the river or reservoir name
- **B Part** - The B Part or second part, of the DSS record's pathname. Usually the more specific location of the A Part name. For example: the section of the river or reservoir.
- **C Part** - The C Part or third part, of the DSS record's pathname. Typically named after the data type contained in the record.
- **D Part** - The D Part or forth part, of the DSS record's pathname is the data's time step. For example: 1DAY, 1HOUR, etc.
- **F Part** - The F Part or fifth part, of the DSS record's pathname. There is no convention for this part of the pathname, but it usually contains a more detailed description of the data.

The variables listed in the Location column require DSS time series records as input. To assign a DSS file and pathname to a variable:

1. Select the variable's row, then click the **Browse DSS Paths button**. The DSS Browser will appear.
2. To open a DSS file, select **File->** **Open** on the menu bar. A File Browser will display.
3. Using the file browser, select a DSS file.

4. Once a DSS file is chosen, the file's pathname parts will fill in the DSS Browser.
5. Choose a pathname for your variable by highlighting a path in the list.
6. Click the **Set Pathname button** to assign the path to the variable.
7. The pathname will be displayed in the variable's row back on the **Input Time Series tab**'s Table.
8. To select another variable pathname, leave the DSS Browser on.
9. Click on the **Alternative Editor** to set it active.
10. On the **Input Time Series tab** of the **Alternative Editor** highlight a variable's row.
11. Return to the DSS Browser by clicking on it.
12. Repeat steps 5 through 7.

The following is a list of current variables that may require dss input:

- Met Station ETO
- Met Station Precip
- Precip Water Quality
- Reservoir Storage
- Reservoir Instream Flow Requirement
- Delivery Manager Groundwater Minimum Use
- Delivery Manager Groundwater Maximum Use
- Delivery Manager Groundwater Quality
- Other Supply (in the Delivery Manager Editor) Transmission Capacity
- Other Supply (in the Delivery Manager Editor) Water Quality
- Urban demand distribution factor

Additional Information:

- Alternatives
- Creating an Alternative
- Editing Alternatives
- Running Alternatives

Additional Tools

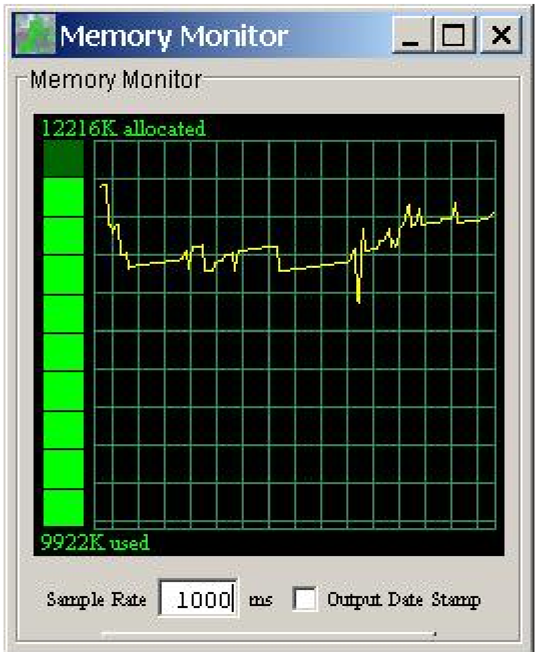
Additional LAWS Tools include:

- Calendar
- Memory Monitor
- Default Map Properties
- Options Dialog

Calendar Tool

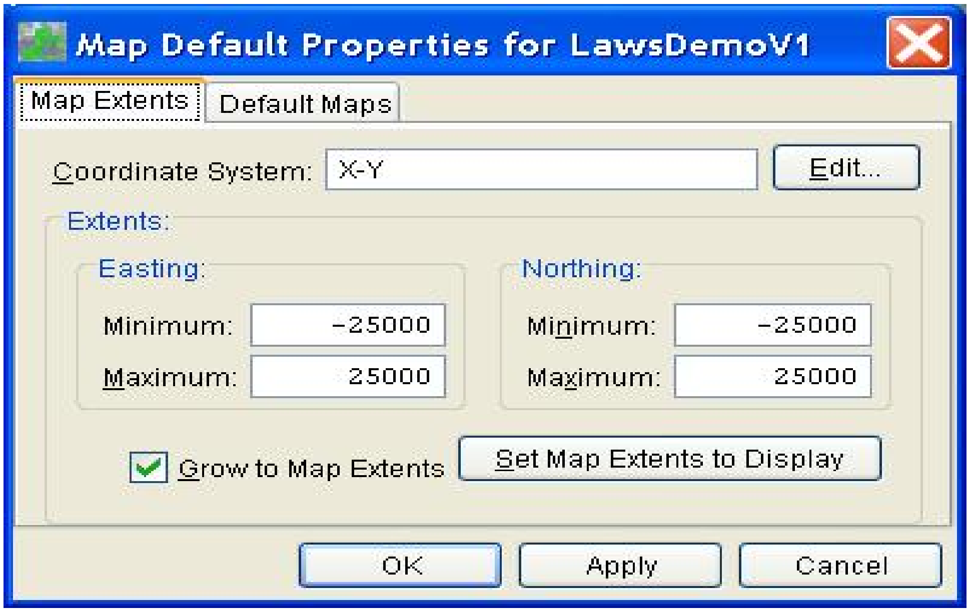
The Calendar Tool is available in for variables to which dates need to be assigned. It is usually accessed through an eclipse button that appears in the text field when the field is double-clicked in. The Calendar Tool allows you to easily view and select dates. Use the back and forward buttons to scroll through months and years. To select a date, highlight a numbered day square (27 is selected in the picture above) on the calendar and click **OK**. The date will fill the text field using the correct format.

Memory Monitor



The Memory Monitor is a real-time graphical representation of the amount of memory used by the application. This tool is mainly used by the development team to spot potential problems within the application.

Default Map Properties



The **Default Map Properties** editor contains information and settings for the **Map Schematic**'s display area. It allows you to adjust these settings, change the coordinate system, and assign default maps. There must be an open Map Schematic window to access this editor. Once a window is open, select the **Project** menu on the **Menu Bar** then **Default Map Properties**.

Map Extents Tab

On the **Map Extents tab** the viewing area (Map Extents) and coordinate system can be changed.

Coordinate System:

The coordinate system can be changed by using the **Map Coordinate Information** editor accessed through the **Edit...** button located next to the **Coordinate System** text field. The current coordinate systems supported are:

- X-Y
- Geographic
- Universal Transverse Mercator
- State Plane Coordinates
- Albers Equal-Area Conic
- Lambert Conformal Conic
- Transverse Mercator
- Albers Equal-Area Conic (SHG)

- Polar Stereographic (HRAP)

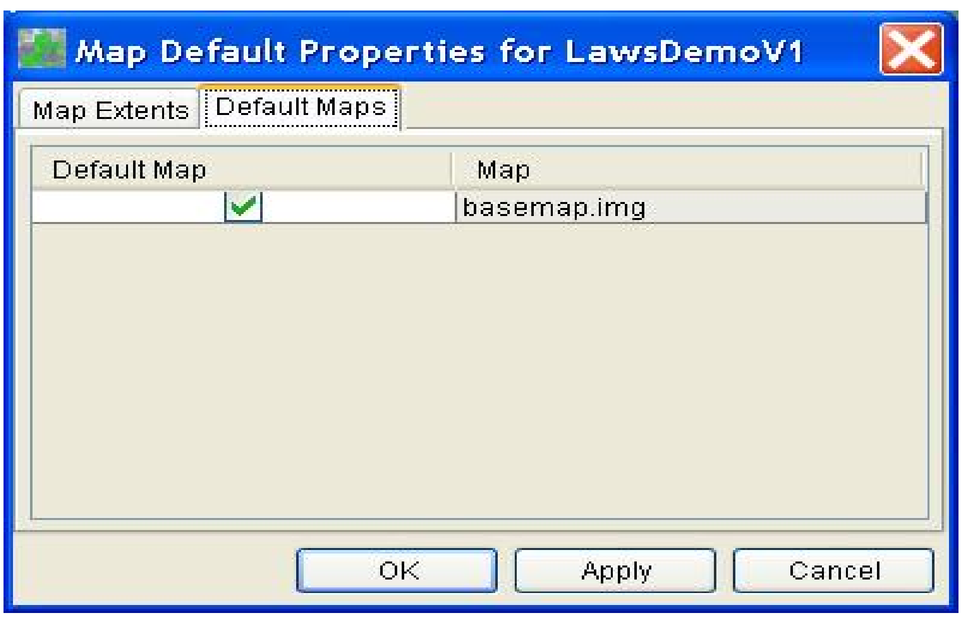
Each coordinate system has additional information which may be changed to suite your map needs. Selecting a particular system will display the editable information. For example, by selecting Geographic you have access to units used, Radian, Seconds of Arc, or Degrees of Ar.

Map Extents

The **Map Extents** sets the map area of the project displayed within the Map Schematic window. **Easting Minimum** and **Maximum** values represent the West and East view respectively for the selected coordinate system. **Northing Minimum** and **Maximum** values represent the South and North view respectively. By default the **Grow to Map Extents** is selected to let these values grow or shrink according to the union of the extents from the maps assigned in the project. To view these map extents, click the **Set Map Extents to Display** button. The Easting and Northing areas will fill out with the current extents. Alternatively, the option can be turned off by unselecting the **Grow to Map Extents** checkbox and you can manually enter the extents.

Default Map Tab

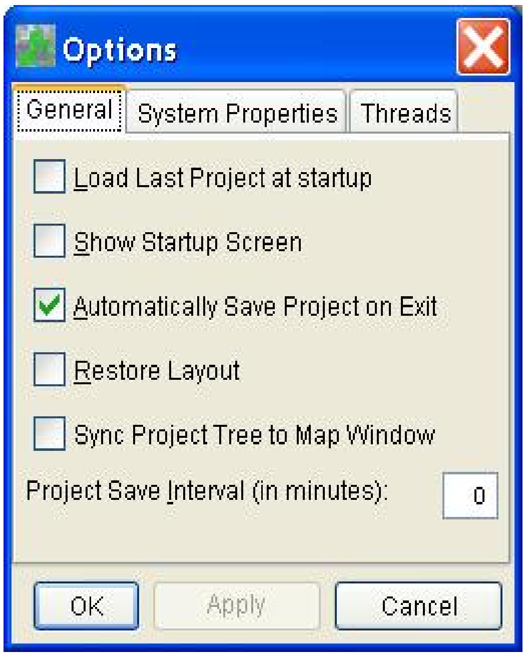
Existing project maps can be selected to display in the Map Schematic through the **Default Map Tab**. To select a map to display, click the checkbox next to the map's name in the list of available project maps. More than one map can be set to display.



Options Dialog

The **Options Dialog** allows access to Application specific settings, variables, and program information. Through this dialog you to customize specific Application behavior. Each tab is described below in detail.

General Tab



The **General tab** contains settings for how the LAWS application handles Projects. Clicking a checkmark next to the description will set the option active. The following options are available:

- **Load Last Project at Startup** - On initially opening the LAWS program, the last Project opened in LAWS will be loaded and displayed in the Project Tree.

- **Show Startup Screen** - The Startup Screen is the initial screen displayed when the LAWS program is started. It displays the LAWS icon, version date and number, and production information. This screen is also viewable through the Help -> About LAWS menu option from the main Menu Bar.

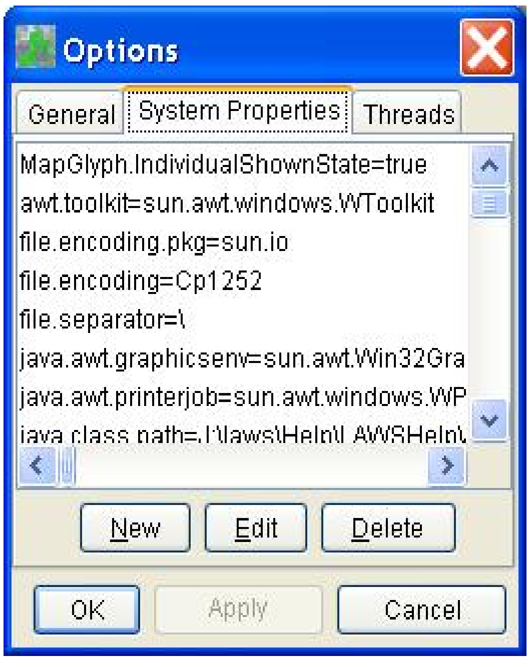
- **Automatically Save Project on Exit** - This option will save any changes made to the open Project before exiting the program.

- **Restore Layout** - The Layout of the Map Schematic area will be restored when the LAWS program is restarted. For example: If the Map Schematic windows are set to display as panes in the Map Schematic Area, the next time you open multiple windows they will display as panes.

- **Sync Project Tree to Map Window** - Synchronizes Project and Maps

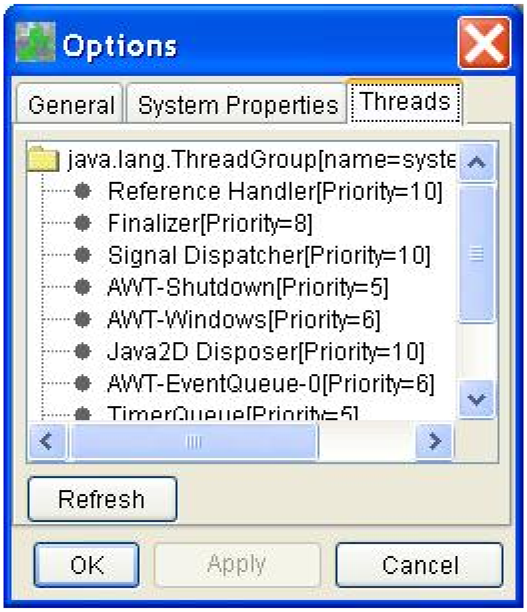
- **Project Save Interval (in minutes)** - Setting a number in the decimal field of this option will have the program automatically save the open project every <*number*> of minutes.

