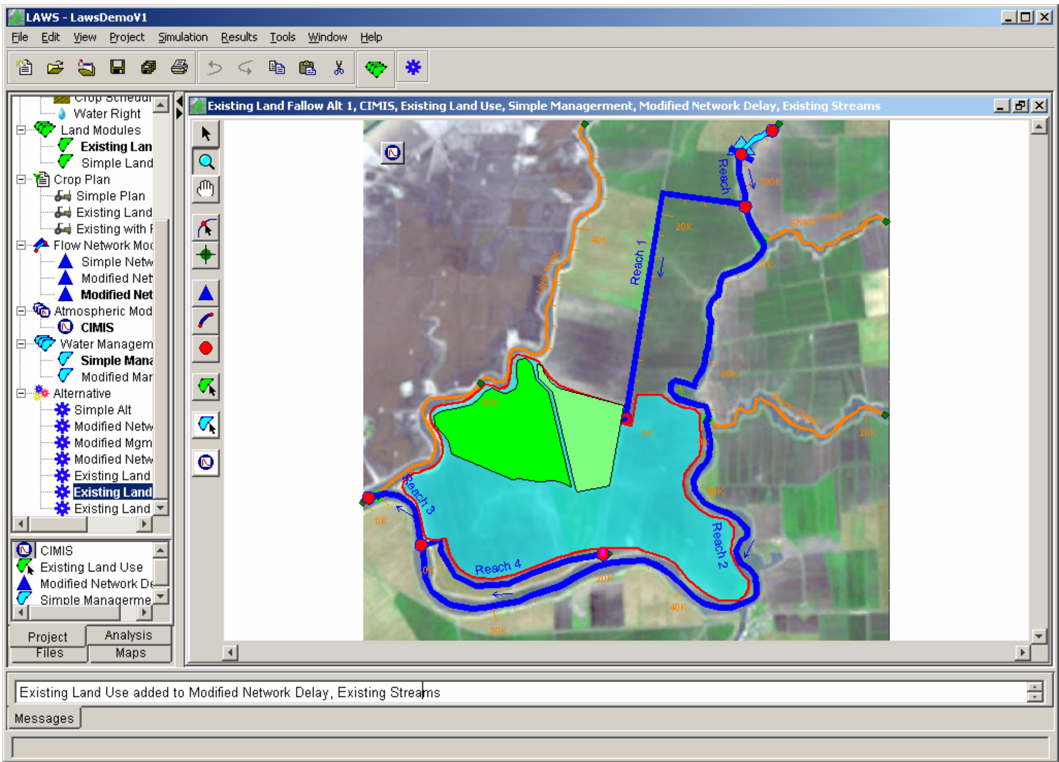
Land Atmosphere Water Simulator



LAWS 1.0

RECLAMATION
Managing Water in the West

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Land Atmosphere Water Simulator (LAWS)
Version 1.0

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1. INTRODUCTION

The Land Atmosphere Water Simulator is an integrated, flexible, and scalable suite of tools for efficiently developing and comparing alternative water management strategies with either historical or forecasted water supply conditions. LAWS provides users with the capability to evaluate alternative water management strategies based on multiple factors including:

- Delivery priorities
- Reservoir and conveyance infrastructure
- Irrigation system characteristics
- Crop types
- Soil moisture management practices
- Groundwater and drain water recycling

LAWS 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 types and growth stage. LAWS makes field scale calculations of important plant, soil and water budget characteristics including:

- Evapotranspiration
- Soil water content
- Depth of ponding and tail water runoff
- Deep percolation
- Conveyance and drain losses
- Return flow to river

LAWS gives users with ability to aggregate these results within larger user definable areas so that water budgets can be readily computed for arbitrary organizational regions.

LAWS has a powerful graphical user interface (GUI) that allows users to readily change water allocation and delivery priorities, land and crop management practices, weather conditions, and infrastructure characteristics to compare the effects of alternative system configurations on reservoir water supplies. LAWS has a native GIS capability built directly into the GUI which provides users with the capability to import imagery, maps, and GIS information developed with commercially available software packages.

2. Module Development

Deliverable 2.1 LAWS Data Modules Design

Land Atmosphere Water Simulator (LAWS) is a water management application that allows users to simulate alternative water management strategies and determine their effects on water supplies. A software prototype has been designed and is being developed to demonstrate the functionality of LAWS using data developed for San Joaquin County, California for the years 1975 to 2000. This time period was selected because the land, water, weather, and vegetation data required for a LAWS simulation was available or could be developed from other sources of information.

LAWS is a physically-based simulation tool that helps water managers determine water delivery demands and characterize the risks of not meeting those demands as the irrigation season develops based on either historical or forecasted water supplies, crops, and weather information. The LAWS application uses a geographic information system (GIS) to develop the geospatial data and a geodatabase with linked temporal information to provide input data to the physical computational modules. LAWS uses simple models of physical processes to provide efficient processing of relevant soil, vegetation, weather, and water supply data. The LAWS design integrates analytical solutions of the physical processes controlling consumptive use with the GIS based simulation tool. Specific information, available at different levels of detail, is utilized to perform simulations including:

- Historical or current classification of agricultural crops based on remote sensing or other crop identification technologies.
- Consumptive use simulation capabilities using the historical or current weather and water supply information.
- User selected crop and water management strategies to meet predicted consumptive use.

Although the primary use of LAWS is to allow water managers to investigate the effects of irrigation and crop management practices on water supplies, this information is, however, very useful for many other purposes including using LAWS results as inputs to other types of water management models such as reservoir and river operations models requiring agricultural water demands, groundwater models requiring estimates of deep percolation from agricultural fields, and economic models requiring estimates of the effects of water shortages on crop yields. For the Mid-Pacific Region of Reclamation, examples of specific applications include providing agricultural water demand inputs to CALSIM, forecasting the risk of exceeding the San Luis Reservoir low-point; management of EWA assets, quantifying the effects of land retirement on CVP water supplies, evaluating the effects of changes in crop and water management practices on drainage water in the San Joaquin Valley, determining the quantity of water transferable from fallowed land; or performing Water 2025 planning studies.

LAWS users perform simulations using its six component modules.

- GIS Database Module
- Vegetation Module
- Atmospheric Module
- Vadose Zone Module
- Water Management Module
- User Interface Module

The geospatial information such as water district boundaries, vegetation types, and soil properties, and the temporal information such as water supply and weather data are stored in the GIS Database Module. The daily crop water demand is computed in the Atmospheric Module based on the reference crop evapotranspiration (ET_0). The Vegetation Module computes crop consumptive use (ET_c) based on the vegetation type and the growth period. The soil water content computed in the Vadose Zone Module triggers irrigation events based on soil parameters spatially averaged at the field scale. The Water Management Module allows the LAWS user to change water conveyance infrastructure, irrigation system type, cropping pattern, and irrigation priorities to evaluate the effects of alternative water management methods on water supplies from multiple sources of water. The User Interface Module allows the LAWS user to setup the GIS database, perform the LAWS simulations, evaluate the results, and prepare graphs, tables and maps for presentation of the LAWS results.

Deliverable 2.2 Vegetation Module

This section describes the remote sensing methods used for crop classification. For the purpose of LAWS simulation the satellite image analysis was performed to classify the agricultural crops. Crop specific water use coefficients are then used in the LAWS simulation. A reasonable estimation of crop classes in the area of simulation is important for reliable LAWS simulation. The major steps of crop classification methodology is shown in Figures 2.2.1, 2.2.2, and 2.2.3.

Ideally, ground truth data should be collected on the field at the time of image acquisition. This method has been used very successfully by the Bureau of Reclamation for the Lower Colorado River Accounting System (LCRAS). However, the problem of historical reconstruction of cropping patterns precludes this approach. For historical crop type reconstruction, ground truth data is typically limited or unavailable. The ground truth data from one or more years must be used to classify imagery from other years. The ground data for this historical crop classification was collected only in the years 1988 and 1996. In these years of California Department of Water Resources (DWR) crop surveys, each field was visited and current crop type recorded at various times during the growing season. These times did not typically correspond with the satellite imagery. These ground survey data were used instead of ground truth by randomly selecting 20% of the DWR survey fields (fig. 2.2.1, step 2). This subsample was later divided into fields for crop classification (fig. 2.2.1, step 7) and fields for accuracy assessment (fig. 2.2.1, step 6).

Our preference would be for annual ground truth data (survey time corresponding with the image acquisition time) randomly surveying 20% of the fields (random 20% of each crop) in the study area. For a reliable signature set development, the ground truth data needs to be collected concurrently with the satellite imagery. The ground truth fields should be selected randomly but it may not be necessary as long as all crop classes are represented. A quality ground truth data set may be obtained by surveying individual growers (randomly selected) who will provide cropping plans for their farms. This information can be used to create a map with their fields and crops. This survey could be then used as a basis for the crop classification in the area of interest.