System Properties Tab



The **System Properties tab** lists all the LAWS programs runtime variables. These variables are set at the startup of the application and should only be changed if directed by a knowledgeable LAWS user or programmer. Otherwise, do not change these settings!!!

Threads Tab



The **Treads tab** is another programmer tool. It displays information to calls inside the code and is not editable.

Output Displays

Currently LAWS provides several ways to view output:

- Summary Reports
- Plots
- Animations

Summary Reports

Area and Delivery Manager Monthly Summary

Delivery Manager Monthly Summary report provides outputs for Area and Delivery Manager water budget components. The variables contained in the outputs are indicated in the Table below.

Delivery Manager Monthly Summary	
Alternative Node Context Menu Option	**Monthly totals for Area and Delivery Managers values**
View Delivery Manager Monthly Output	• Total Area • Canal Evap • Canal Seepage • GW Pumping • DW Recycled • Consumption Use • RZ Flow to GW • RZ Flow to DW • Irrig Tailwater • Ponded Water Runoff • Total DW Inflow • DW Evap • DW Flow to GW • DW Available for Recycling • Target DW Recycling • DW Imported • DW Exported • DW Returned • Total LM Request • Net Canal Request • Pending Delivery • AM Resvr Request

Area and Delivery Manager Daily Summary

Delivery Manager Daily Summary report provides outputs for Area and Delivery Manager water budget components. The variables contained in the outputs are indicated in the Table below.

Delivery Manager Summaries	
Alternative Node Context Menu Option	**Daily totals for Area and Delivery Managers**
View Delivery Manager Output	• Total Area • Canal Evap • Canal Seepage • GW Pumping • DW Recycled • Consumption Use • RZ Flow to GW • RZ Flow to DW • Irrig Tailwater • Ponded Water Runoff • Total DW Inflow • DW Evap • DW Flow to GW • DW Available for Recycling • Target DW Recycling • DW Imported • DW Exported • DW Returned • Total LM Request • Net Canal Request • Pending Delivery • AM Resvr Request

Land Manager Daily Summary

Land Manager Daily Summary report provides outputs for Land Managers' water budget components. The variables contained in the outputs are indicated in the Table below.

Land Manager Summary	
Alternative Node Context Menu Option	**Daily totals of Land Manager Values**
View Land Manager Output	• Water Applied • Canal Delivery • GW Pumping • Rainfall • Total Water Loss • Application Loss • Runoff • RZ Inf • SWC After Inf • Crop Active • Crop Dead • RZ Depth • RZ SW Gain • ETO • Kc • ETC • RZ Drain Inflow • RZ Seepage • RZ Loss • SWC • SWC at MAD • RZ Storage Cap • Application Request • CV • CVAW • Depth Surface Pond • Pond Evap • Pond Inf • Pond Losses • SWC FC • SWC PW • HC • PH at FC • Application Eff

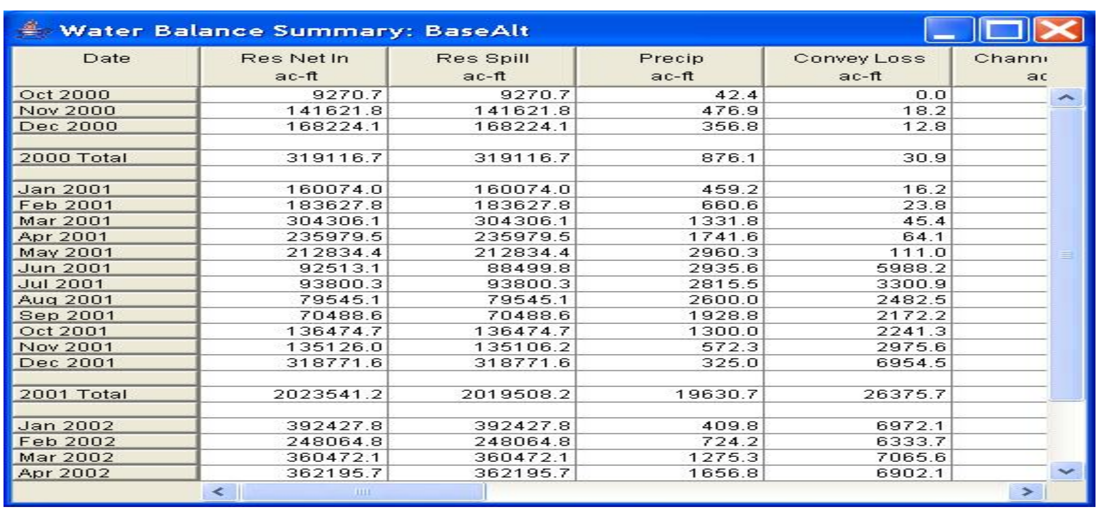
Water Balance Summary

Water Balance Summary report provides outputs of monthly and yearly water budget components. The variables contained in the outputs are indicated in the Table below.

Water Balance Summary	
Alternative Node Context Menu Option	**Monthly and yearly totals**
View Water Balance Summary	• Reservoir Net Flow • Reservoir Spill • Precip • Convey Loss • Channel Delry • GW Pumping • Drain Ruse • Deep Perc • Loss to Atm • Total CU • CU AW • Drain Return • Crops Planted • Crops Lost

An example of creating a Water Balance Summary report is presented below. Summaries are available through the Alternative node's right-click popup menu. The summaries display the total monthly values for a variety of variables computed for the time period.

- View a summary by selecting **View Water Balance Summary** from the Alternative node's popup menu.


Water Balance Summary: BaseAlt

Date	Res Net In ac-ft	Res Spill ac-ft	Precip ac-ft	Convey Loss ac-ft	Chann ac
Oct 2000	9270.7	9270.7	42.4	0.0	
Nov 2000	141621.8	141621.8	476.9	18.2	
Dec 2000	168224.1	168224.1	356.8	12.8	
2000 Total	319116.7	319116.7	876.1	30.9	
Jan 2001	160074.0	160074.0	459.2	16.2	
Feb 2001	183627.8	183627.8	660.6	23.8	
Mar 2001	304306.1	304306.1	1331.8	45.4	
Apr 2001	235979.5	235979.5	1741.6	64.1	
May 2001	212834.4	212834.4	2960.3	111.0	
Jun 2001	92513.1	88499.8	2935.6	5988.2	
Jul 2001	93800.3	93800.3	2815.5	3300.9	
Aug 2001	79545.1	79545.1	2600.0	2482.5	
Sep 2001	70488.6	70488.6	1928.8	2172.2	
Oct 2001	136474.7	136474.7	1300.0	2241.3	
Nov 2001	135126.0	135106.2	572.3	2975.6	
Dec 2001	318771.6	318771.6	325.0	6954.5	
2001 Total	2023541.2	2019508.2	19630.7	26375.7	
Jan 2002	392427.8	392427.8	409.8	6972.1	
Feb 2002	248064.8	248064.8	724.2	6333.7	
Mar 2002	360472.1	360472.1	1275.3	7065.6	
Apr 2002	362195.7	362195.7	1656.8	6902.1	

TIP: You can also use the **Results** menu to access the summaries.

TIP: Use the scrollbars located on the right-side and bottom of the summary dialog to view more data.

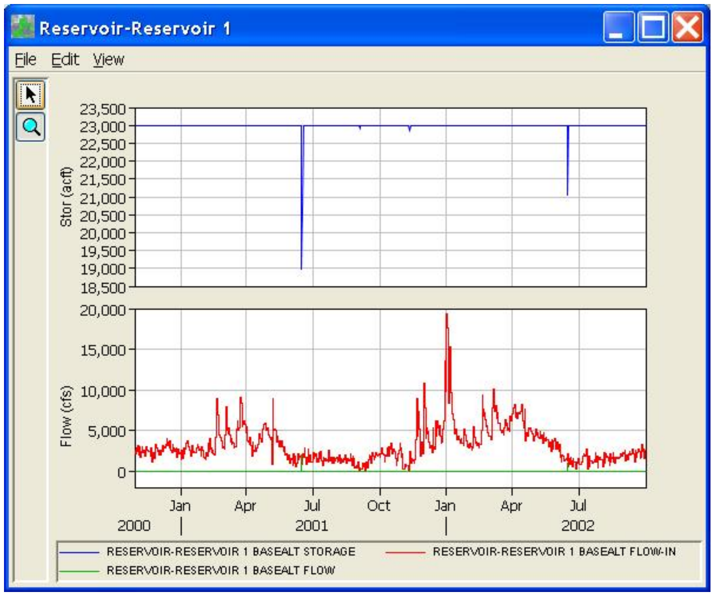
Plots

Once an Alternative has been successfully computed, a user can access the resulting plots. Plots are obtained by right-clicking context menus in the Graphic in the Map Schematic. Below is a Table of available plots.

Available Plots		
Graphic	**Popup Menu Option Name**	**Plots**
Reservoir	Plot Flow and Storage	Displays two plots in the dialog. One is Flow vs. Time, the other, Storage vs. Time
	Plot reservoir Accounts	The Reservoir Accounts Storage vs. Time
Reaches	Plot Flow	Flow through the Reach vs. Time
Junctions	Plot Flow	Flow through the Reach vs Time
Delivery Manager	Plot DM Request and Deliveries	Delivery Manager's water requested and actual water delivery vs. Time
	Plot AM Water Accounts	Area Manager water account volumes vs. Time

Plots are accessed through right-click context menus on specific graphics on the Map Schematic. An example of displaying a Reservoir Storage and Flow Plot is provided below.

- Select the **Pointer Tool** in the Map Schematic.
- Right-click on Reservoir1 and select **Plot Flow and Storage** from the popup menu.



- The **Reservoir Flow and Storage Plot** dialog will appear. Play around with the plot. Use the **Zoom Tool** to get a closer look at the data. Place the mouse over the plot line. Explore the menu options. When you're done, close the Plot window.

- Right-click on other graphics in the map and locate more plots.

Animation

Viewing Animation Results

The use of the animation tool is illustrated with the following example. In this case two Alternates are compared. The animations are defined by color variations in crops growing in the Land Managers, which change with each time step.

Both Alternatives are opened in separate Map Schematic windows. The first Alternative, BaseAlt, is already be displayed in a Map Schematic window. The Alternative is opened by double-clicking on the BaseAlt2 node in the Alternative Module located in the Project Tree Pane.

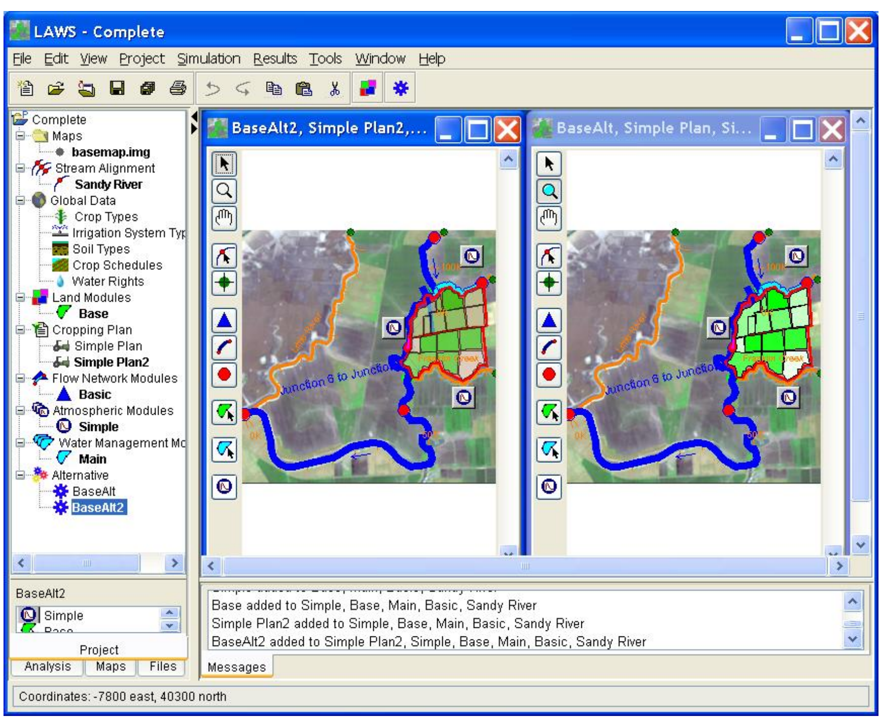
A **Select Map** dialog should appear.

- In the **Select Map** dialog, click the **New Map Window** radio button and then click **OK**.

- The BaseAlt2 Alternative will appear in a new Map Schematic window.

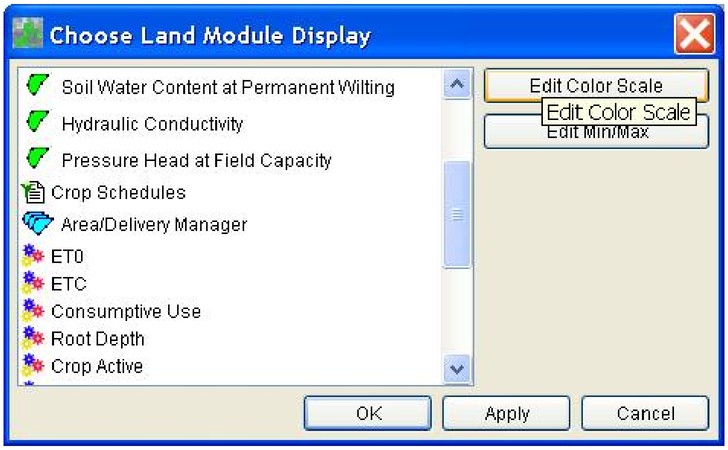
Display the two alternatives side-by-side.

- Select **Window** -> **Tile** in the main LAWS menu bar.



To Animate Results:

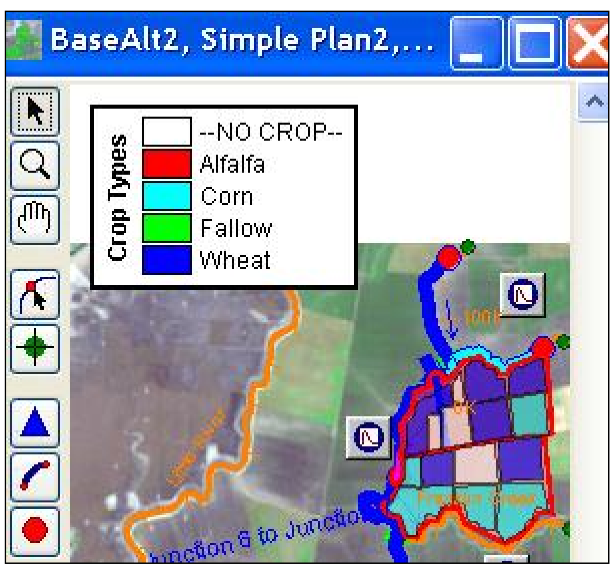
- Select the **Land Module Display Properties Tool** on the main LAWS Toolbar. The **Land Module Display Properties** dialog will display.



- The model properties available for animation are listed on the left side of the **Land Module Display Properties** dialog.

- Select the **Crop Types** property and click **OK**.

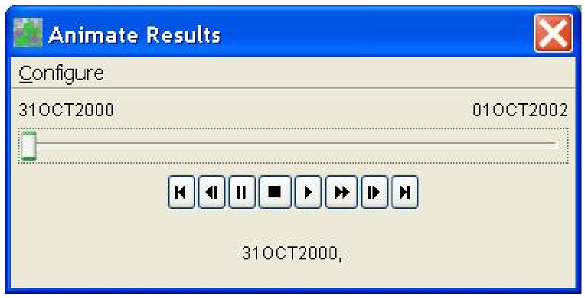
- Notice a color legend appears in the Map Schematic. The legend indicates a color for each Crop Type. As the results are animated, the Land Managers will change color according to the Crop Type's assigned growing at each the time step.



- Select the next Alternative's Map Schematic window and add a Legend to it by repeating the steps above.

Animate both windows at once.

- Click on the **Animation Tool** on the main toolbar.
- The **Animation Results** dialog appears.



- The dialog functions similar to a VCR. There is a play button, fast forward button, etc.
- Click on the play button.
- To speed up the play, click the fast-forward button.

TIP: You can also speed up the play be increasing the **Play Delays** in the **Set Delays** dialog. To access this dialog select **Configure** -> **Delays** in the **Animation Results** dialog.

As the slider moves along in time, the color variations on the Land Managers will change according to there output values at the time step.

- Continue exploring different variables in the **Land Module Display Properties** dialog.

TIP: The only variables that show color variation when played are those with the gear icon next to them.

Technical Reference

The following Technical Reference section presents background information on the concepts, methods and assumptions employed in the LAWS V2 Model.

Introduction

The Land Atmosphere Water Simulator (LAWS) is a tool designed for the management of large-scale, multi-organizational water supply systems. LAWS differs from other water management models in several significant ways.

First, LAWS simulates daily, field-scale land, crop, and water management practices. It provides users with tools to simulate alternative methods for managing soil moisture on a daily basis during the irrigation season based on soil properties, crop type and growth stage. This approach permits LAWS to compute evapotranspiration, soil water content, surface water ponding, runoff, canal and drain losses, return flows to rivers, and deep percolation to groundwater at level of spatial and temporal resolution not present in existing planning and operations models. Although LAWS performs these calculations at the field scale, LAWS also provides users with ability to aggregate these results within larger user definable areas so that water budgets can be readily computed for arbitrary organizational regions.

Second, LAWS does not solve any governing flow equations except continuity nor is it an optimization model. However, LAWS V2 does offer several capabilities not typically found in most water resource system operations models. These features include the ability to simulate soil evaporation and crop transpiration as separate components of evapotranspiration, effects of soil moisture content on crop transpiration, crop rotations and root zone dynamics, effects of unsaturated flow on infiltration and runoff, effects of irrigation on water quality and effects of groundwater pumping on aquifer water levels and stream seepages. These effects are all simulated using analytical functions as opposed to numerical methods. This approach allows LAWS to be very computationally efficient but it requires the LAWS user to provide key input data from other sources of information such as field studies, remote sensing, GIS databases, physical process models, and expert judgment. In some instances such as for unsaturated flow soil properties and groundwater simulation, LAWS provides tools to assist the user in model parameterization. Although LAWS provides users with multiple methods for allocating water supplies and making priority based delivery decisions, LAWS does not employ any mathematical methods to determine what is the "best" allocation of water. In contrast, LAWS provides users with a powerful graphical user interface (GUI) that allows users to readily change water allocation and delivery priorities, land and crop management practices, and infrastructure characteristics to compare the effects of alternative system configurations on reservoir water supplies.

Third, LAWS has a native GIS capability built directly into the GUI. This GIS capability allows users to setup and analyze spatially accurate LAWS simulations across a span of scales ranging from large regional watersheds to sub-regions contained with individual fields. LAWS also provides users with the capability to import imagery, maps, and GIS information developed with commercially available software packages. Furthermore, LAWS has been developed from the Corp of Engineers Water Management System (CWMS) software from which it has inherited a powerful suite of tools to examine model outputs including side by side comparisons of outputs from multiple alternative simulations and animations of spatial and temporal time series results.

System Manager

LAWS captures both the spatial and hierarchical organization of a water supply system. In LAWS, the supply system is conceptualized as a series of nested spatial units that range in size from multi-regional watersheds to individual land units as small as fields. The largest scale land area is associated with a System Manger (SM). In a LAWS simulation, there may be one or more SMs. At the next smaller spatial scale, each Area Manager (AM) manages a particular region within the system. Within these regions, there are one or more Delivery Managers (DM). These DMs represent sub-regions within the AM region where water management is performed differently based on some unique characteristics of the land or the water supply associated with the sub-region. At the smallest scale, an individual land unit is represented by a Land Manager (LM). Each LM is located within a single DM sub-region. In LAWS, the geospatial locations of major reservoirs, rivers, canals and drains are explicitly located through its GIS capability down to the AM-scale. Although simulated mathematically, smaller scale conveyance infrastructure at the DM- and LM-scales is not explicitly geospatially referenced. The LAWS spatial organization is shown in Figure 1 below.

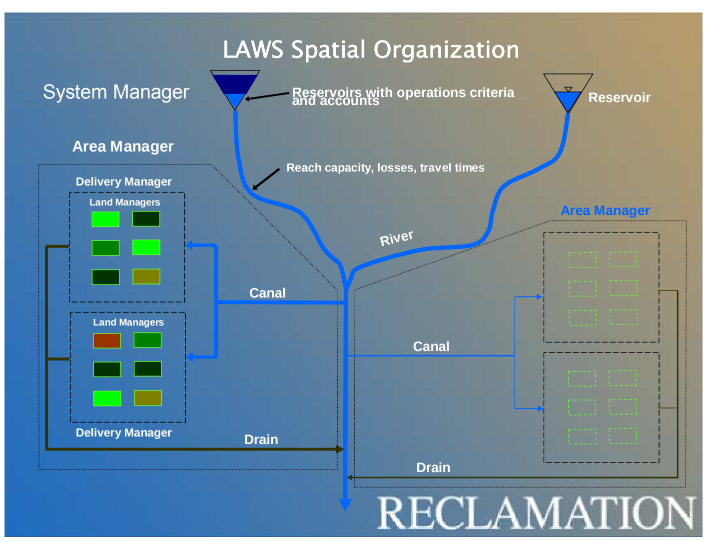


Figure 1. LAWS Spatial Organization

The LAWS hierarchical organization represents the basic structure for managing requests for water supplies and making management decisions necessary for determining the amounts of water to be released from reservoirs as well as the amounts of supply to be provided by groundwater pumping and drain water reuse by individual Land Managers. The LAWS hierarchical organization is presented on Figure 2 below.

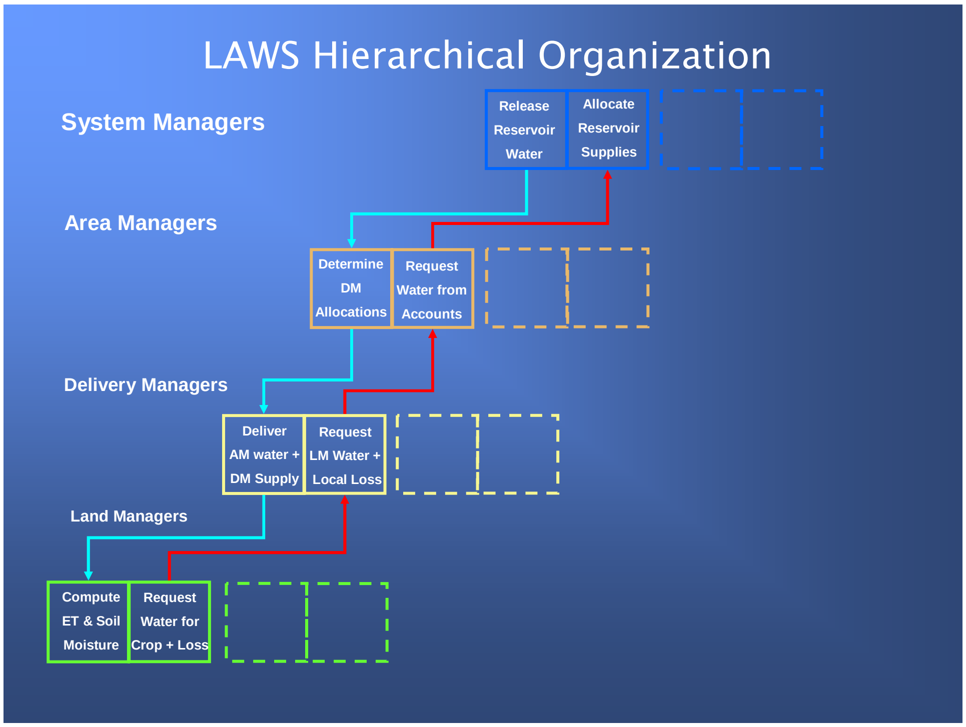


Figure 2. LAWS Hierarchical Organization

Each SM operates one of more reservoirs which may be located on different rivers systems within a regional watershed. Each reservoir consists of one or more accounts each of which is associated with a specific AM. The volume of water in each AM account is determined by a user specified percentage of the conservation pool. The amount of water in the conservation pool is reset on annual basis during the course of a multi-year simulation. The LAWS user has the option to allow an AM account to receive additional supply during a simulation in order to determine how much additional supply would be necessary to meet their water requirements over the simulation period.

At each daily time step, the SM can use either a sequential or balanced allocation method to determine how much water to release from each of the reservoirs it manages. In a sequential allocation the highest ranking account associated with a particular AM is fully depleted before the next highest ranking account is utilized. In a balanced allocation, water from each reservoir account associated with a particular AM is utilized simultaneously in a user specified proportion. If an account is completely utilized before the simulation is complete, the balance allocation ratios are recomputed to reflect the relative weighting of the accounts that still have remaining water supplies.

The total amount of the SM deliveries must be constrained by the available release capacity of the reservoir and the capacity of the downstream river channels to convey releases without causing flood damage. Since LAWS is intended to work in conjunction with other water management models, the reservoir release capacity can be specified at every time step. This approach permits LAWS reservoir releases to be constrained by other in-stream flow requirements that are not explicitly modeled in a LAWS simulation. This capability is accomplished by specifying a LAWS reservoir release capacity as the maximum physical release capacity minus the non-consumptive use flows that are released for other in-stream flow or water quality requirements. Typically, these regulatory releases would be simulated with another model and a daily time series of maximum reservoir release capacities would be computed for a LAWS simulation.

In LAWS, SM reservoir releases are delivered to AMs through an explicitly modeled network of rivers, canals, and drains. The hydraulic properties of these conveyance system features are represented explicitly at user defined reaches along the channels. The LAWS user specifies a maximum flow capacity for each reach and can simulate accretions and depletions in these reaches with simple gain/loss factors. The transit time for water flowing through reaches is also specified by the user.

It is important to recognize that LAWS does not solve the governing equations of flow in open channels. LAWS simulates flow hydraulics and surface-groundwater interactions by using user specified factors. Consequently, the LAWS user must develop this information from field studies, simulations using hydrodynamic and groundwater models, or expert judgment. This simplistic approach used throughout LAWS avoids the computational overhead and complex data requirements of numerical models. However, since LAWS is a mass conservative model, it can be used to determine water budgets from the regional-scale all the way down to the field-scale. Further, the simplicity of the approach permits the LAWS user to efficiently compare alternative land and water management practices, infrastructure characteristics and configurations as well as water delivery priorities explicitly established at each level of the multi-organizational hierarchy.

Area Manager

A LAWS Area Manger is one of the four levels in the LAWS hierarchical organization. An AM represents an organizational unit that manages of water supplies for a particular spatial region within the water supply system. In the LAWS hierarchy, an AM is the intermediary between a System Manager (SM) and the Delivery Managers (DM) which supplies water to individual Land Managers (LM).