The crop classification methodology used in LAWS is described in detail in **Appendix A** of this report. It shows the following major steps:

- Data structure
- Ground survey preparation
- Image preparation
- Selecting the signature and accuracy assessment subsets
- Signature development
- Crop classification

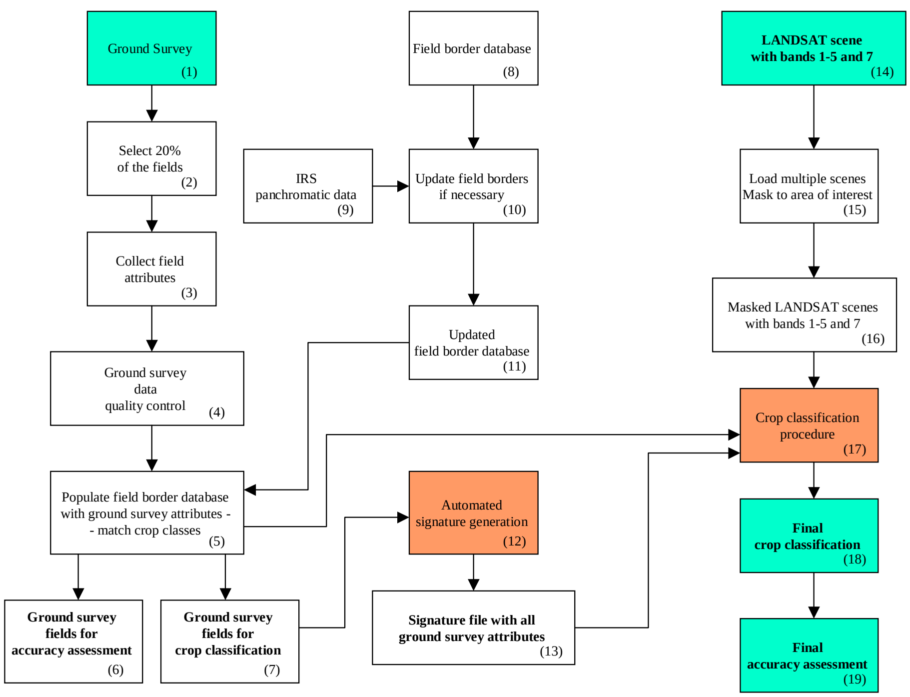
- Accuracy assessment
- Signature set adjustments
- Final accuracy assessment

This detailed description is summarized in Figures 2.2.1-2.2.3. The blue rectangles represent initial and final steps. The brown rectangles indicate steps in which more detailed information is provided in other figures.

2.2.1 Crop Classification Overview

Crop classifications are performed by using ERDAS Imagine image processing application and ArcGIS suite of applications. Tasks are automated using AML scripting language. Detailed description of image and survey data manipulations are in **Appendices A and B**.

Steps 1 – 7 were described in the preceding section. Steps 8 – 11 of Figure 2.2.1 show field border database updates. Changes to the field borders are done only if necessary. Visual inspection of the field borders against the satellite imagery is part of the quality control (fig. 2.2.1, step 4). The inspection showed that the ground truth data field borders were suitable for further analysis and no changes were made.



Crop Figure 2.2.1 Crop Classification Overview

Image pre-processing begins with step 14 on figure 2.2.1. LANDSAT scenes are masked to area of interest, which was the San Joaquin County (fig. 2.2.1, step 15). Before starting with the crop classification (fig. 2.2.1, step 17), spectral signatures need to be developed. Signature generation has been automated (fig. 2.2.1, step 12) and involves several steps.

2.2.2 Automated Signature Generation

Automated signature generation is described in Figure 2.2.2. The procedure uses the field polygons and LANDSAT scene. Ground survey fields are buffered 30 meters inside. This step (fig. 2.2.2, step 2) reduces the size of each field for image analysis and eliminates mixed pixels that include non-crop areas such as field roads or ditches. LANDSAT image is then masked with buffered fields (fig. 2.2.2, step 4). Image Processing Workbench (IPW) is used to develop spectral regions within each field designated for signature development (fig. 2.2.2, step 5). Once these small areas are back in ArcGIS format (fig. 2.2.2, step 8), a signature set is developed. Several criteria have been established for signatures to become part of the representative signature set. First the standard deviation in each spectral band for the pixel reflectance (256 bit) within the signature subset should be less than three. Second the number of pixels in the signature subset should be at least 10. Finally, visual inspection by the analyst assures that no samples with unusual shape or location are included (fig 2.2.2, steps 10-12). Such a refined or representative spectral signature set (fig. 2.2.2, step 13) is used in crop classification.

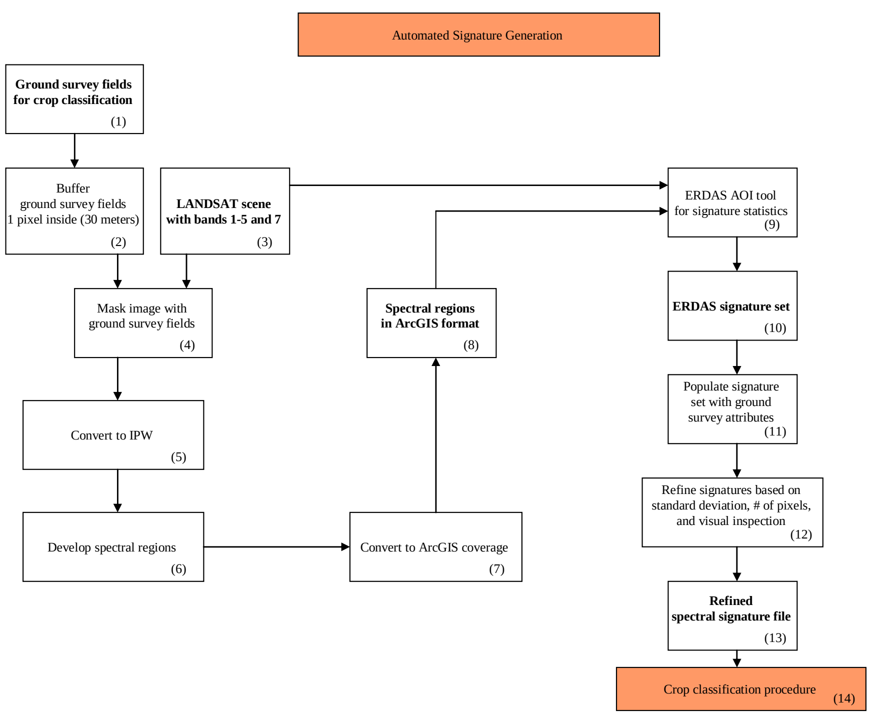


Figure 2.2.2 Automated Signature Generation

2.2.3 Crop Classification Procedure with Ground Truth Data

The crop classification procedure is shown in Figure 2.2.3. An original LANDSAT scene is masked only for the area of interest, which in this study were agricultural fields of San Joaquin County. The scene is completely classified using representative spectral signature set (fig 2.2.3, step 3). This data pair (satellite imagery and ground observation) is used in development of the spectral signature set by supervised classification method. In supervised classification, the analyst has a spectral sample (spectral signature) for each known class. Spectral signatures are then compared to the unknown pixels and a class is assigned to each pixel. The success of the supervised classification depends on the level of spectral definition of each class. In unsupervised classification, analyst creates spectral classes based on the spectral difference in the pixel reflectance. The number of classes is arbitrary.

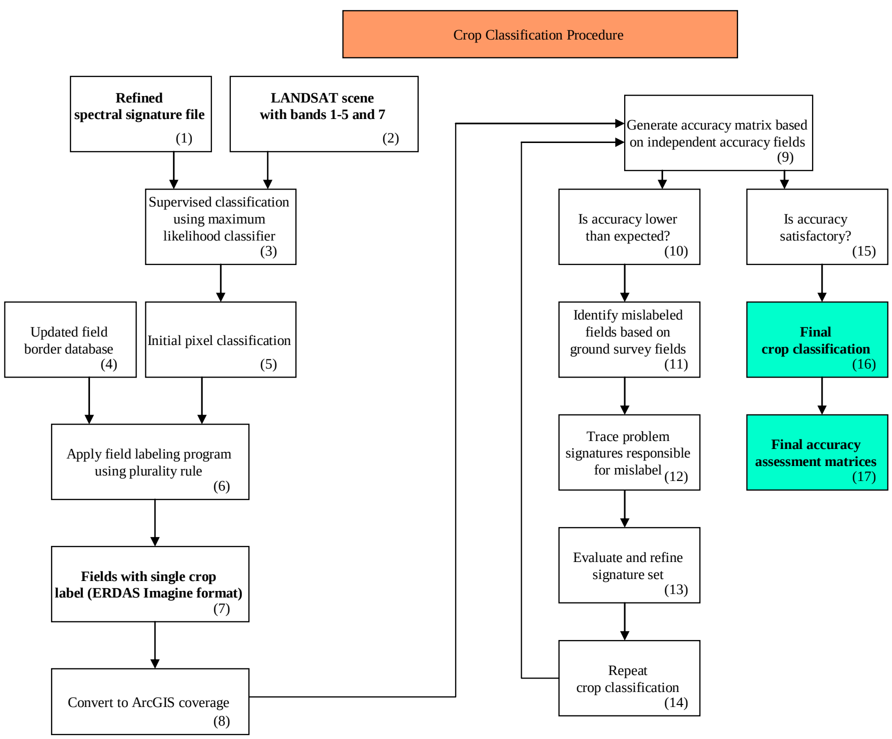


Figure 2.2.3 Crop Classification Procedure

The more the crop classes are spectrally distinguished, the better the crop classification results are likely to be. A field labeling algorithm using plurality rule is employed (fig. 2.2.3, step 6) to establish the crop type. An accuracy assessment subset is used to generate accuracy matrix. Mislabeled fields are identified and responsible signatures eliminated. The method is repeated until satisfactory accuracy is achieved (fig 2.2.3, steps 9-15). Final crop classification is done and accuracy assessed.