The AM manages one or more water accounts. Each of these accounts is associated with a particular SM and has a specified maximum volume. An AM may have accounts with multiple SMs and more than one account with the same SM. The AM is responsible for managing the use of its accounts during a simulation. There are two account utilization mechanisms in LAWS. In a sequential utilization operation, the highest priority account is used completely before water from the next highest priority account is delivered from reservoir storage. In a balanced utilization operation, water from each account is utilized simultaneously in a user specified proportion. If an account is completely utilized before the simulation is complete, the balanced utilization ratios are recomputed to reflect the relative weighting of the accounts that still have remaining water supplies.

Although the SM determines the actual daily amounts of water released from an AM reservoir account, the AM is responsible for establishing the amounts of the groundwater pumping and drain water reuse to be used to meet consumptive use requirements within its DM sub-regions. In LAWS, the total volume of ground water use is not absolutely constrained to a specified amount. However, the amount of drain water recycling is limited to a user specified fraction of the total drain water inflow during each time step. These user specified factors represent the percentage of the total consumptive use requirement that is to be met from these sources of supply. The groundwater pumping and drain water reuse factors are set by the user for each DM in the AM region at each time step. In the event that the amount of drain water available for recycling is not sufficient to meet the AM target, groundwater pumping is automatically increased to make up for the deficit. Since the groundwater pumping and recycling factors may be set to zero by the user, alternative simulations using only reservoir supplies may be readily performed for comparison with various pumping and drain water recycling alternatives.

The AM is responsible for establishing the water delivery priorities that are to be implemented within its region. LAWS employs a user specified hierarchical system to determine how water is delivered to individual LM within a DM sub-region. The application delivery logic is designed to be user extensible so that multiple factors such as seniority of water rights, types of crop, growth stage, moisture stress or other user defined criteria could be employed in the delivery decision logic in future versions of the model.

The AM is responsible for managing the DMs within its region. At each time step, the AM must determine how much water to supply to each of its DMs. After receiving deliveries for each of its accounts from one or more SMs, the AM may use one of three different delivery priority mechanisms. In a sequential delivery operation, each DM is given a fixed priority relative to the others in the AM region and the highest priority DM's consumptive use requirement is completely satisfied before water from the next highest priority DM is delivered. In a balanced delivery operation, delivery is made to each DM in a user specified proportion. In hierarchical delivery operation, deliveries are to each DM based on the priority of individual LMs within the DM. This mechanism essentially treats all DMs with equal priority but insures that LMs meeting the highest ranking in the highest hierarchical level are completely satisfied before lower priority water deliveries are made. If a ranking is reached for which the remaining water supply is inadequate, a shortage delivery is made to the LMs in this ranking group.

At each daily time step, the AM is responsible for receiving and accumulating the requests for water supplies from each of its DMs. Using this request information, the

AM employs its account utilization methods to determine how much water to request from its various accounts. The amounts of requests are adjusted to account for conveyance depletions/accretions and forwarded to the SMs associated with each of its accounts.

Delivery Manager

Within the overall structure of LAWS, the Deliver Manager serves as an intermediary between the Land Manager (LM) whose function is to apply water to an individual land unit and the Area Manager (AM) that requests and distributes water received from the System Manager (SM). Each DM is associated with a single AM and operates to meet requests for water from multiple LMs.

At each time step, the DM is responsible for accumulating the amounts of water requested by each of its LMs. After all the LMs' application requests have been received, the DM has the responsibility for determining an appropriate amount of water to request from its AM to meet the needs of all the land units within its sub-region.

In order to determine the amount to request, the DM takes into account a number of physical and management factors impacting water use within its sub-region. The physical factors include conveyance losses from canals, inflows and outflows associated with adjacent DM sub-regions, deep percolation to groundwater, as well as various inflows and outflows from drains. Management factors include the desired amount of groundwater pumping and drain water reuse within the DM's sub-region. The water budget components of the DM system are shown on the Figure 3 below.

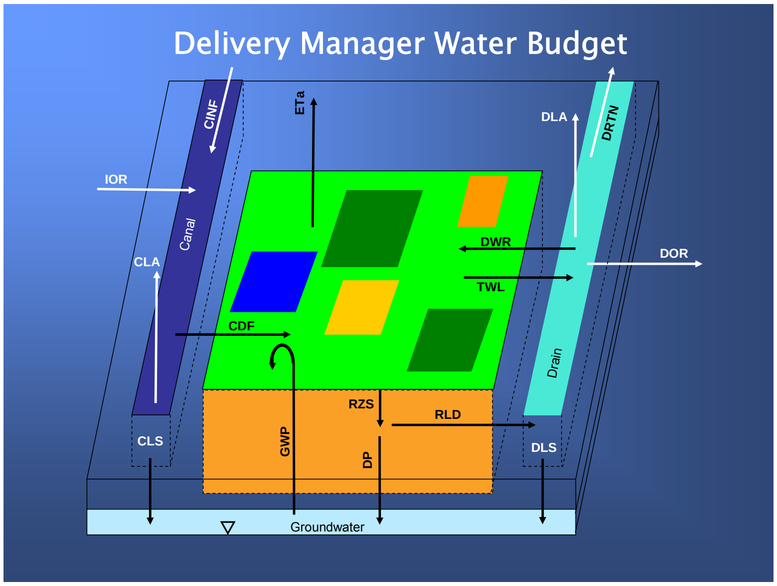


Figure 3 Delivery Manager Water Budget Components

It is important to recognize that the canals and drains within a DM sub-region are not explicitly represented as physical features within a LAWS model. The DM canals and drains represent the affect of field scale canals and drains on the overall water budget within the sub-region. This approach allows simulation of a sub-region's water balance without the difficult and time consuming task of explicitly accounting for all field-scale infrastructure typically found in a water delivery system. At the same time, this approach allows users ample flexibility to investigate the important effects these features exert on the amount the water needed to meet consumptive use requirements.

During each time step, the three major functions of a DM are to deliver to the LMs the water received from the AM, receive water application requests from LMs and determine an appropriate amount of water to request from the AM in the next time step. It is important to recognize that the actual amounts of water received from the AM for delivery to the LMs may be less than the amount requested.

At each time step, the AM establishes the deliver priorities within its region and notifies each DM of the supply available for delivery. The total amount consists of reservoir releases, groundwater pumping, and recycled drain water. Using the delivery priorities established by the AM, the DM delivers water to all the LMs for which sufficient supply is available.

As the DM delivers water, LMs inform the DM of any unmet water needs by making an application request for whatever amount is still required for consumptive use based on the final soil water content after delivery to the land unit. Once all the possible deliveries have been made, the DM queries the remaining LMs to determine their application requests. This process insures that every land unit is queried and results in the soil water content and other water budget components of every land unit being updated at every time step.

After the DM has completed the delivery process, the total amount of all LM application requests is known. The DM must now determine the total amount of water to request (DIV) for the entire sub-region. This process involves accounting for gains, losses and reuse of water within the sub-region. In addition to water supplied by the AM, other sources of supply to the DM sub-region include inflows into canals from adjacent sub-regions (IOR) and groundwater pumping (GWP). Other than consumptive use of applied water (CUAW), losses from the sub-region include canal seepage (CLS), drain seepage (DLS), and deep percolation (DP) to groundwater, evaporation from canals (CLA) and drains (DLA) to the atmosphere, outflows from drains to adjacent sub-regions (DOR) and return flow from DM drains to AM drains (DRTN). Tail water losses (TWL) and drain water reuse (DWR) within the DM's sub-region are other user defined management factors that affect the amount of water the DM requests from the AM.

At each time step, the DM employs results from the LMs to compute the sub-region's consumptive use of applied water and its application efficiency factor (AEF). To perform these calculations, the DM uses the following results from each LM.

1. Amount of the application request (AAR)
2. Consumptive use requirement (CUR)
3. Root zone losses to drains (RLD)
4. Root zone losses to seepage (RLS)
5. Rainfall and pond runoff to drains (RFO)
6. Tail water losses (TWL)
7. Land Unit Application Efficiency (LUEF)
8. Land Manager Area (AREA)

Calculation of the amount of water to request from the Area Manager requires the following totals from the Land Managers associated with each DM.

Sum of the land manager Application Amount Request, TAAR
Sum of the land manager Drain Inflow, DINF
Sum of the Drain Inflow from Other Regions, DIOR

The DM's TAAR is equal to Net Canal Delivery (NCD) plus Groundwater Pumping (GWP) plus Local Drain Water Reuse (DWR)

TAAR = NCD + GWP + DWR

The Canal Inflow (CIN) is equal to the Area Manager Delivery (AMD)

CIN = AMD

The Net Canal Delivery is the Canal Inflow less Canal Losses to Atmosphere (CLA) and Canal Losses to Seepage (CLS), which are fractions of the total canal inflow

NCD = CIN – CLA – CLS
NCD = CIN*(1-CLAF-CLSF)
NCD = AMD*(1-CLAF-CLSF)

Groundwater Pumping Factor (GWPF) is used to determine groundwater pumping

GWP=TAAR*GWPF

Drain Water Reuse Factor (DWRF) is used to determine Target for Drain Water Reuse (TDWR). Note that there may not be enough local drainage to meet the target!

TDWR = TAAR*DWRF

LAWS determines the Drain Water Available for Reuse (DWAR) based on the total drain water less losses to atmosphere (DLA) and seepage DLS) and exports to other Delivery Managers (DEXP)

DWAR=DINF+DIOR-DLA-DLS-DEXP

DWAR=DINF*(1-DLAF-DLSF-DEXPF)+DIOR

If DWAR is greater than or equal to TDWR, then we meet the objective and the DWR is equal to the target, and the Drain Water Return Flow (DWRTN) is the difference

DWR = TDWR
DWRTN=DWAR-DWR

If DWAR is less than TDWR, then the DWR is equal to the available drain water, and there is no return flow

DWR=DWAR
DWRTN=0

The Area Manager Delivery, AMD, is computed as follows.

TAAR = NCD + GWP + DWR
TAAR= AMD*(1-CLAF-CLSF)+ TAAR*GWPF+DWR
AMD=(TAAR*(1-GWPF)-DWR)/(1-CLAF-CLSF)

The DM calculates the total amount of deep percolation (DPG) traveling to groundwater table at each time step from results of the LM calculations and the results described above.

$$DPG = \sum_{i=1}^{N} RLS_i + DLS + CLS$$

Unless the groundwater module is employed, LAWS V2 does not include the physical processes needed to determine the rate of subsurface flow or resultant changes in the elevation of the water table.

Land Manager

Within the overall structure of LAWS, the role of the Land Manager (LM) is to apply water received from the Delivery Manager (DM) to the land, determine the soil moisture content after application and request an appropriate amount of water from the DM depending on the status of the soil water content.

In LAWS V2, soil water flow is simulated using a 1-dimensional 2 layer model to calculate bare soil evaporation, plant transpiration, surface water runoff, infiltration, groundwater table upflux, and deep percolation. Infiltration into the soil profile is simulated using a 1-dimensional unsaturated flow analytical equation (Philip, 1957). Soil evaporation and plant transpiration are computed using the well known dual crop coefficient method. Upflux and deep percolation are also computed by accounting for the effects of variable saturation in a dynamically changing root zone. These results are used to determine the soil moisture content at each daily time step. When the soil moisture is reduced to a user specified management allowable depletion, the LM notifies the DM that delivery of additional water is required. Since certain crops and management practices require ponding of water on the soil surface, a provision is made to manage water under both ponded and unponded conditions. The effects of irrigation on changes in a non-reactive, conservative constituent can also be simulated. The details of these calculations are provided below.

Soil moisture flow is modeled in LAWS using a 1-dimensional 2 layer model that calculates bare soil evaporation, plant transpiration, surface runoff, infiltration, groundwater table upflux, and deep percolation (Figure 1). Evaporation and transpiration are modeled using the dual crop coefficient approach described in Food and Agriculture Organization Irrigation and Drainage Paper 56 (Allen, et al, 1998), hereafter referred to as FAO 56. The top layer of the model is layer 1 or the bare soil evaporation layer as described in FAO 56. The bottom layer is the remainder of the root zone and increases in depth as the plants mature.

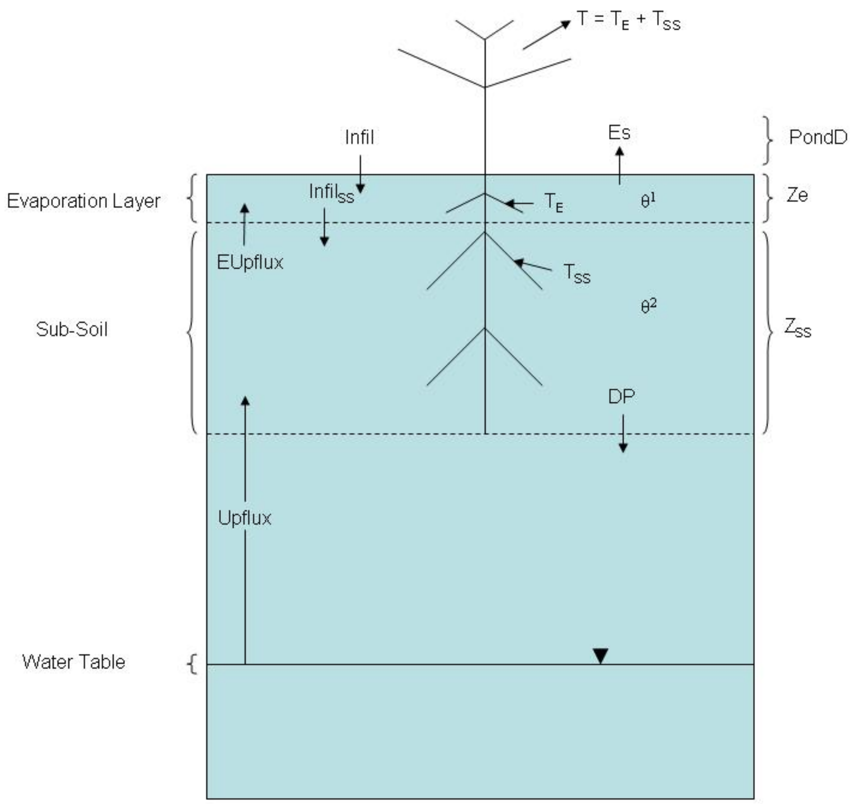


Figure 1. Schematic of two layer soil water balance model.

Bare soil evaporation

Bare soil evaporation is calculated using the method described in FAO 56. It removes water from the "evaporation layer" or layer 1 which has thickness Ze which is specified by the user in the **Soil Type Editor**.

$$\mathbf{Es = Ke*ETo} \qquad \textbf{Eq. 1}$$

Es - evaporation from bare soil (L/T);
Ke - soil water evaporation coefficient;
ETo - reference evapotranspiration (L/T).

Soil water evaporation coefficient, Ke:

$$\mathbf{Ke = MIN[Kr\ (Kc_{max}-Kcb),\ few\ Kc_{max}]} \qquad \textbf{Eq. 2}$$

Kr - soil water evaporation reduction coefficient;
Kc_{max} - maximum value of the climate adjusted crop coefficient;
Kcb - basal crop coefficient;
few - fraction of soil surface that is wetted and exposed.

Soil water evaporation reduction coefficient, Kr:

Kr is a function of the soil water content in the evaporation layer (θ_{se}) and the soil physical properties:

If $\theta_{se} > \theta_{REW}$ then Kr =1, if $\theta_{se} < \theta_{REW}$ then

$$Kr = 1 - \frac{\theta_{REW} - \theta_{SE}}{\theta_{REW} - \theta_{TEW}} \qquad \textbf{Eq. 3}$$

where bare soil evaporation is described by the simple model mentioned above and illustrated in Figure 2.

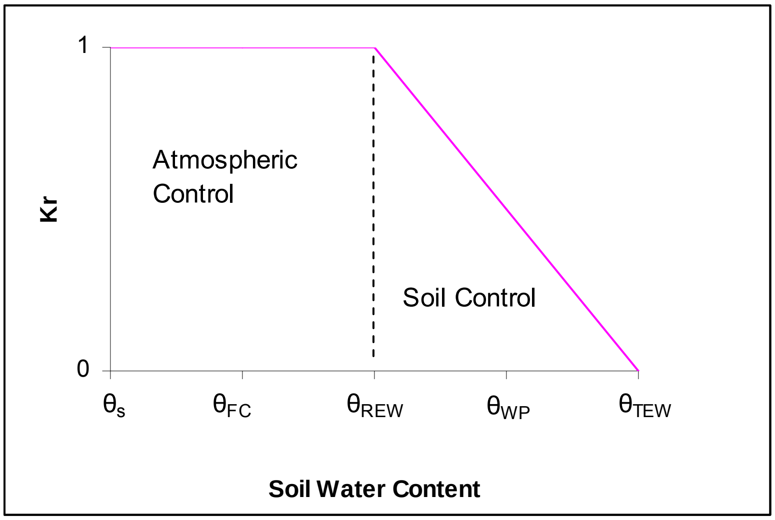


Figure 2. Bare soil evaporation model. Kr is a function of soil water content. For θ_{se} greater than θ_{REW} the atmospheric conditions are the limiting factor on evaporation rate. For θ_{se} less than θ_{REW} the evaporation rate is limited by the soil physical properties.

θ_{se} - soil water content in evaporation layer;
θ_s - soil water content at saturation;
θ_{FC} - soil water content at field capacity;
θ_{REW} - soil water content at limit of "**readily evaporable water" (REW)**;
θ_{WP} - soil water content at wilting point;
θ_{TEW} - soil water content at limit of "total evaporable water", note is assumed to be $\theta_{TEW} = 0.5\ \theta_{WP.}$

Information on determining the value of REW can be found in FAO 56, Table 19, p. 144. Its value is specified in the **Soil Type Editor**. Generally, the thickness of the evaporation layer, Ze, ranges between 10 and 20 cm.

Maximum crop coefficient, Kc_{max}

$$\mathbf{Kc_{max} = MAX[\{1.2 + [0.04(u_2-2) - 0.004(RH_{min}-45)](h/3)^{0.3}\},\{Kcb+0.05\}]} \quad \textbf{Eq. 4}$$

Kc_{max} - upper limit on evaporation and transpiration;
u_2 - seasonal daily average wind speed at 2 m height (m/s);
RH_{min} - mean daily minimum relative humidity (%);
h - seasonal maximum plant height (m).

u_2, RH_{min}, and h are specified in the **Crop Type Editor.**

Fraction of soil surface that is wetted and exposed, few

$$few = MIN(1-fc, fw) \qquad \textbf{Eq. 5}$$

fw - fraction of soil surface wetted by the irrigation or rainfall event, this value is specified in the **Irrigation Systems Type Editor**;
fc - effective fraction of the soil surface covered by the vegetation canopy, this value can be entered into the **Crop Type Editor** or the following equation can be used.

$$fc = \left(\frac{Kcb - Kc\min}{Kc\max - Kc\min}\right)^{(1+0.5h)} \qquad \textbf{Eq. 6}$$

Kcmin - minimum value of Kc for a bare dry soil;
Kcmax - maximum value for Kcb;
h - plant height (m).

Kcmin and h are specified in the Crop Type Editor.

Plant transpiration

Plant transpiration is modeled using the basal crop coefficient method described in FAO 56.

$$T = K_{cb} * ETo * f \qquad \textbf{Eq. 7}$$

K_{cb} - basal crop coefficient;
f - soil moisture limiting factor.

The basal crop coefficient is used to scale the reference evapotranspiration based on the development stage of the plant (Figure 3).

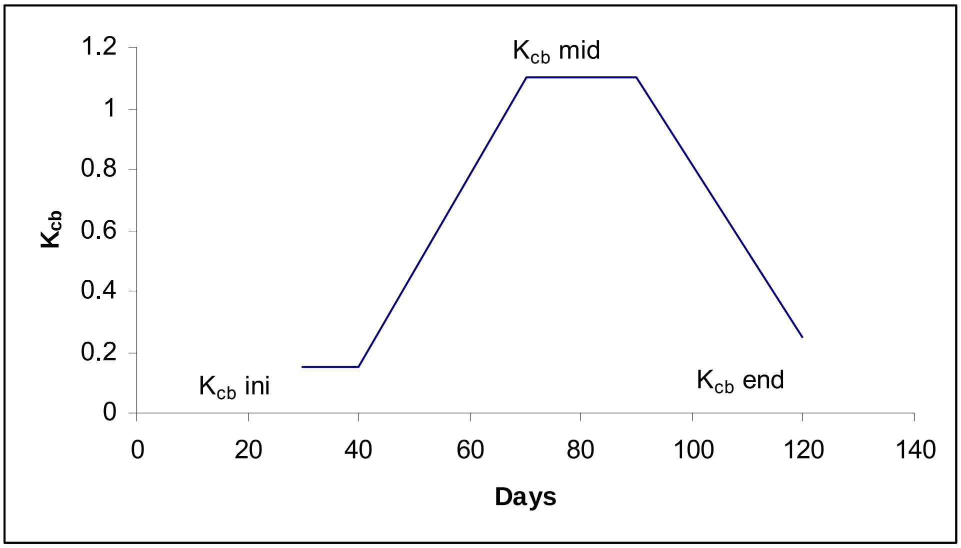


Figure 3. Example of the basal crop coefficient.

K_{cb} ini - basal crop coefficient during the initial growth stage;
K_{cb} mid - basal crop coefficient during the period during which the crop has reached full cover;
K_{cb} end - basal crop coefficient at then end of the growing season.

The values for the basal crop coefficient can be found in Table 17 of FAO 56 and are entered into the **Crop Type Editor.**

The soil moisture limiting factor, f, reduces transpiration as a function of the soil pressure head. (Feddes et al.,1978). Its form is shown on Figure 4 below.

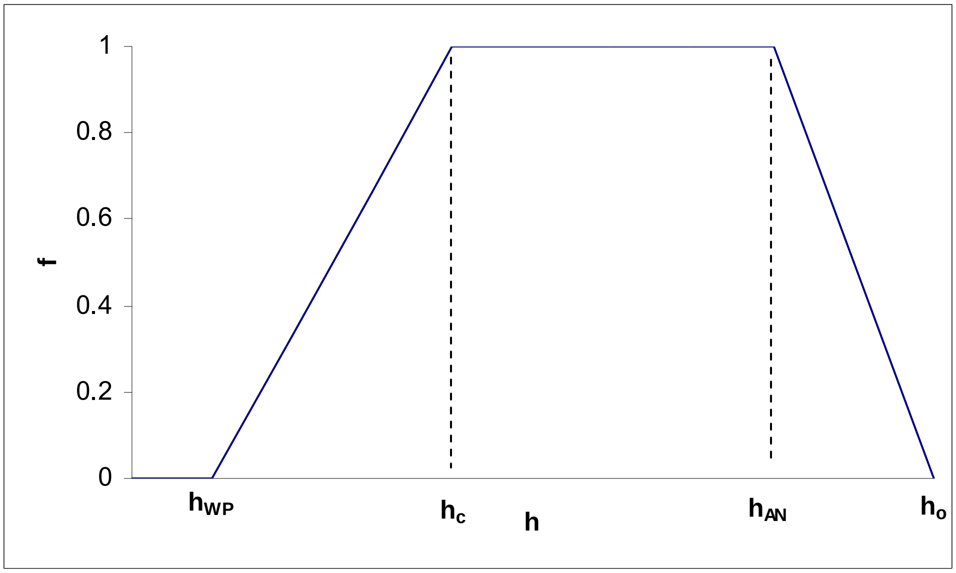


Figure 4. Transpiration limiting factor f as a function of matric potential.

h_{WP} - pressure head at which the plant dies (cm);
h_c - pressure head below which transpiration is limited due to moisture stress(cm);
h_{AN} - pressure head l above which transpiration is limited due to anoxic conditions (cm);
h_o - pressure head at which transpiration ceases due to anoxia (cm).

h_{wp} is assumed to be -15,000 cm of pressure head. h_c is entered into the **Crop Type Editor** in the "Max Pressure Head for Full ET (L)" field. h_{AN} is entered into the **Crop Type Editor** in the "Min Pressure Head for Full ET (L)." h_o is assumed to be 0 cm of pressure head.

Infiltration and runoff

Daily maximum infiltration is modeled in LAWS using the 1-dimensionl Philip's equation (Philip, 1957).

$$DMI = S*t^{1/2} + K*t \qquad \text{Eq. 8}$$

DMI - daily maximum infiltration (L/T);
S - soil sorptivity (L/T);
t - time (T);
K - hydraulic conductivity which is assumed to be the saturated value - K_s (L/T).

The soil sorptivity is calculated using the following equation.

$$S = [\frac{2(\theta_S - \theta_{t-1})K_S H_{cm}}{\beta}]^{1/2} \qquad \textbf{Eq. 9}$$

θ_s - saturated moisture content;
θ_{t-1} - average root zone moisture content at end of previous time step;
H_{cm} - effective capillary drive;
B - viscous correction factor (ranges from 1.1-1.7), in LAWS it is assumed to be 1.3.

Using the derivation of the effective capillary drive found in Morel-Seytoux, et al. (1996).

$$H_{cm} = (\frac{1}{\alpha})\frac{0.46m + 2.07m^2 + 19.5m^3}{1 + 4.7m + 16m^2} \qquad \textbf{Eq. 10}$$

where:

α - van Genuchten parameter (1/cm);
m - = 1-1/n, where n is a van Genuchten parameter.

Using the Philip equation, the maximum daily infiltration can be calculated. Rainfall or irrigation in excess of the daily maximum infiltration and user defined pond depth is assumed to be runoff. The following algorithm is used in the LAWS model.

If R + I + $PondD_{t-1}$ > DMI **Then**
  If R + I + $PondD_{t-1}$ > DMI + MaxPondD **Then**
    Runoff = R + I + $PondD_{t-1}$ – DMI – MaxPondD
    $PondD_t$ = MaxPondD
    Infil = DMI
  Else
    Runoff = 0.0 **Eq. 11**
    $PondD_t$ = R + I + $PondD_{t-1}$ - MaxInfil
    Infil = DMI
  Endif
Else
  Infil = R + I + $PondD_{t-1}$
  Runoff = 0.0
  $PondD_t$ = 0.0
Endif

where:

R - rainfall (L/T);

I - irrigation water applied (L/T);
DMI - daily maximum infiltration (L/T);
Runoff - surface runoff (L/T);
Infil - infiltration (L/T);
$PondD_{t-1}$ - depth of ponded water from previous time step (L);
MaxPondD - maximum pond depth (L).

Water Table Upflux

In regions with a shallow water table, a portion of the crop water demand can be met from water that moves upward through capillary action to the root zone. In LAWS, this process is modeled using a Darcy's Law approach.