It is important to note that final crop classifications are done separately for spring and summer. The purpose of having two images per year is to capture winter-spring crops that are usually senescent or harvested at the time of summer image acquisition. This type of crop may also be missing from the DWR survey.

Appendix B of this report describes in detail the development of the summary crop classification. It also describes the methodology for classifying crops in years without ground truth data and how the remote sensing results may be fine tuned.

Appendix B shows the following major steps:

- Crop classification using representative signature set
- Mapping unclassified areas such as orchards and vineyards
- Adjusting for fallow areas
- Fine tuning the crop classification results using ancillary data
- Final crop classification

2.2.4 Crop Classification with Limited Ground Truth Data

For historical crop type reconstruction, the representative signature from a year with ground truth set is used to classify imagery from other years without ground truth. In general the historical crop classification is done with limited data. The resulting impact of using limited data is the introduction of additional errors into the classification procedure and therefore reduced reliability.

As discussed previously, the 1988 DWR crop survey was used. This dataset has several limitations. The timing of DWR crop survey data did not correspond closely to the timing of the satellite images. Furthermore, the DWR survey was conducted only during the months from April to August, which results in some of winter-spring crops being omitted. Other major data limitations pertain to the availability of the satellite imagery. It is preferable to have satellite imagery from the same date of each year. In reality, however, we used a signature set that was developed from the May 1988 imagery that was used to classify the June 1989 imagery.

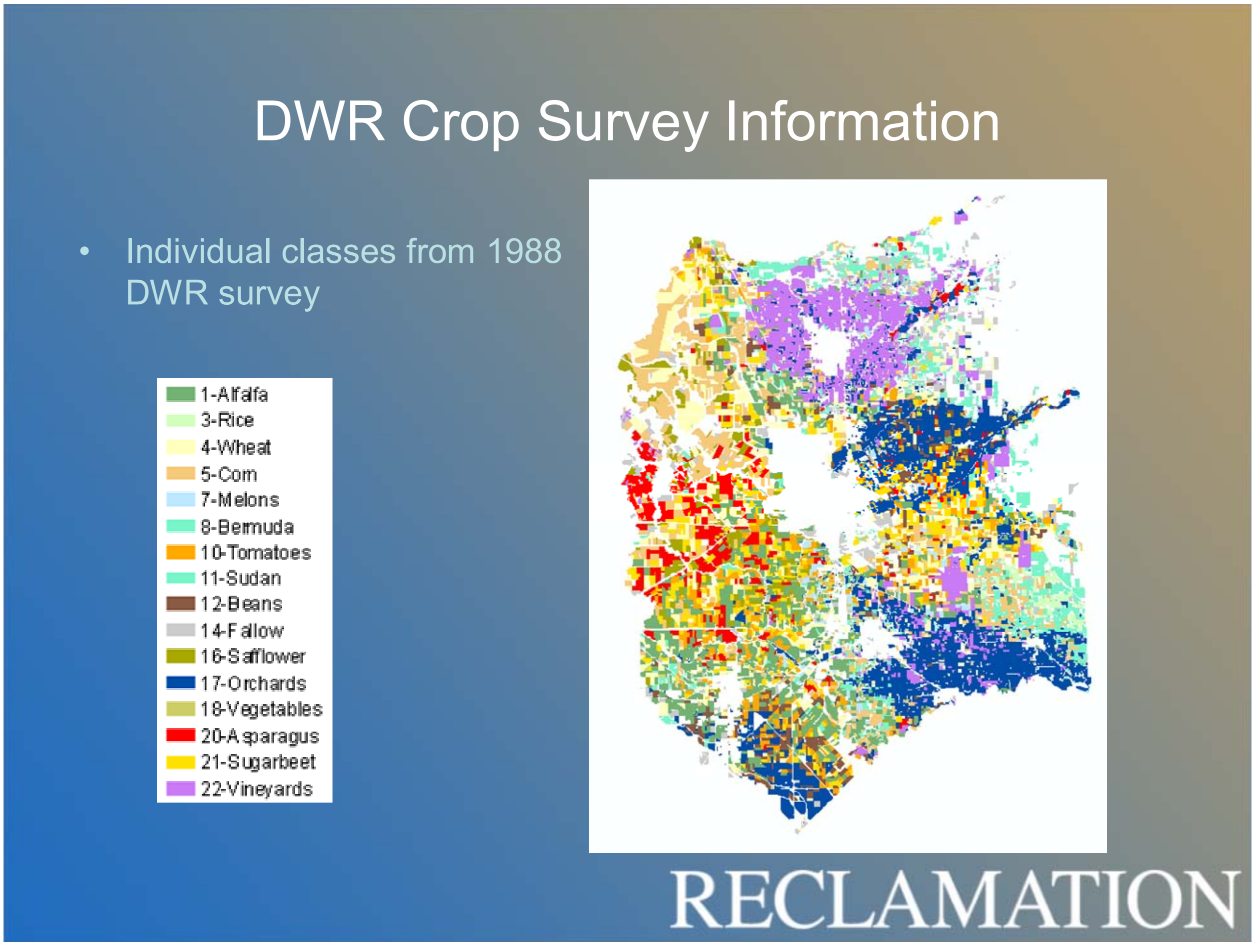


Figure 2.2.4 DWR Crop Class Information

2.2.5 Crop Class Information

Figure 2.2.4 displays the distribution of crop classes in the San Joaquin County from the 1988 DWR crop survey. Individual crop classes are color coded. It may be observed that crops create specific patterns that divide the area of interest into several zones. A different crop classification method needs to be used to distinguish tree crops from other crops and different tree crops among each other. Orchards and vineyards were not classified using the remote sensing methods described above. They were identified in the database using ground survey information. Fields surveyed as orchards or vineyards were considered as having permanent crops for the time period given by the survey year.

2.2.6 Reliability of Classification Methods by Crop Type

To access the accuracy of the classification procedures, 40% of the randomly selected fields, described previously, were analyzed by comparing the classification results with the crop survey acreages. For this assessment accuracy matrices were constructed. Two accuracy matrices were developed, one for summer and one for spring crop classifications (Figure 2.2.5). Rows in each of the matrices represent classified crops while columns represent DWR surveyed crop classes. If the crop classification were one hundred per cent accurate all the acreage would fall on the diagonal. Acreage that falls off the diagonal represents misclassified fields. For example, the second column (crop type 1) represents acreages of fields surveyed as alfalfa and shows how these fields were classified as alfalfa (row 1) and other crops (rows 2 – 24).

Acreage that is off the diagonal and in the rows represents errors of commission, while acreage that is off the diagonal and in columns represents errors of omission. In the example of alfalfa, acreages of other crops classified as alfalfa represent errors of commission. On the other hand, acreages in the alfalfa column represent how different crops were assigned to alfalfa fields. These fields were omitted with respect to alfalfa and they result in errors of omission.

Sum of ACRES	CROP																									
M1SUM	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Grand Total		
1	59228		67	4010	5207		920	18529	72	1034	631	1567	91	4238		3530		658		880	497			101158	0.59	0.63
2		0																						0	#DIV/0!	#DIV/0!
3	121		4684	666	2743		44	310		599	80	404		170		124		73		356	398			10771	0.43	0.45
4				0																				0	#DIV/0!	#DIV/0!
5	1719		61	712	28328		270	285	5	1371	38	220		156		842		32		1252	404			35693	0.79	0.80
6						0																		0	#DIV/0!	#DIV/0!
7	4			19	6		53	14		141		42		48				4		86	76			493	0.11	0.21
8	3854			61	228		308	19042			82	43		117		330		18			58			24141	0.79	0.79
9									0															0	#DIV/0!	#DIV/0!
10	172		4	446	271		418	187	56	13427		525	4	122		690		87		427	3389			20223	0.66	0.67
11	370			41	55		41	78			327					15								926	0.35	0.35
12	451		26	454	1559		438	234	14	1496	57	2808		297		33		139		929	509			9444	0.30	0.33
13													0											0	#DIV/0!	#DIV/0!
14	673			38577	2828		2231	1020	39	4687	249	9495	736	22732		405		1619		2014	7699			95003	0.24	0.48
15															0									0	#DIV/0!	#DIV/0!
16	54			453	8			125		72				12		8389								9114	0.92	0.92
17																	100593							100593	1.00	1.00
18					18		3			54								39						113	0.34	0.34
19																			0					0	#DIV/0!	#DIV/0!
20	343		2	813	3766		186	173	23	3101	12	1000		901		616		98		16932	655			28624	0.59	0.62
21	259	14	50	2825	2734	36	1574	120		4338	150	6088	485	928		744		812		2122	24006			47284	0.51	0.53
22																						62572		62572	1.00	1.00
23																							0	0	#DIV/0!	#DIV/0!
Grand Total	67248	14	4893	49076	47750	36	6484	40117	210	30319	1625	22192	1316	29723	0	15717	100593	3580	0	24998	37691	62572	0	546153		
	0.88	0.00	0.96	0.00	0.59	0.00	0.01	0.47	0.00	0.44	0.20	0.13	0.00	0.76	#DIV/0!	0.53	1.00	0.01	#DIV/0!	0.68	0.64	1.00	#DIV/0!	0.66		
	0.89	0.00	0.96	0.79	0.65	0.00	0.35	0.50	0.19	0.60	0.35	0.55	0.56	0.76	#DIV/0!	0.56	1.00	0.46	#DIV/0!	0.76	0.84	1.00	#DIV/0!	0.67		