To calculate water table upflux into the bottom layer, the gradient between the water table and the mid-point of the bottom layer is calculated. The soil between the water table and this layer is assumed to be at field capacity and the hydraulic conductivity is set accordingly. The ground surface is used as the datum. In LAWS, the field capacity is assumed to be at -1/3 bar pressure head or -333 cm of water pressure.

$$Upflux = K(h_{FC})\frac{(h_{WT} - Z_{WT}) - (h_{RZ} - Z_{RZ}/2)}{Z_{WT} - Z_{RZ}/2} \qquad \textbf{Eq. 12}$$

where:

Upflux - flux of water from water table into root zone (L/T);
$K(h_{FC})$ - unsaturated hydraulic conductivity at field capacity (L/T);
h_{WT} - pressure head at water table surface (= 0.0 cm);
Z_{WT} - depth of water table below ground surface (cm);
h_{RZ} - average pressure head in root zone (cm);
Z_{RZ} - thickness of root zone (cm);
$Z_{RZ}/2$ - depth of mid-point of root zone (cm).

Water can also flow up into the evaporation layer due to capillary forces. This flux is calculated in a manner similar to the Upflux.

$$EUpflux = K(h_{RZ})\frac{(h_{RZ} - Z_{RZ}/2) - (h_E - Z_E/2)}{Z_{RZ}/2 - Z_E/2} \qquad \textbf{Eq. 13}$$

$Z_E/2$ - elevation head at mid-point of evaporation layer (cm);
EUpflux - flux of water from root zone into evaporation layer (L/T);
h_E - average pressure head in evaporation layer (cm).

Soil Moisture Routing

The water balance in the soil layers is calculated as a sum of the inflows and outflows. The water balance equation used depends upon the relative magnitudes of the fluxes and storage from the previous time step. Below, the equations are presented following a description of the conditions for which they are appropriate.

Layer 1 (Evaporation Layer)

Layer 1 - Case 1

If the sum of infiltration plus upflux minus evapotranspiration in Layer 1 is greater than the unsaturated pore space at the end of the previous time step ($Infil+EUpflux-Es-T_E/Ze > \theta_s - \theta_{t-1}$), then soil water content during the current time step is calculated based on the following equations. (Williams et al., 2008):

$$\theta^1_t = (\theta_s - \theta_{FC})\exp(-1/TT) + \theta_{FC} \qquad \textbf{Eq. 14}$$

θ^1_t - soil moisture content in layer 1 at end of time step i;
θ_s - soil moisture content at saturation;
θ_{FC} - soil moisture content at field capacity;
T_E - transpiration from evaporation layer, $T_E = T^*(Z_E/Z_{RZ})$;
TT - travel time (d), where:

where:

$$TT = Ze * (\theta_S - \theta_{FC})/(K_s) \qquad \textbf{Eq. 15}$$

and

Ze - thickness of evaporation layer (cm);
K_s - hydraulic conductivity at saturation (L/T).

Infiltration ($Infil_{SS}$) into Layer 2 of the root zone is calculated as:

$$Infil_{SS} = IN - OUT - \Delta S$$

where each of the terms in the equation are given in Eq. 16 below:

$$Infil_{SS} = (Infil+EUpflux) - (Es+T_E) - ((\theta^1_t - \theta^1_{t-1})*Ze) \qquad \textbf{Eq. 17}$$

Layer 1 - Case 2

If the infiltration plus upflux minus evapotranspiration in Layer 1 results in a moisture content between saturation and field capacity (θ_s > (Infil+EUpflux-Es-T_E)/Ze + θ_{i-1} > θ_{FC}), then the new soil water content and infiltration into Layer 2 are calculated by Equations 15, 17 and 18.

$$\theta^1_t = ((Infil+EUpflux-Es-T_E)/Ze + \theta^1_{t-1} - \theta_{FC}) \exp(-1/TT) + \theta_{FC} \qquad \text{Eq. 18}$$

Infiltration into Layer 2 of the root zone is calculated as:

$$Infil_{SS} = IN - OUT - \Delta S$$

where each of the terms in the equation are given in Eq. 18 below:

$$Infil_{SS} = (Infil+EUpflux) - (Es+T_E) - ((\theta^1_t - \theta^1_{t-1})*Ze) \qquad \text{Eq. 19}$$

Layer 1 - Case 3

If the infiltration plus upflux minus evapotranspiration in Layer 1 results in a soil water content less than field capacity ((Infil+EUpflux-Es-T_E)/Ze + θ_{t-1}) < θ_{FC}), then the new soil water content and infiltration are calculated as:

$$\theta^1_t = ((Infil+EUpflux-Es-T_E)/Ze + \theta_{t-1}) \qquad \text{Eq. 20}$$

Infiltration into Layer 2 of the root zone is calculated as:

$$Infil_{SS} = 0$$

Layer 2 (Root Zone Sub-Soil)

The equations presented below illustrate the method used to calculate deep percolation and soil moisture changes in the portion of the root zone that is not in the evaporation layer. The thickness of this layer is $Z_{SS} = Z_{RZ} - Ze$.

where Z_{RZ} is the root zone thickness during the current time step.

Layer 2 - Case 1

If the infiltration plus upflux from the water table into Layer 2 minus plant transpiration and upflux from Layer 2 to Layer 1 is greater than the unsaturated pore space at the end of the previous time step ((Infil$_{SS}$+Upflux-T$_{SS}$-EUpflux/ Ze > θ_s - θ_{i-1}), then the soil water content during the current time step is calculated based on the following equations.

$$\boldsymbol{\theta^2_t = (\theta_s - \theta_{FC})\ \exp(-1/TT) + \theta_{FC}} \qquad \textbf{Eq. 21}$$

θ^2_t - soil moisture content in layer 2 at end of time step i;
Tss - portion of transpiration that occurs in Layer 2 assumed to be T * Z_{SS}/Z_{RZ};
TT - travel time (d), where:

$$\boldsymbol{TT = (Z_{SS}) * (\theta_S - \theta_{FC})/(K_S)} \qquad \textbf{Eq. 22}$$

Zss - thickness of subsoil layer (L);
K_s - hydraulic conductivity at saturation (L/T).

Deep percolation (DP) from the Layer 2 is calculated as:

$$\boldsymbol{DP = IN - OUT - \Delta S}$$

where each of the terms in the equation are given in Eq. 22 below:

$$\boldsymbol{DP = (Infil_{SS} + Upflux) - (T_{SS} + EUpflux) - (\theta^2_t - \theta^2_{t-1}) * Z_{SS}} \qquad \textbf{Eq. 22}$$

Layer 2 – Case 2

If the sum of infiltration plus upflux into Layer 2 minus plant transpiration and upflux from Layer 2 to Layer 1 results in a moisture content between saturation and field capacity (θ_s > (Infil$_{SS}$+Upflux-T$_{SS}$-EUpflux)/Z$_{SS}$ + θ^2_{i-1} > θ_{FC}), then the soil water content and deep percolation from Layer 2 during the current time step are calculated by Equations 21, 23 and 24.

$$\boldsymbol{\theta^2_t = ((Infil_{SS} + Upflux - T_{SS} - EUpflux)/Z_{SS} + \theta^2_{i-1} - \theta_{FC})\ \exp(-1/TT) + \theta_{FC}} \qquad \textbf{Eq. 23}$$

Deep percolation from Layer 2 is calculated as:

$$\boldsymbol{DP = IN - OUT - \Delta S}$$

where each of the terms in the equation are given in Eq. 24 below:

$$\mathbf{DP = (Infil+Upflux) - (T_{SS}+EUpflux) - (\theta^2_t - \theta^2_{t-1})* Z_{SS}} \quad \textbf{Eq. 24}$$

Layer 2 - Case 3

If the infiltration plus upflux minus evapotranspiration in Layer 1 results in a soil water content less than field capacity ($((Infil_{SS}+Upflux-T_{SS}-EUpflux)/Z_{SS} + \theta_{i-1}) < \theta_{FC}$), then the new soil water and deep percolation are calculated as follows:

$$\mathbf{\theta^2_t = (Infil_{SS}+Upflux-T_{SS}-EUpflux)/Z_{SS} + \theta^2_{t-1}} \quad \textbf{Eq. 24}$$

$$\mathbf{DP = 0}$$

Irrigation Demand

In LAWS, irrigation water demand is based on the amount of the soil moisture deficit when an irrigation event is requested by a Land Manager and the user specified distribution uniformity, DU. Irrigation is requested when the soil moisture content of the root zone is less than the user specified management allowable depletion (MAD). The irrigation demand is computed by:

$$\mathbf{ID = (\theta_{FC} - \theta_{RZ})*Z_{RZ}/DU} \quad \textbf{Eq. 25}$$

where:

ID - irrigation demand (L);
$\theta_{FC} - \theta_{RZ}$ - soil moisture deficit
Zrz - root zone thickness
DU - distribution uniformity.

The Management Allowable Depletion (MAD) is defined as the fraction of the water content between field capacity and wilting point that is allowed for plant use prior to irrigation. when the root zone moisture content is below θ_{MAD} irrigation water is requested.

$$\mathbf{\theta_{MAD} = (1-MAD)* (\theta_{FC} - \theta_{WP})+ \theta_{WP}} \quad \textbf{Eq. 26}$$

Solution Method

For each daily time step, the LAWS model performs the following operations in the order specified.

1. **Adjust water content from previous time step to account for increase in root zone thickness.** As the root zone increases in thickness, the average root zone moisture content must be updated to reflect the newly occupied soil. This is done by adding the new depth increment into the moisture content calculations. It is assumed that the new depth increment has a moisture content of field capacity.

2. **Calculate upflux from water table into Layer 2 and upflux from Layer 2 into Layer 1.** The equations presented are used to calculate the flow of water from the water table up into the Layer 2 and from Layer 2 into Layer 1.

3. **If irrigation or rainfall occurs, calculate infiltration, ponding depth, and runoff.** The irrigation or rainfall rate is compared to the Daily Maximum Infiltration rate (DMI). If the irrigation and/or rainfall rates are in excess of the DMI and the user defined ponding depth, then runoff is produced. Surface watervrunoff becomes part of the Drain water budget.

4. **Calculate potential daily bare soil evaporation.** The potential daily bare soil evaporation rate is calculated using the procedure described. In this step, the daily bare soil evaporation rate is calculated as a function of the soil moisture content from the previous time step. However, if on that day irrigation or rainfall occurs the value of Kr is adjusted to account for the additional plant available soil moisture. If the ponding depth is non-zero then the value of Kr is set to 1.0. For rainfall events, the fraction of the soil surface that is wetted, fw, is set to 1.0. For irrigation events fw is the user specified value.

5. **Calculate potential daily soil moisture limited transpiration.** The potential daily transpiration rate is calculated using the algorithm described.

6. **Calculate actual transpiration and soil evaporation for the day based on the available soil moisture storage.** Due to the length of the model time step, it is possible for the potential evaporation and transpiration rates to remove more water from the soil than is actually available. To correct for this problem, logic in the model checks to see if there is enough moisture available to supply water at the calculated evapotranspiration rates. If not, the rates are reduced so that only the available soil moisture is transpired or evaporated.

7. **Using the values calculated above, the change in soil moisture storage in Layer 1 and the infiltration of water into Layer 2 are calculated.**

8. **Using the values calculated in steps 1 - 6, the change in soil moisture storage in Layer 2 and the amount of Deep Percolation are calculated.**

9. **If necessary, the soil moisture content is adjusted to account for the presence of the water table in the root zone.** The new root zone soil moisture content is calculated by averaging the soil moisture content over the saturated and unsaturated portions of the root zone.

$$\theta_{RZ} = ((Z_{RZ} - Z_{WT})^{*}\ \theta_{RZ} + Z_{WT}^{*}\ \theta_{S}\ \theta_{RZ})/Z_{RZ} \qquad \textbf{Eq. 27}$$

10. Calculate irrigation demand.

Modeling Water Quality in LAWS

Introduction

The LAWS V2 model has the capability to model a single non-reactive, mass conservative water quality constituent. This capability was designed to model constituents like total dissolved solids (TDS) which are commonly important to irrigation water quality. Such constituents are also affected by plant transpiration and soil evaporation which remove water without a corresponding removal of salts. This capability can be activated by selecting the **Compute Water Quality** checkbox in the Run Controls tab of the **Alternative Editor.**

Water Quality Model

The water quality model employed in LAWS uses assumptions based on a non-reactive, mass conservative constituent. Starting with reservoirs, the water quality of water exiting the reservoir is computed using the assumption of instantaneous mixing:

$$\mathbf{Rel_{WQ} = (Inflow * Inflow_{WQ} + ResVol(i\text{-}1) * ResVol_{WQ}(i\text{-}1))/(Inflow + ResVol(i\text{-}1))}$$

where:

Rel_{WQ} - Water quality of water released by the reservoir during timestep i [M/V];
Inflow - Volume of inflow to reservoir during time step i [V];
$Inflow_{WQ}$ - Water quality of reservoir inflow [M/V];
ResVol(i-1) - Volume of water storage at end of time step i-1 [V];
$ResVol_{WQ}(i\text{-}1)$ - Water quality of reservoir water at end of time step i-1 [M/V].

As water flows downstream from the reservoir in stream reaches it can interact with the groundwater system. Currently, the concentration of the water in the channel is assumed to remain constant.

Upon arrival at a Delivery Manager (DM), the water is mixed with all other potential sources such as groundwater, recycled drain water, and other supplies. The resulting mixed water is supplied to Land Managers.

where:

$$\mathbf{DelWat_{WQ} = (Rel_{WQ} * Rel_{DM} + GW_{WQ} * GW + DW_{WQ} * DW + OS_{WQ} * OS)/(Rel + GW + DW + OS)}$$

$DelWat_{WQ}$ - Water quality of water delivered to Land Manager during timestep i [M/V];
Rel_{DM} - Volume of water released by reservoir for DM and delivered during timestep i [V];

GW_{WQ} - Water quality of groundwater [M/V];
GW - Volume of groundwater pumped during time step i [M];
DW_{WQ} - Drain water quality [M/V];
DW - Volume of drain water used by DM during time step i;
OS_{WQ} - Other supply water quality [M/V];
OS - Volume of other water supplies used by DM during time step i [V].