Figure 2.2.5 Summer Accuracy Matrix

Sum of ACRES	CROP																									
M1SPG	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Grand Total		
1	58253	14	11	10335	3778		637	36469	121	1295	365	2729	275	17136		1143		398		494	2001			135455	0.43	0.56
2		0																						0	#DIV/0!	#DIV/0!
3			0																					0	#DIV/0!	#DIV/0!
4	4091			29104	10618		1202	2298	50	2266	477	5361	187	2119		2508		657		3312	4431			68680	0.42	0.45
5					0																			0	#DIV/0!	#DIV/0!
6						0																		0	#DIV/0!	#DIV/0!
7							0																	0	#DIV/0!	#DIV/0!
8								0																0	#DIV/0!	#DIV/0!
9									0															0	#DIV/0!	#DIV/0!
10										0														0	#DIV/0!	#DIV/0!
11											0													0	#DIV/0!	#DIV/0!
12												0												0	#DIV/0!	#DIV/0!
13													0											0	#DIV/0!	#DIV/0!
14	3810		4882	5582	27295	36	4646	921	39	26124	762	13425	854	8353		9458		2511		17602	28817			155116	0.05	0.11
15															0									0	#DIV/0!	#DIV/0!
16																0								0	#DIV/0!	#DIV/0!
17																	100593							100593	1.00	1.00
18																		0						0	#DIV/0!	#DIV/0!
19																			0					0	#DIV/0!	#DIV/0!
20	66			34				104						455						69				727	0.10	0.72
21																					0			0	#DIV/0!	#DIV/0!
22																						62572		62572	1.00	1.00
23																							0	0	#DIV/0!	#DIV/0!
Grand Total	66219	14	4893	45055	41691	36	6484	39793	210	29685	1605	21515	1316	28062	0	13109	100593	3567	0	21477	35249	62572	0	523144		
	0.88	0.00	0.00	0.65	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	#DIV/0!	0.00	1.00	0.00	#DIV/0!	0.00	0.00	1.00	#DIV/0!	0.63		
	0.94	0.00	1.00	0.77	0.65	1.00	0.72	0.02	0.19	0.88	0.48	0.62	0.65	0.30	#DIV/0!	0.72	1.00	0.70	#DIV/0!	0.82	0.82	1.00	#DIV/0!	0.53		

Figure 2.2.6 Spring Accuracy Matrix

In the following figures the reliability of crop classification is shown. Figure 2.2.7 compares the overall classification results on a net acreage basis with DWR survey results. For the accuracy assessment purposes, we have used 1988 signature set for 1988 image classification. In this case, difference ranged from -100% to +423%.

Accuracy can also be assessed using the 1988 signature set and the 1996 survey data. The 1988 DWR crop survey was used to develop the 1988 signature set and these signatures were used to predict 1996 crops. Results shown in Figure 2.2.7 indicate a deterioration in accuracy for most of the crops.

A strict spatial comparison of differences indicates less accurate results for most crop types in both the 1988 and 1996 comparisons. These comparisons always result in negative errors because commission errors are eliminated. It is important to note that field borders changed during the eight years between 1988 and 1996 which introduces additional errors.

	1988			1996		
Crop Class	**DWR Survey**	**Crop Class.**	**% Difference**	**DWR Survey**	**Crop Class.**	**% Difference**
1- Alfalfa	67827	94379	39	61273	40482	-34
3 - Rice	4934	4	-100	5991	5785	-3
4 - Wheat	57052	103090	81	75219	97973	30
5 - Corn	60335	15549	-74	73344	18489	-75
7 - Melons	6499	22985	254	8654	958	-89
8 - Bermuda	40555	16119	-60	35100	28779	-18
10 - Tomatoes	30886	35007	13	38861	29134	-25
12 - Beans	22337	20048	-10	26430	16252	-39
14 - Fallow	32484	169926	423	8733	117257	1243
16 - Safflower	18505	14893	-20	20313	4567	-78
17 - Orchards	100593	99484	-1	107376	107376	0
18 - Vegetables	3720	1251	-66	4844	1011	-79
20 - Asparagus	29893	13459	-55	29188	7837	-73
21 - Sugarbeet	38991	30581	-22	6575	14624	122
22 - Vineyards	62572	61573	-2	76893	76893	0

Figure 2.2.7 Overall Comparison of Surveyed and Classified Acreage

Crop Class	1988 DWR Survey	1988 Crop Class.	1988 % Difference	1996 DWR Survey	1996 Crop Class.	1996 % Difference
1 - Alfalfa	67827	59228	-13	61273	19944	-67
3 - Rice	4934	4684	-5	5991	2410	-60
4 - Wheat	57052	29104	-49	75219	18685	-75
5 - Corn	60335	28328	-53	73344	15577	-79
7 - Melons	6499	53	-99	8654	0	-100
8 - Bermuda	40555	19042	-53	35100	4424	-87
10 - Tomatoes	30886	13427	-57	38861	1870	-95
12 - Beans	22337	2808	-87	26430	3250	-88
14 - Fallow	32484	22732	-30	8733	1212	-86
16 - Safflower	18505	8389	-55	20313	1573	-92
17 - Orchards	100593	100593	0	107376	107376	0
18 - Vegetables	3720	39	-99	4844	66	-99
20 - Asparagus	29893	16932	-43	29188	15255	-48
21 - Sugarbeet	38991	24006	-38	6575	813	-88
22 - Vineyards	62572	62572	0	76893	76893	0

Figure 2.2.8 Spatial Comparison of Surveyed and Classified Acreage

2.2.7 Fine-tuning to Develop Summary Crop Classification

Since the crop classification with limited ground truth data yielded relatively low accuracy, a procedure was developed to achieve improved results. Three additional types of information were available for use in the fine-tuning procedure. First as can be seen at Figure 2.2.4, there are several distinct regions of characteristic cropping patterns in San Joaquin County. These regions were used to establish vegetation zones. A second source of information came from analyzing the LANDSAT image to determine the presence of active vegetation. The results of this analysis can be expressed in terms of the NDVI, which is described in more detail below. A third source of information is the annual report crop developed by the County Agricultural Commissioner's Office.

The fine-tuning procedure involved assigning zones based on differences in management practices. Each zone includes one or more crop classes that have similar planting characteristics. Each field was classified as belonging to one of the six management zones. Numbers in parentheses represent individual crop type classes (see Appendix B).

Zone 1 = pasture (1, 8, 11)
Zone 2 = double crops (4, 5, 6, 7, 10, 12, 13, 16, 18, 21)
Zone 3 = rice (3)
Zone 4 = orchards, vineyards (9, 17, 22)
Zone 5 = asparagus (20)
Zone 6 = fallow (14)

The crop classification was done separately within each management zone. The crop planting zone was incorporated in the classification procedure to determine the correct crop for spring and summer. The crop zone information was assigned based on the DWR crop survey and every field was in one of the six zones. In other years without ground truth data, the same crop zone was used for the field in decision making for final spring and summer crop classification.

The Normalized Difference Vegetation Index (NDVI) was also calculated for each field. Low NDVI indicates fallow field while fields with high NDVI are vegetated. A threshold was set to distinguish between fields with and without vegetation (fallow, most likely vegetated, and vegetated) – maturity levels (1, 2, 3). The Agricultural Commissioner's crop report was also used in the fine-tuning although the data has no spatial component within the county boundary. Acreage is reported as one value for each crop for the entire county. This data had several limitations including the fact that non-productive fields and green harvest fields are not reported. Finally, Agricultural Commissioner's Report includes areas, which are outside the DWR crop survey area.

The final crop classification was determined based on four attributes – spring classification, summer classification, zone item based on the 1988 survey, and maturity level based on the summer imagery as shown in Figure 2.2.9. A frequency file was developed showing total acreages for all combinations of these four attributes. Factor combinations were sorted from those having the highest acreage in fields to the lowest acreage. Several rules were defined:

1. The largest acreages were assigned first for combinations where the zone number matched the spring or summer classification.
2. Summer crop classification is more important than spring.
3. Fields with maturity level 3 (vegetated) are more likely to be correctly classified that those with lower level maturity. The following figure shows the

methodology.