Within a Land Manager, the quality of soil water is calculated using the following equation.

$$LM_{WQ} = (LMW(i-1) * LM_{WQ}(i-1) + Infil * Infil_{WQ} + Upflux * Upflux_{WQ})/(LMW(i-1) + Infil + Upflux - E - T)$$

LM_{WQ} - Water quality of soil water in Land Manager at end of time step i;
LMW(i-1) - Volume of soil water at end of time step i-1;
$LM_{WQ}(i-1)$ - Water quality of soil water in Land Manager at end of time step i-1;
Infil - Volume of water that infiltrates into root zone during time step i;
$Infil_{WQ}$ - Water quality of infiltration water (same as $DelWat_{WQ}$);
Upflux - Volume of water that enters root zone as upflux from water table during time step i;
$Upflux_{WQ}$ - Water quality of upflux water;
E - Volume of bare soil evaporation during time step i;
T - Volume of plant transpiration during time step i.

Data Input

If the **Water Quality option** is selected, the user will be prompted in several of LAWS Modules to provide data related to the simulation of water quality.

1. **Alternative Editor - Initial Condition tab**, initial water quality of reservoirs.
2. **Alternative Editor - Input Time Series tab**, reservoir inflow water quality, junction node inflow water quality,
3. **Land Manager Editor** - Initial Water Quality of soil water.
4. **Non-Agricultural Land Manager** - Initial Water Quality of soil water.
5. **Atmospheric Module Editor** - Rainfall Water Quality. A constant or time series can be chosen, if a time series is to be used then it needs to be specified in the **Alternative Editor** on the **Input Time Series tab**.
6. **Delivery Manager Editor - Management Parameters tab**, groundwater quality and other supply water quality. Both of these parameters can be specified as either a constant value or a time series, if a time series is to be used then it needs to be specified in the **Alternative Editor** on the **Input Time Series tab**.

Modeling Groundwater in LAWS

Introduction

LAWS provides users with two methods to represent groundwater in a model. The first and most straightforward is to simply assign a water table depth to each Land Manager. This value is then used in the calculations of water table upflux to determine the effect, if any, of the proximity of the water table on soil moisture conditions. This approach is useful when groundwater depth and pumping are not significant concerns for the application. A more comprehensive method available to LAWS users is to use discrete kernels (aka linear response functions) to represent the dynamic behavior of the groundwater system within the study area. **In order to use this approach the LAWS user must have a previously built groundwater flow model of the study area using the MODFLOW-2005 groundwater modeling code (Harbaugh, 2005) and the SFR1 streamflow routing package (Prudic, et al., 2004).** This approach also assumes the user is a knowledgeable about MODFLOW and is comfortable in determining if and where the limiting assumptions inherent in the discrete kernel approach are violated. There are many assumptions and restrictions that must be satisfied by the user to properly implement this approach; therefore, the user is strongly urged to read the entirety of this section on the use of discrete kernels to represent groundwater flow in LAWS.

Discrete Kernel Method

The theory and application of discrete kernels, also referred to as "Linear Response Functions" was developed by several researchers over the past several decades including: Maddock (1972), Maddock (1974a), Morel-Seytoux and Daly (1975), and Maddock and Lacher (1991). Some applications of discrete kernels found in the literature include: Gupta et al. (1996), Hubbel et al. (1997), Frederick et al. (1998), and Cosgrove and Johnson (2005). A good general description of discrete kernels and associated assumptions is provided in Cosgrove and Johnson (2005). The approach that was developed for this work is discussed below.

Definition and Assumptions

A discrete kernel is an expression of the expected change in head at a given location due to a stress imposed at another location within the groundwater system. It is a way to directly link a localized stress, such as groundwater pumping/recharge or a change in stream flow, to each of the modeled cells within its area of influence. It is a convenient and efficient way to predict changes in head without having to explicitly solve groundwater flow equations numerically during a LAWS simulation. A discrete kernel may be defined as the ratio of the change in head at a groundwater or stream node associated with a particular stress to the stress that caused the change in head or stage.

$$DK = \frac{Head_{Orig} - Head_{Alt}}{Stress}$$

where:

DK - Discrete kernel (ft/TAF);
$Head_{Orig}$ - Groundwater or stream head without additional stress (ft);
$Head_{Alt}$ - Groundwater or stream head with additional stress (ft);
Stress - Volume of water added to groundwater or stream node (TAF).

The intent of the discrete kernel methodology is to translate information contained in a groundwater model into a database of coefficients that can be accessed and used by a water resources systems model like LAWS to estimate changes in groundwater and stream heads given a set of initial conditions and system stresses (i.e. net groundwater pumping/recharge, boundary inflows, and changes in stream flow). Because discrete kernels are generated using a calibrated groundwater model, they carry with them all of the groundwater system characterization inherent in the groundwater model.

An important assumption associated with the use of discrete kernels is that the equations used to calculate groundwater flow and changes in groundwater head are linear. This characteristic has been observed for many confined aquifers. Its validity is important for using discrete kernels, which are in effect are constant values used to calculate changes in groundwater elevation or river stage per unit of stress. Where linearity holds it means that a single coefficient may be used to characterize the hydraulic head response at a given location due to a stress applied at a remote location, where that stress may vary by several orders of magnitude throughout the course of a simulation. This implies, for example, that a doubling of a stress will result in a linear doubling the response at another location.

Another implication of the linearity assumption is that groundwater and stream responses to stresses are reversible. That is, when a unit of groundwater pumping results in some measurable decrease in groundwater head, a similar unit of water that enters the groundwater system as recharge will result in a rise in the groundwater level of the same magnitude.

The final implication of the linearity assumption is that the property of superposition applies. That is, the hydraulic head change at a given location can be calculated as the sum of the responses due to all previous stresses in the groundwater system. An example of this assumption (valid for linear systems) is changes hydraulic head in an observation well that is close to a pumping well and a river. To calculate head changes at the observation well, the changes caused by the pumping well and the stream flow changes can be added to obtain the net change in head at the observation well.

While the assumption of linearity is often reasonable for many groundwater systems, there are instances worthy of mention where non-linearities may be introduced. One source of non-linearity is flow in unconfined aquifers. These aquifers are theoretically non-linear with respect to head, however, it has been shown that if the change in the water table elevation is small in comparison to the saturated thickness of the aquifer, the groundwater-stream system behaves in a linear fashion (Maddock, 1974b).

Another potential source of non-linearity is when the water table elevation rises or falls below the top or bottom elevations of groundwater model layers. When water table in a MODFLOW cell falls below the top elevation of a layer, MODFLOW switches the node from a confined to an unconfined state. This change results in the use of different storage term in the model (ie the storage coefficient in the confined case and specific yield in the unconfined case). These storage terms are often orders of magnitude different and will result in very different groundwater responses to system stresses. Another problem occurs when the groundwater elevation falls below the elevation of the bottom of a layer, MODFLOW considers such a cell as "dry" and flow is no longer calculated in this cell until it meets user defined criteria that allow it to "rewet." For both cases, it is important that the user of the discrete kernel approach in LAWS be aware of these limitations and attempt to design a groundwater model that minimizes the likelihood of these events occurring.

The interaction between aquifers and streams is also a potential source of non-linearity in MODFLOW. Discrete kernels generated for a connected stream, that is when groundwater elevation is greater than the stream bottom elevation, will be different than kernels generated while the stream is "disconnected" (ie the reverse condition). For this reason, it is important that the user determine which state is more likely to occur and generate discrete kernels accordingly. It is also incumbent on the user to decide when the degree of violation of the linearity assumption makes the application of discrete kernels miss leading.

Artificial Steady State

It is common within large groundwater systems for changes in hydraulic head to occur some time after a stress has been applied, because the responses to a given stress generally propagate slowly through the groundwater domain. Furthermore, once these responses have reached their maximum expression, the groundwater system often requires a recovery period during which groundwater heads slowly return to their initial state (assuming no additional stresses have been applied). Consequently, stresses may influence groundwater heads and stream seepage rates for a significant periods of time after a stress has been applied.

However, It is possible to simulate this phenomenon by developing discrete kernels that express the magnitude of a response at any future time after an applied stress. This approach is analogous to using a unit hydrograph to describe stream flows for periods following a precipitation event. Implementing the approach requires that the model consider time-lagged effects of stresses and reference simulated results from several previous time-steps to determine the current status of groundwater and stream-aquifer interactions. Since stream flows and pumping/recharge rates change continually from time-step to time-step, it is imperative that simulated results from previous time-steps be properly linked to the appropriate time-lagged effect. This method creates a large computational burden. Fortunately, there is an alternative approach for implementing discrete kernels that requires the groundwater stresses from only one time-step to predict changes in groundwater and stream heads through time. This method uses the concept of the "artificial steady state" to define a baseline by which the current stresses can be assessed. The artificial steady state is an assessment of the magnitude of the stresses necessary to sustain groundwater and stream heads at their current levels. (Stated in another way, it is the amount of water that needs to be added or removed from a cell in order to keep the hydraulic head in the cell constant.) The difference between the simulated stresses and the baseline stresses are the stresses that are applied to calculate changes in groundwater and stream heads.

To illustrate the approach, imagine that steady-state groundwater pumping in an aquifer with an initially flat groundwater surface results in the drawdown pattern shown in Figure 5. In this hypothetical example, we assume for simplicity that the system is initially in equilibrium, that the simulated pumping rate is 1000 cfs per time-step, that the areal recharge rate is 0 cfs, and that the discrete kernel for a change in groundwater head due to net pumping/recharge is 0.0063 ft/cfs. When pumping begins in the first month of the simulation the baseline stress is 0 cfs, because the system is initially at equilibrium. Drawdown for the first month is then calculated by multiplying the discrete kernel times the full 1000 cfs pumping stress. This stress results in a drawdown of 6.3 ft (i.e. 0.0063 ft/cfs * {1000 cfs – 0 cfs}).

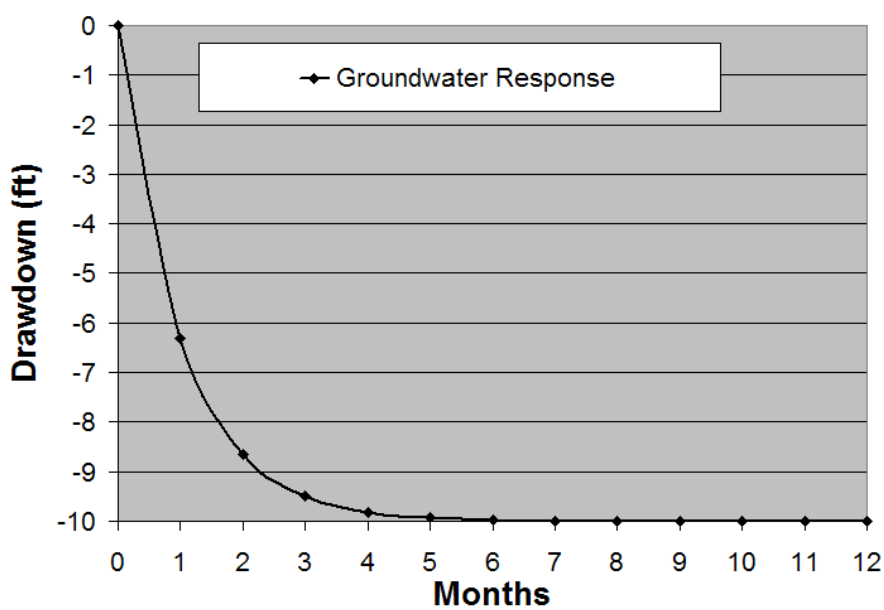


FIGURE 5 - TYPICAL DRAWDOWN UNDER STEADY STATE GROUNDWATER PUMPING

At the beginning of a second time-step the system is no longer in equilibrium, so we must calculate an artificial steady state condition for maintaining groundwater head at 6.3 ft below the initial elevation. This amount of pumping turns out to be of 630 cfs. Now, to calculate the change in groundwater head for the second time-step, we multiply the difference between the 1000 cfs steady pumping rate and the 630 cfs baseline stress times the discrete kernel. This results in an additional drawdown of 2.33 ft (i.e. 0.0063 ft/cfs * {1000 cfs – 630 cfs}) which brings the groundwater head down to 8.63 ft (i.e. 6.3 ft + 2.33 ft) below the initial elevation. Notice that the hydraulic effect of the dynamically expanding cone of depression has been captured even though we're are using a single constant discrete kernel.

To continue the example, at the beginning of the third time-step, we calculate a baseline stress for maintaining the groundwater head at 8.63 ft below the initial elevation. This turns out to be 863 cfs. So, to calculate the change in groundwater head for the third time-step, we multiply the difference between the 1000 cfs steady pumping rate and the 863 cfs baseline stress times the discrete kernel. This results in an additional drawdown of 0.86 ft (i.e. 0.0063 ft/cfs * {1000 cfs – 863 cfs}) and brings the groundwater head down to 9.49 ft (i.e. 8.63 ft + 0.86 ft) below the initial elevation.

This procedure can be repeated until the groundwater head approaches 10 ft below the initial elevation. At that point, the baseline stress for maintaining the groundwater head at that level approaches 1000 cfs. This results in little further drawdown, because the baseline stress is almost equal to the steady pumping rate. When the pumping stress is shut off, the change in head will be described as 0.0063 ft/cfs*(0 cfs – 10000 cfs) or -6.3 feet (negative is a water table recovery) and the system will begin to respond back towards its initial equilibrium flat aquifer condition.

The example above illustrates how the concept of the artificial steady state can be used to propagate groundwater responses to stresses through time. This routine is very important in the context of this current work, because it significantly reduces the computational requirements for calculating groundwater and stream-aquifer responses using discrete kernels, because the time lag effects of a particular stress do not need to be stored in a database and managed during a simulation.

Discrete Kernel Implementation in LAWS

To develop a LAWS model that employs the discrete kernel methodology the user must perform the following series of steps to prepare the necessary input files that LAWS needs.

MODFLOW Model Requirements

The user is required to have functioning MODFLOW model of the study area. The the LAWS model supports the following MODFLOW packages:

1. BCF6 - block centered flow
2. BAS6 - basic
3. DIS - discretization
4. SFR - streamflow-routing 1 (SFR1)
5. GHB - general head boundary
6. DRN - drain boundary
7. WEL - well boundary

The following are the requirements that must be met in order to have the model run correctly:

1. The user must use the BCF6 package and not the LPF package.
2. The MODFLOW model must only have contiguous layers – no confining beds.
3. The user must specify conductivity, not transmissivity in the BCF6 input file.
4. The conductivity is isotropic.
5. The user must specify leakance (VCONT).
6. LAYCON (right digit of Ltype) will equal 1 or 3 (variable transmissivity, head dependent).
7. The left digit of Ltype will be equal to 0 which specifies the use of the harmonic mean in calculating interblock transmissivity.
8. The stream network cannot have a single stream splitting into two tributaries. For instance, there cannot be an explicitly modeled canal diverting water from a stream. Diversions must only occur through linkages to delivery managers.

Specification of input for the streamflow-routing package also has some important requirements:

9. Each stream segment can have only one reach.
10. The user must specify the stream head v. flow v. width relationship using the rating table, ICALC = 4.
11. The stream(s) must interact with the aquifer only through layer 1.

In constructing the MODFLOW model the user should create a Name file (*.nam) that lists all the package input files and all input files referenced in the package input files as DATA files. The files listed in the name file should be referenced only by their name with no path. The OPEN/CLOSE command can not be used in the input files, only the EXTERNAL command can be used to reference other data files. The reason for this is that LAWS will read the name file and copy all listed files into the LAWS directory. If any necessary files are not listed in the name file the model will not run correctly. In the Name file all unit numbers should be less than 999. When the MODFLOW files are copied they will be placed in subdirectory "/modflow/FlowNet" under the project directory where FlowNet is the name of the flow network that the MODFLOW model is associated with.

Stream Network Consistency

The stream networks defined in the MODFLOW and LAWS models must be completely consistent. It was assumed that users have a GIS file containing the stream network used in the MODFLOW model and that this file would be used as the basis for the construction of the stream network in LAWS. This could be most easily be done using the Stream Network Import functionality provided in LAWS. The stream networks must be consistent because LAWS will read the MODFLOW files and compare them to the LAWS stream network and construct a lookup table that relates LAWS junction nodes to MODFLOW stream nodes. LAWS will place this file (NodeMap.txt) in the "modflow" directory

Pumping Fraction File

The LAWS user is required to provide a pumping fraction file. The purpose of this file is to provide the vertical pumping distribution for each row and column location in the MODFLOW model. As such, this file should contain a series of NLAY arrays (NCOL x NROW) that contain the proportion of the pumping that will occur in each layer at each column, row location. Ideally, these proportions will sum to 1.0 for each column, row location, however, LAWS will normalize them if necessary. If all values for a given column, row location in the file are zero it is assumed that pumping occurs in the top layer.

Discrete Kernel File

The generation of discrete kernels is done using a modified version of MODFLOW-2005. The executable is included in the LAWS installation directory and is called DK_Code.exe. In order to properly run this code, a MODFLOW model is needed. For the model to be used to generate discrete kernels, the following requirements must be met:

1. The model must use a time unit of days. The length units, either feet or meters, must match the units used in LAWS.
2. The model is setup to run for one stress period only. The stress period length must be one day.
3. The initial heads are set in such a manner that the discrete kernels generated are what the user needs. For instance, aquifer heads in cells containing stream nodes are set so that the stream is disconnected or connected depending on the requirements of the user.
4. The model must be setup so that there is stream flow in every stream segment during the stress period. The reason for this is that the discrete kernels are calculated by adding additional flow to each segment.

5. It is assumed that the MODFLOW model could have any combination of the following boundary conditions:
    a. Streams – using the SFR1 package.
    b. General head boundaries – using the GHB package.
    c. Well boundaries – using the WEL package.
    d. Drain boundaries - using the DRN package.
    e. Constant head boundaries can be represented using the initial head and the IBOUND < 0.
6. Discrete kernels will be generated using the WEL and SFR1 packages. The program does not currently support the RIV package or any reservoir or lake packages.
7. The name file must have an SFR1 and WEL packages listed. It is assumed that the model of interest will have streams in it and therefore it is a requirement that the SFR1 package is listed in the name file. It is not required that wells be in the model, however, it is required that the WEL package be listed in the name file and that if no wells are in the model that information similar to the following be entered into the WEL package input file:

```
# Well file
          1     0
          0     0
```

8. The code creates stream stresses by adding water to each stream **segment** through the FLOW variable. It is assumed that each segment has only one reach.

To create the discrete kernel file, run the utility DK_Code.exe. This utility should be copied into the directory that contains the MODFLOW input files since it expects all files to be located in the same directory as it is located. The utility generates discrete kernels by first running the model with only the stresses that are specified in the input files provided by the user. Second, it runs the model with one additional stress (pumping or increased streamflow) and compares the resulting heads with those from the first run. The discrete kernels are calculated as the ratio of the change in head over the magnitude of the stress.

The utility requires the presence of an input file called "DKGen_Input.txt". This file uses a free format read and contains:

NameFileName - the name of the MODFLOW model's name file.

Min_DK - this value determines how many of the calculated discrete kernels to keep in the output file. All discrete kernels less than Min_DK are discarded and not written to the output file. There is a tradeoff associated with the magnitude of this value. If a small value is used for Min_DK then more discrete kernels will be written to the output file. This will result in a more accurate simulation of the groundwater system. However, if more discrete kernels are saved then the groundwater simulation will take longer to execute. Experience has shown that a value around 1e-6 will yield an accurate simulation in most cases. Users are urged to experiment with smaller or larger values to see if potential gains in simulation run time or model accuracy can be made.

PumpDepth - this value determines the magnitude of the pumping stress that is applied to the groundwater system within each cell. A value of 0.25 ft, 0.075 m, or 7.5 cm, depending on MODFLOW length units, yields acceptable discrete kernels.

StrmStressFrac - this value is used to calculate the magnitude of the stream flow stress using the following:

Stress = StreamFlow (StrmStressFrac - 1)

A value of 1.1 often yields acceptable results.

The MODFLOW 2005 code was modified by creating a program named "DK_Code" which calls MODFLOW 2005 as a subroutine. The gwf2bas7.f, gwf2gag7.f, gwf2sfr7, gwf2wel7.f, mf2005.f, and utl7.f files were altered in order to have MODFLOW 2005 interact correctly with the code presented in DK_Code.f90. At every location that an alteration was made to the original code, 2 comment lines were added (one before and one after the alteration) that contains the string "CYoung". This was done so that users can quickly locate all changes to the original MODFLOW 2005 code.

Initial Conditions

An initial conditions file must be provided that specifies the initial stream water surface elevations. The file must contain one comment line and then an entry for each stream node in the MODFLOW model:

"Initial Stream Heads"
InitialStreamhead(segment 1)
InitialStreamhead(segment 2)
InitialStreamhead(segment 3)

•

•

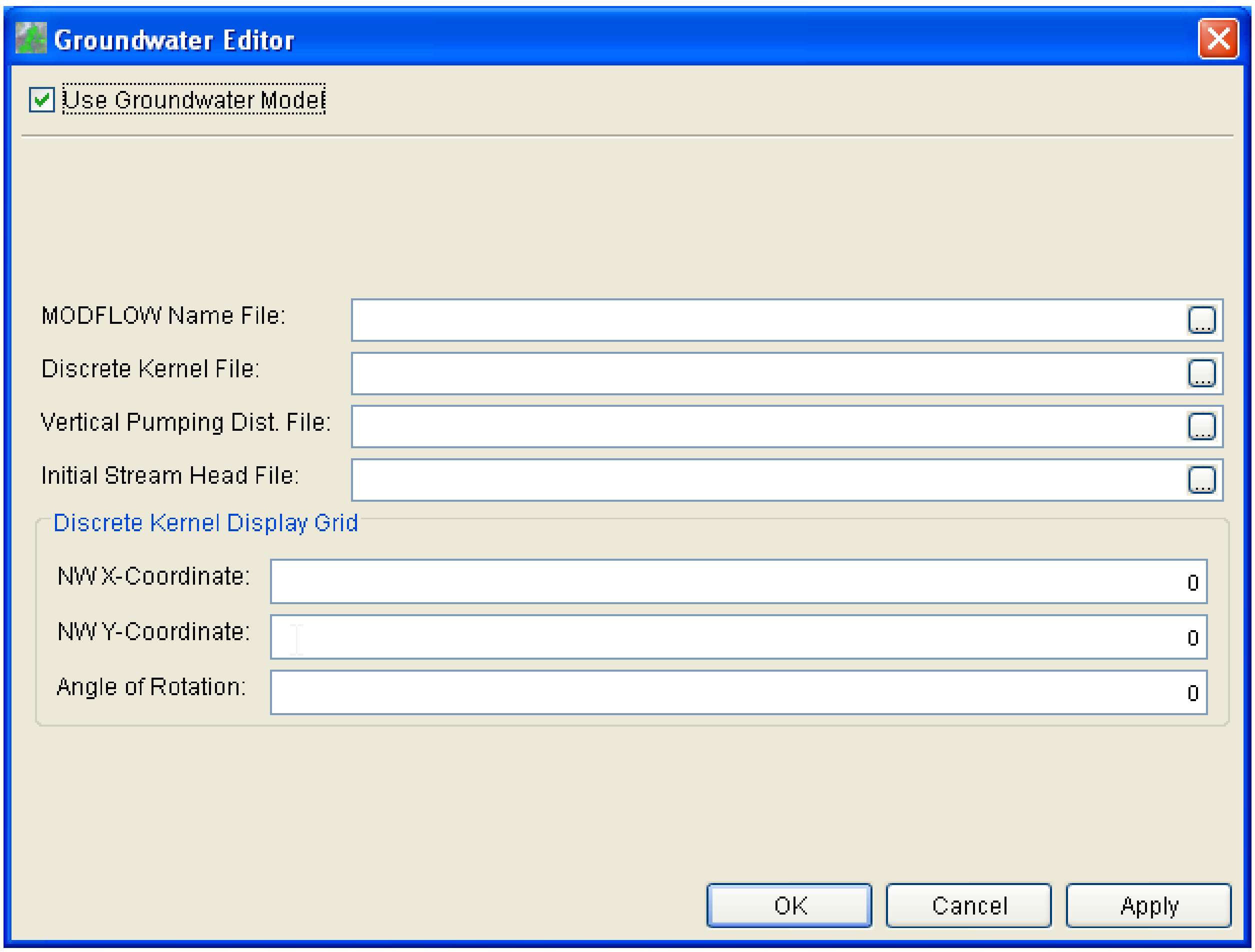
•

InitialStreamhead(segment NSS)

Running the Groundwater Model

Once the appropriate input files have been created (as described above), a discrete kernel representation of the MODLFOW model can be joined to an existing LAWS model. This is done by associating the set of MODFLOW input files with a particular flow network module. Groundwater models are associated with Flow Network Modules because the groundwater model must have the same streams as defined in the flow network.

To initialize a discrete kernel model, right click on the flow network's name in the project tree and select "Edit." Next, select "Groundwater." The following dialog will appear:



To activate the discrete kernel groundwater model place a "check" in the "Use Groundwater Model" box. The following inputs are required:

MODFLOW Name File - Enter the path and name of the MODFLOW name file. LAWS will read this file to determine which files need to be copied from the MODFLOW model directory into the LAWS project directory. The files will be placed in /*Project Directory Name*/modflow/*Flow Network Name*/.

Discrete Kernel File - Enter the path and name of the file containing the discrete kernels. This file should have been generated by DK_Code.exe utility that resides in the LAWS installation directory. LAWS will copy this into /*Project Directory Name*/modflow/*Flow Network Name*/.

Vertical Pumping Dist. File - iEnter the path and name of the file containing the vertical pumping distribution. LAWS will copy this into /*Project Directory Name*/modflow/*Flow Network Name*/.

Initial Stream Head File - Enter the path and name of the file that contains the initial stream head values (in elevation, not depth). LAWS will copy this into /*Project Directory Name*/modflow/*Flow Network Name*/.

NW X-Coordinate - Enter the x-coordinate of the northwest corner of the model domain. This value needs to be in the same coordinate system as the LAWS model and the MODFLOW model. This value will be used by LAWS to determine where to start drawing the model grid on the LAWS schematic.

NW Y-Coordinate - Enter the y-coordinate of the northwest corner of the model domain. This value needs to be in the same coordinate system as the LAWS model and the MODFLOW model. This value will be used by LAWS to determine where to start drawing the MODFLOW model grid on the LAWS schematic.

Angel of Rotation - Enter the angle of rotation that will be used in draw the MODFLOW model grid on the LAWS schematic. If the grid has not been rotated (cell boundaries run east-west and north-south) then enter a value of 0.0.

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