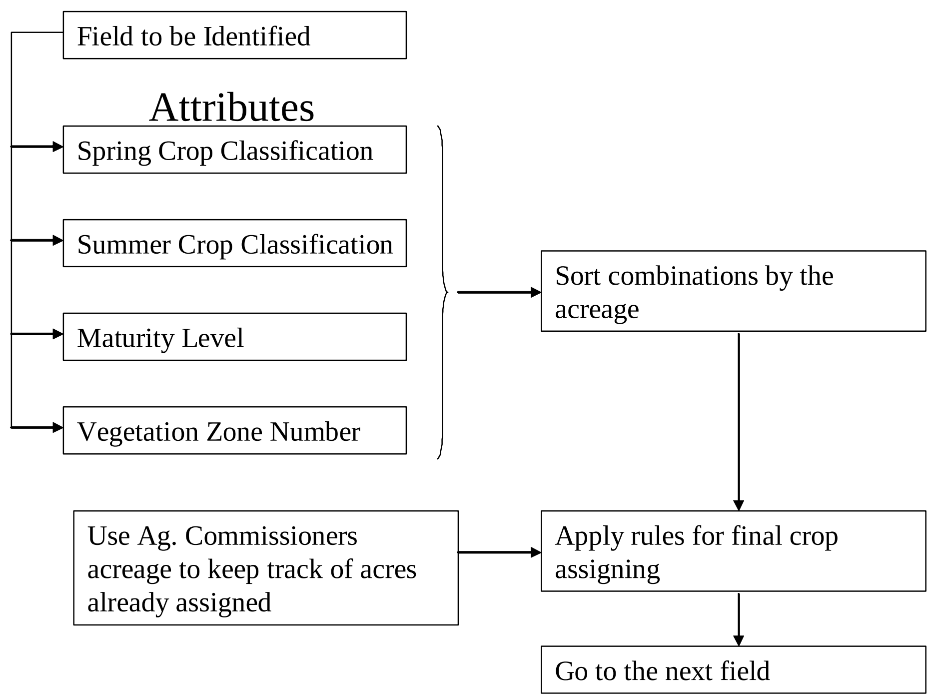


Figure 2.2.9 Fine-tuning Methodology Flowchart

The total acreages for crop classes given by the Agricultural Commissioner's Report were set as targets for assigning the final type of crop. A Visual Basic code was developed to keep track of the distributed acreages and automatically assigned the final crop class based on the defined rules. Figure 2.2.10 shows the overall crop classification results after the fine-tuning method has been applied. Fine-tuning contributed to a great improvement of the classification results. The accuracy generally ranges between –9 and +16%. The same figure also shows how the 1996 data were classified using spectral signatures developed from 1988 dataset. Some of the minor crop classes (such as beans or mixed vegetables) have still low accuracy but major crops (such as alfalfa or corn) compare well on the overall basis. The overall ranges of differences were –29 to +42%.

The fine-tuning method has also improved the spatial accuracy as well as shown in figure 2.2.11. However, the spatial accuracy still remains relatively low.

Crop Class	1988 DWR Survey	1988 Crop Class.	1988 % Difference	1996 DWR Survey	1996 Crop Class.	1996 % Difference
1 - Alfalfa	67827	68845	2	61273	56579	-8
3 - Rice	4934	4934	0	5991	6057	1
4 - Wheat	57052	53848	-6	75219	72672	-3
5 - Corn	60335	61272	2	73344	66958	-9
7 - Melons	6499	7543	16	8654	10838	25
8 - Bermuda	40555	40247	-1	35100	37260	6
10 - Tomatoes	30886	31934	3	38861	33213	-15
12 - Beans	22337	23365	5	26430	18888	-29
14 - Fallow	32484	33523	3	8733	10453	20
16 - Safflower	18505	16829	-9	20313	22420	10
17 - Orchards	100593	100593	0	107376	107376	0
18 - Vegetables	3720	3716	0	4844	6893	42
20 - Asparagus	29893	29988	0	29188	31818	9
21 - Sugarbeet	38991	40004	3	6575	8580	30
22 - Vineyards	62572	62572	0	76893	76893	0

Figure 2.2.10 Overall Comparison of Surveyed and Classified Acreage after Fine-tuning

Crop Class	1988 DWR Survey	1988 Crop Class.	1988 % Difference	1996 DWR Survey	1996 Crop Class.	1996 % Difference
1 - Alfalfa	67827	52075	-23	61273	32596	-47
3 - Rice	4934	4766	-3	5991	5813	-3
4 - Wheat	57052	28635	-50	75219	40907	-46
5 - Corn	60335	38665	-36	73344	27227	-63
7 - Melons	6499	53	-99	8654	9	-100
8 - Bermuda	40555	22475	-45	35100	9788	-72
10 - Tomatoes	30886	14532	-53	38861	4748	-88
12 - Beans	22337	6291	-72	26430	4271	-84
14 - Fallow	32484	23970	-26	8733	5667	-35
16 - Safflower	18505	9231	-50	20313	4466	-78
17 - Orchards	100593	100593	0	107376	107376	0
18 - Vegetables	3720	203	-95	4844	162	-97
20 - Asparagus	29893	28651	-4	29188	27926	-4
21 - Sugarbeet	38991	21924	-44	6575	1165	-82
22 - Vineyards	62572	62572	0	76893	76893	0

Figure 2.2.11 Spatial Comparison of Surveyed and Classified Acreage after Fine-tuning

Deliverable 2.3 Atmospheric Module

2.3.1 CIMIS Data

2.3.1.1 CIMIS Overview

The California Irrigation Management Information System (CIMIS) is a program of the Office of Water Use Efficiency (OWUE), California Department of Water Resources (DWR) that manages a network of over 120 automated weather stations in the state of California. CIMIS was developed in 1982 by DWR and the University of California at Davis to assist irrigators in managing their water resources efficiently.

Evapotranspiration (ET) is a loss of water to the atmosphere by the combined processes of evaporation from soil and plant surfaces and transpiration from plants. Reference evapotranspiration is the loss of water from standardized grass or alfalfa surfaces over which the stations are sitting.

Irrigators use crop factors, known as crop coefficients (k_c), to convert ETo/ETr into an actual evapotranspiration (ETc) for a specific crop class (Eto for grass reference and Etr for alfalfa).

Since most of the CIMIS stations are sitting on standardized grass surfaces, reference evapotranspiration is commonly referred to as "ETo" in this web site. However, it is worth mentioning that a few CIMIS stations are sited on standardized alfalfa surfaces and therefore evapotranspiration from such surfaces is referred to as Etr.

2.3.1.2 Data Collection and Transmission

CIMIS weather stations collect weather data on a minute-by-minute basis, calculates hourly and daily values and stores them in data loggers. A computer at the DWR headquarters in Sacramento calls every station starting at midnight Pacific Standard Time (PST) and retrieves each day's data.

The overview of the CIMIS data management is shown in Figure 2.3.1.

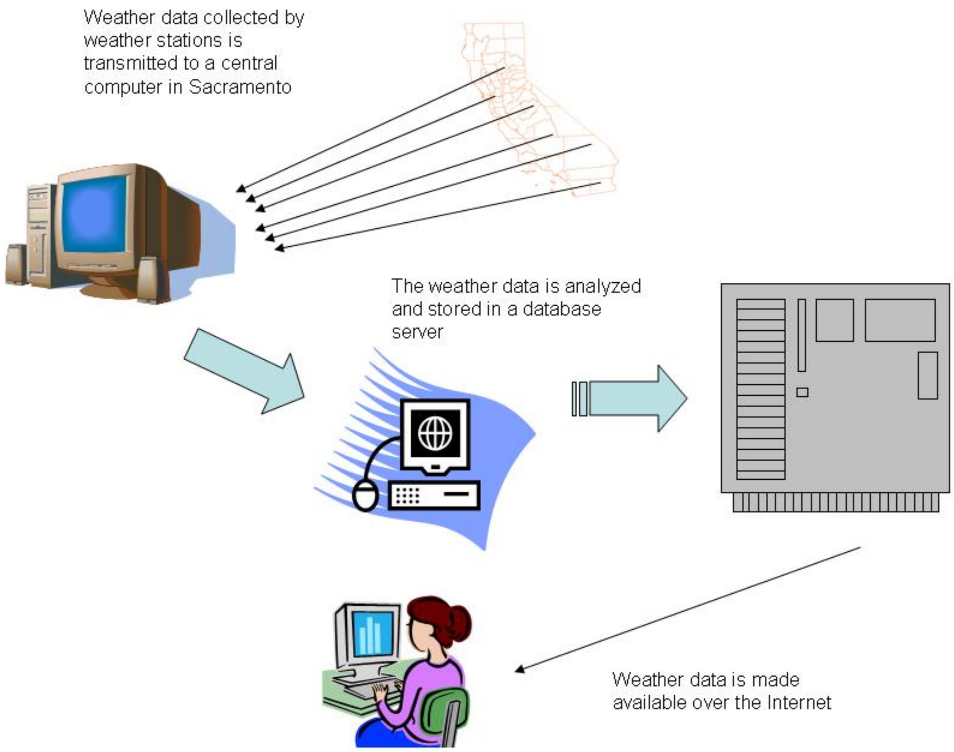


Figure 2.3.1 CIMIS data management

2.3.1.3 Data Processing

Once the data is transmitted, the central computer analyzes it for quality, calculates reference evapotranspiration and other intermediate parameters, flags the data (if necessary), and stores them in the CIMIS database.

2.3.1.4 Data Retrieval

Estimated parameters (such as ETo, net radiation (Rn), dew point temperature, etc.) and measured parameters (such as solar radiation (Rs), air temperature (T), relative humidity (RH), wind speed (u), etc.) are stored in the CIMIS database for unlimited free access by registered CIMIS data users. In addition to the web, CIMIS developed an ftp site for those interested in automated access of the data. However, the ftp site only provides daily data for the previous 7 days and monthly data for the previous 12 months. Also available at the ftp site is one year's worth of rolling daily ETo data. This means that the beginning and ending dates of this data advance forward by one-day everyday.

2.3.1.5 Selecting Representative Stations

The CIMIS weather stations are distributed throughout the State of California. It is very important that the selected station represents the same microclimate as the area of interest. Some resources available to assist users in this regard include the CIMIS web site, local water districts, farm advisors, consultants, and CIMIS staff.

2.3.2 CIMIS Data Incorporation into LAWS Database

LAWS requires daily ET_0 and daily precipitation values that are representative for the individual fields. Due to the limited number of weather stations, an approximation technique is used to develop daily ET_0 and daily precipitation values for each field.

The CIMIS data is downloaded from the website in form of a comma delimited text file. The representative station for the pilot study area (San Joaquin County) was selected. In case of missing data, those are filled in by data from neighboring stations within the same study area. ET_0 values are imported into the LAWS database according to the schema in Figure 2.1.1.

Data in the comma delimited text file (.csv) is imported into LAWS. The user converts .csv files to DSS file format using the DSS view tool. LAWS stores CIMIS data in the DSS file format. For the real time simulations, the CIMIS ftp site may be utilized for automatic weather data downloading.

Deliverable 2.4 Vadose Zone Module

2.4.1 Soil Properties Data Sets

State Soil Survey Geographic (SSURGO) database was used to develop soil properties for LAWS. LAWS uses soil properties that are relevant to irrigation management, which include soil water holding capacity and hydraulic conductivity. The SSURGO database includes field polygons with unique IDs representing various soil types. Figure 2.4.1 shows the spatial variability in soil types in San Joaquin County.

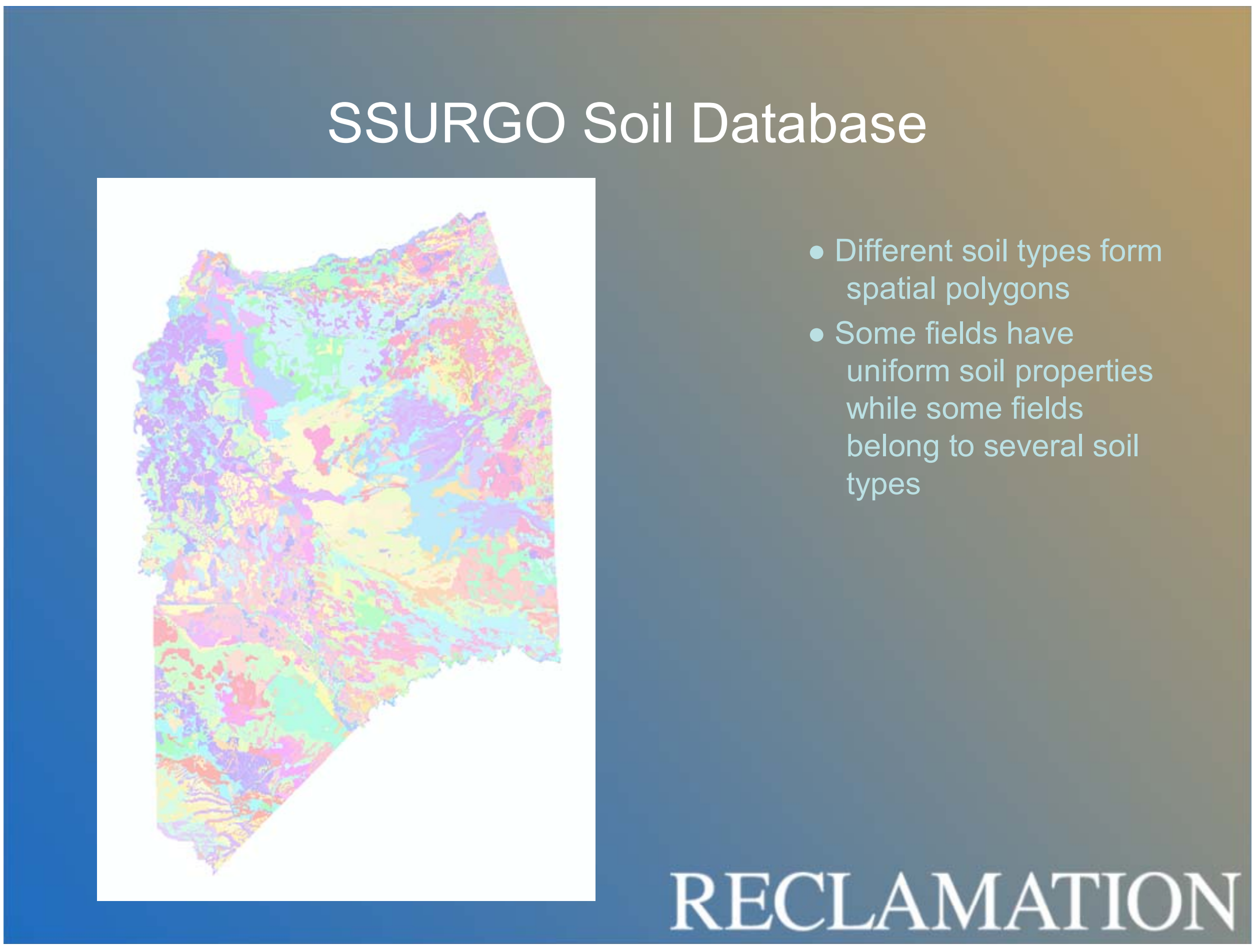


Figure 2.4.1 Soil Types Distribution Map

An extensive database of soil properties is available for each soil type. For LAWS inputs, the following SSURGO data were used to obtain the soil properties:

SSURGO Soil property	Value range	Property name
BDH	0 – 2	Bulk density high (g/cm^{-3})
BDL	0 – 1.8	Bulk density low (g/cm^{-3})
CLAYH	0 – 70	Clay content high (%)
CLAYL	0 – 60	Clay content low (%)
LAYDEPH	3 – 80	Layer depth high (inch)
LAYDEPL	0 – 59	Layer depth low (inch)
SIEVE40H	10 – 90	Sand content high (%)
SIEVE40L	10 – 90	Sand content low (%)
LAYERNUM	1 – 4	Number of layer

For each soil type data are typically present in several layers in the format of high (H) and low (L) values of each of the soil properties. The high and low values were used to define an average value for each soil layer and mean values from each layer were used to compute a vertically weighted average value for the entire soil profile using the layer thickness as a weighing factor.

2.4.2 GIS Analysis

The goal of this analysis was to compute representative soil property values for each individual field polygon in the field border database.

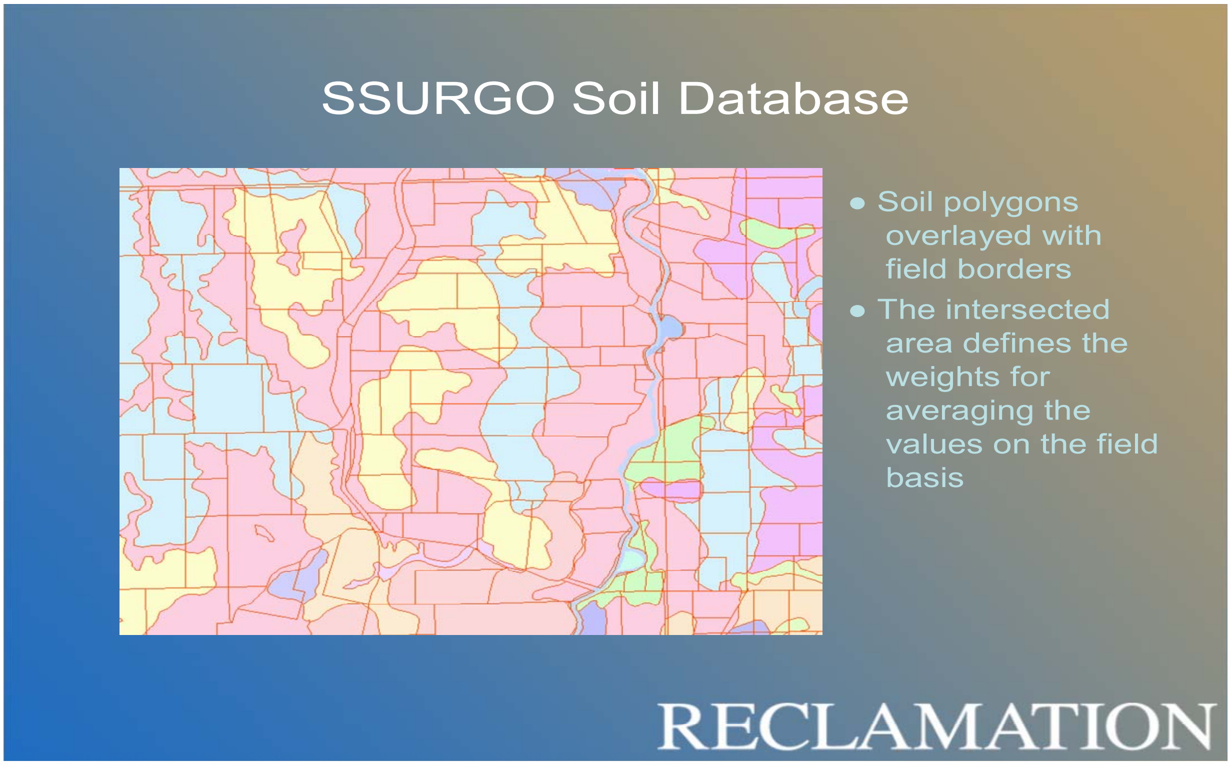


Figure 2.4.2 Soil Polygons Overlayed with Field Polygons

To accomplish this objective, soil polygons and field polygons were overlayed using ArcGIS. Attributes from the soil polygons with soil mapping unit IDs (MUID) were kept together with the field IDs. It is very important to keep a one to one relationship when matching MUIDs with field IDs.

A Visual Basic code was developed to calculate the vertical weighted average for all layers in each MUID. The output soil data includes the percentage sand, silt, clay, as well as bulk density in g/cm^{-3}. The silt content was calculated from the SSURGO data by the relationship

% silt = 100% – % sand – % clay

The Rosetta model developed by the Agricultural Research Service (ARS) Soil Salinity Laboratory (USSL) was used to estimate water holding capacity and hydraulic conductivity. The vertically averaged soil properties (sand, silt, clay and, bulk density) were used as inputs into Rosetta model.

The Rosetta model output values were the soil moisture content at saturation, field capacity, and permanent wilting as well as the hydraulic conductivity.

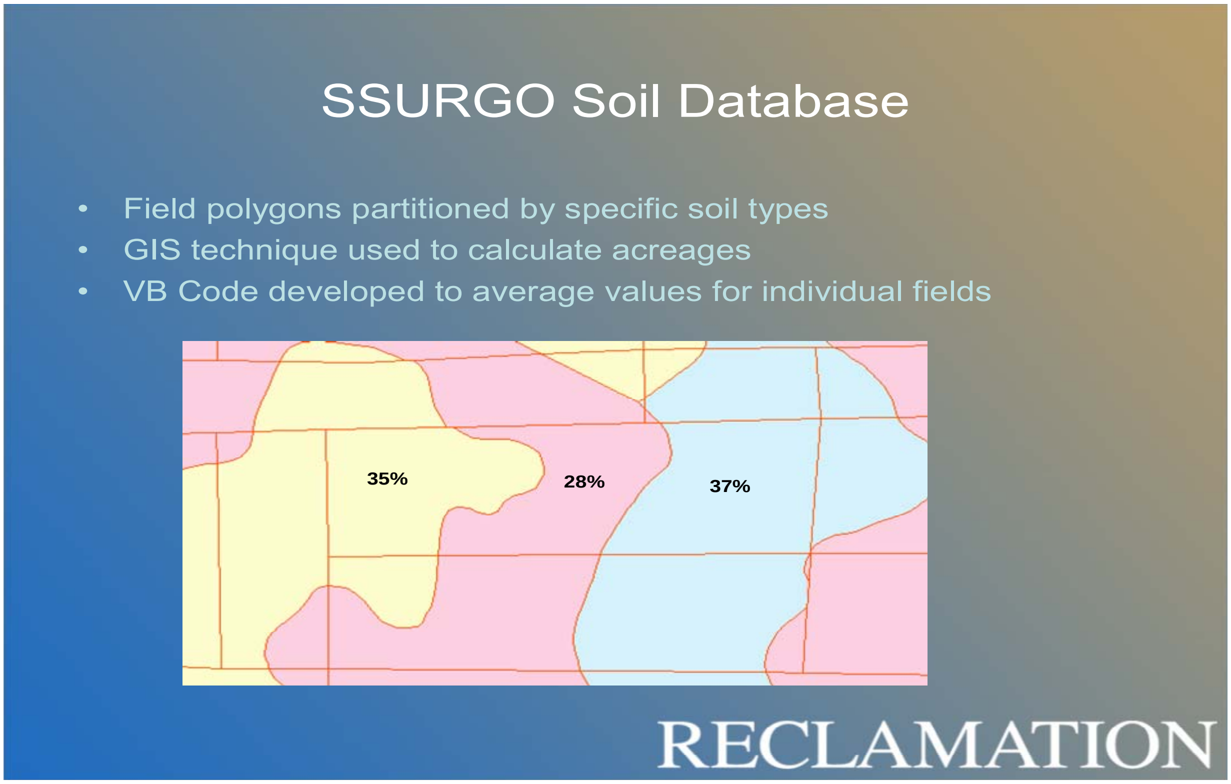


Figure 2.4.3 Field polygons partitioned by specific soil types

As shown in Figure 2.4.3, the Rosetta model outputs for each soil type were associated with the appropriate field using GIS and the percentages of areas within the field were determined. A Visual Basic program was developed that spatially averages the soil properties with each field to develop representative field scale properties for the saturation field capacity, permanent wilting, and hydraulic conductivity parameters. After averaging, each field has a unique set of averaged field scale properties. These soil properties are used as inputs to the vadose zone portion of the LAWS model.

Deliverable 2.5 Water Management Module

The primary purpose of water management model is to provide water resource managers with tools for efficiently developing and comparing alternative water management strategies with either historical or forecasted water supply conditions.

The water management module provides users with the ability to evaluate alternative water management strategies based on multiple factors including:

- Delivery priorities
- Reservoir and conveyance infrastructure
- Irrigation system characteristics
- Crop types
- Soil moisture management practices

2.5.1 LAWS Spatial and Hierarchical Organization

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 2.5.1 below.

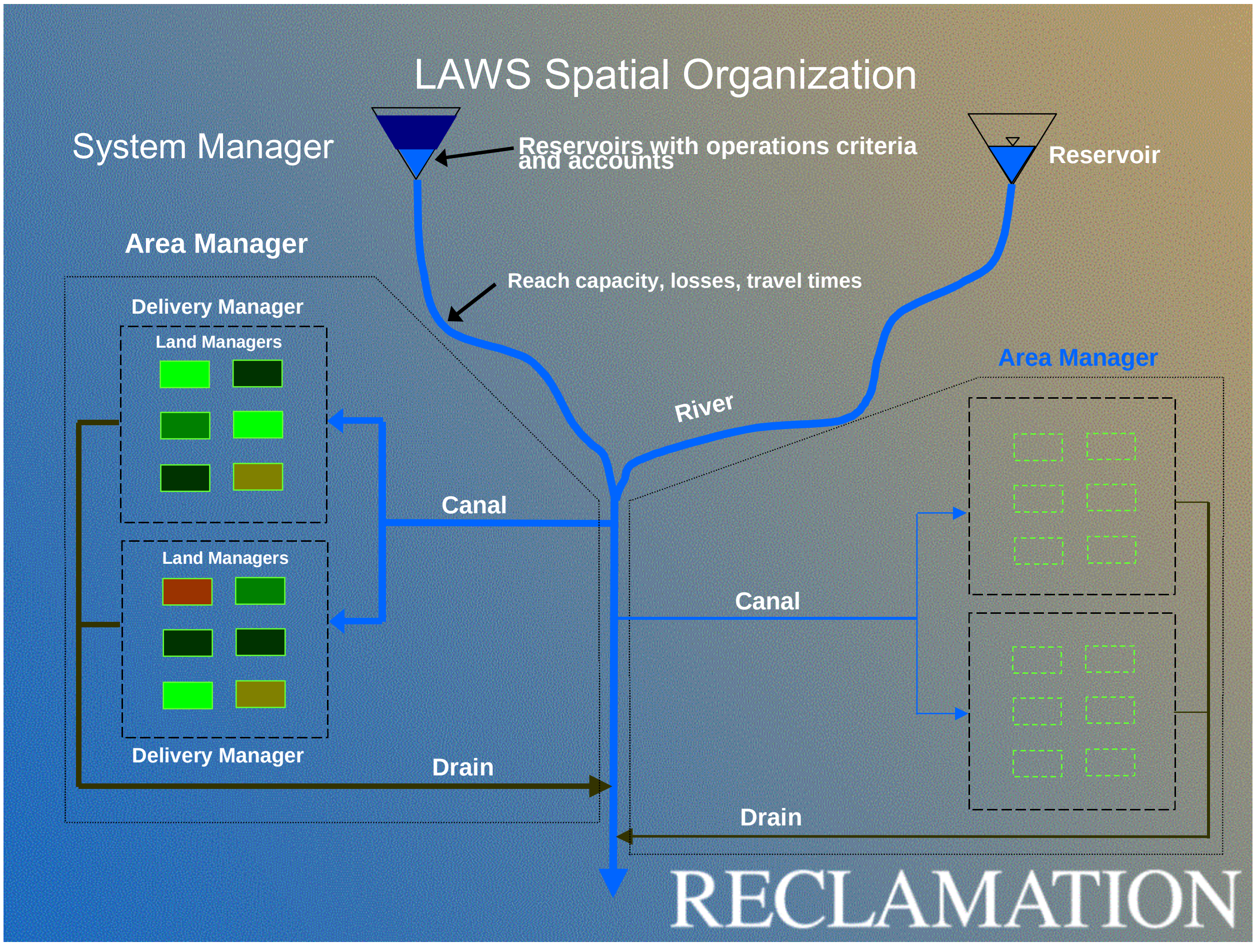


Figure 2.5.1 LAWS Spatial Organization

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 hierachical organization is presented on Figure 2.5.2 below.

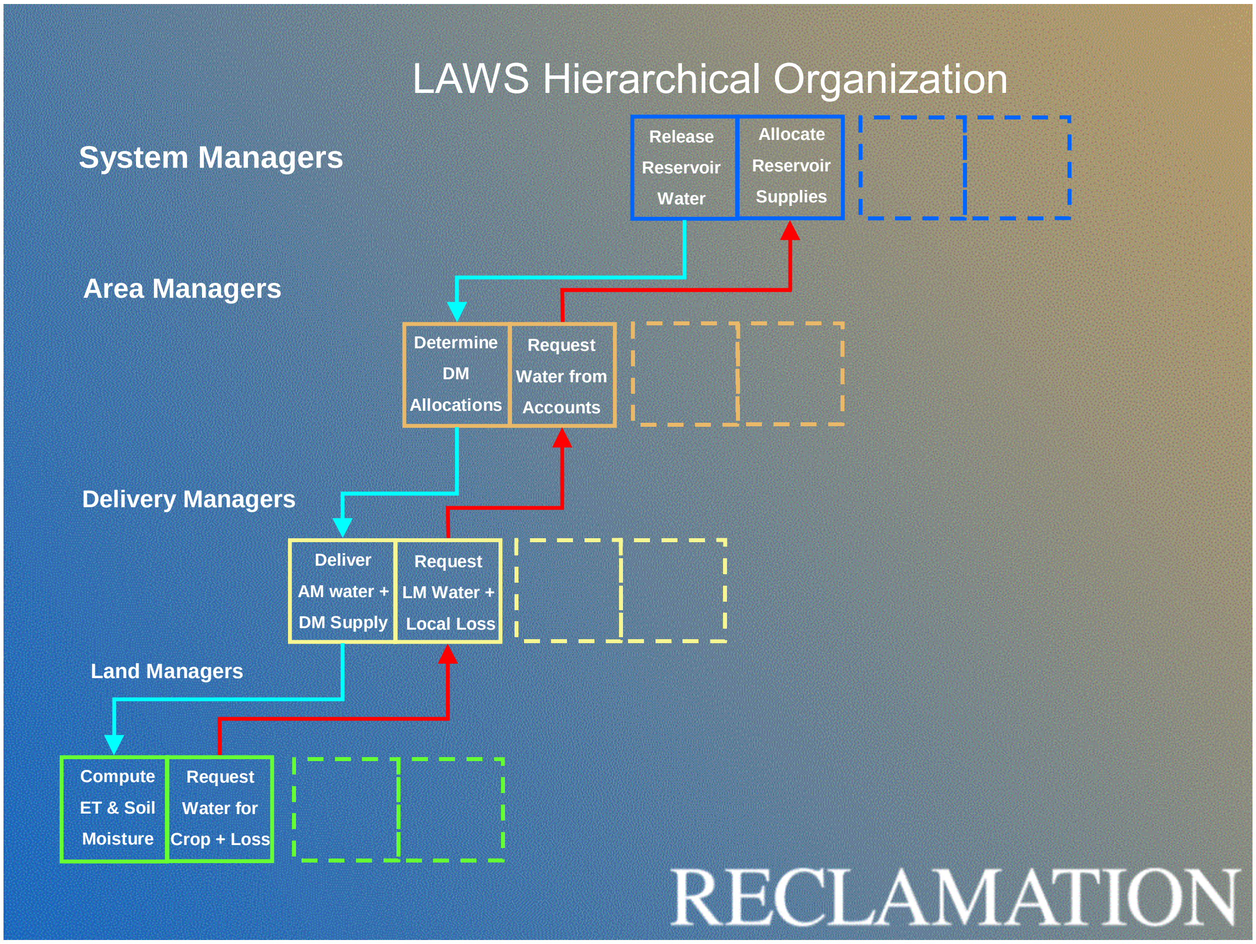


Figure 2.5.2 LAWS Hierarchical Organization

2.5.2 LAWS System Manager

Each system manager (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 manager 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 damages. 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.

2.5.3 LAWS 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) who supply 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 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 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 may be employed in the delivery decision logic.

At each time step, the AM establishes the delivery priorities for its region. To determine which LMs will receive water, the AM uses a hierarchy of priority levels each representing a particular category of priority such as water right seniority, crop type, etc. Within each category, a ranking of LM characteristics is defined to indicate the relative priorities. For example, if water rights seniority is the highest hierarchical level then water rights rankings might include pre-1880, pre-1914, and post-1950 with priority rankings of 1, 2, 3 respectively. If sufficient supply is available for every LM in the highest ranking, they all receive the water they requested and the process is repeated for the next highest ranking group. If the supply is not sufficient, the next highest hierarchical level (ex. crop type) is used and water deliveries are made starting with the highest ranking group (ex. vineyards) in this hierarchical level. When a lower ranking (ex. onions) is finally reached for which the remaining supply is not sufficient to meet the entire consumptive use requirement, a shortage delivery in proportion to their requests is made to all the LMs in this ranking group. The LAWS delivery decision logic is presented on Figure 2.5.3 below.

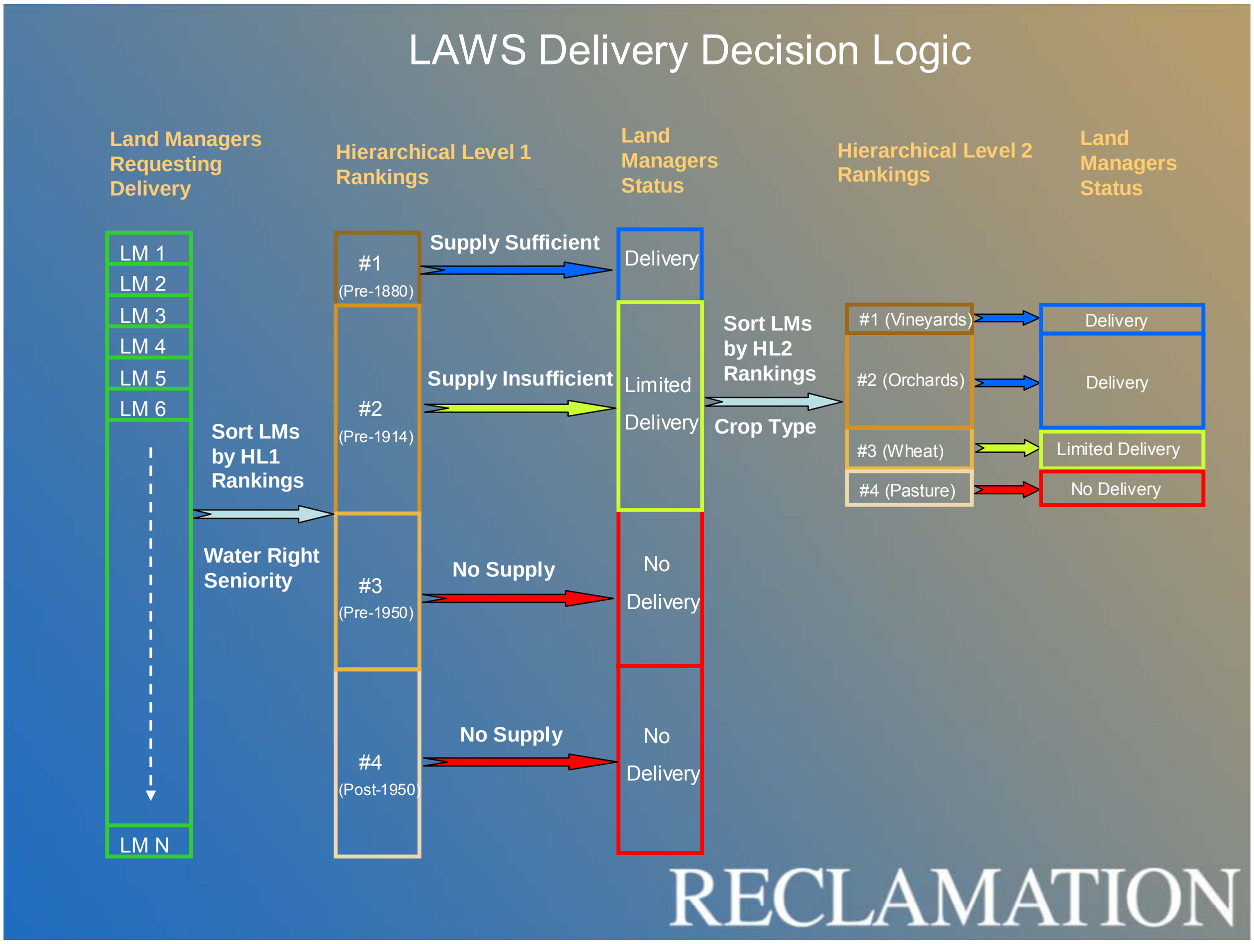


Figure 2.5.3 LAWS Delivery Decision Logic

The AM is also 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.

2.5.4 LAWS 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 2.5.4 below.

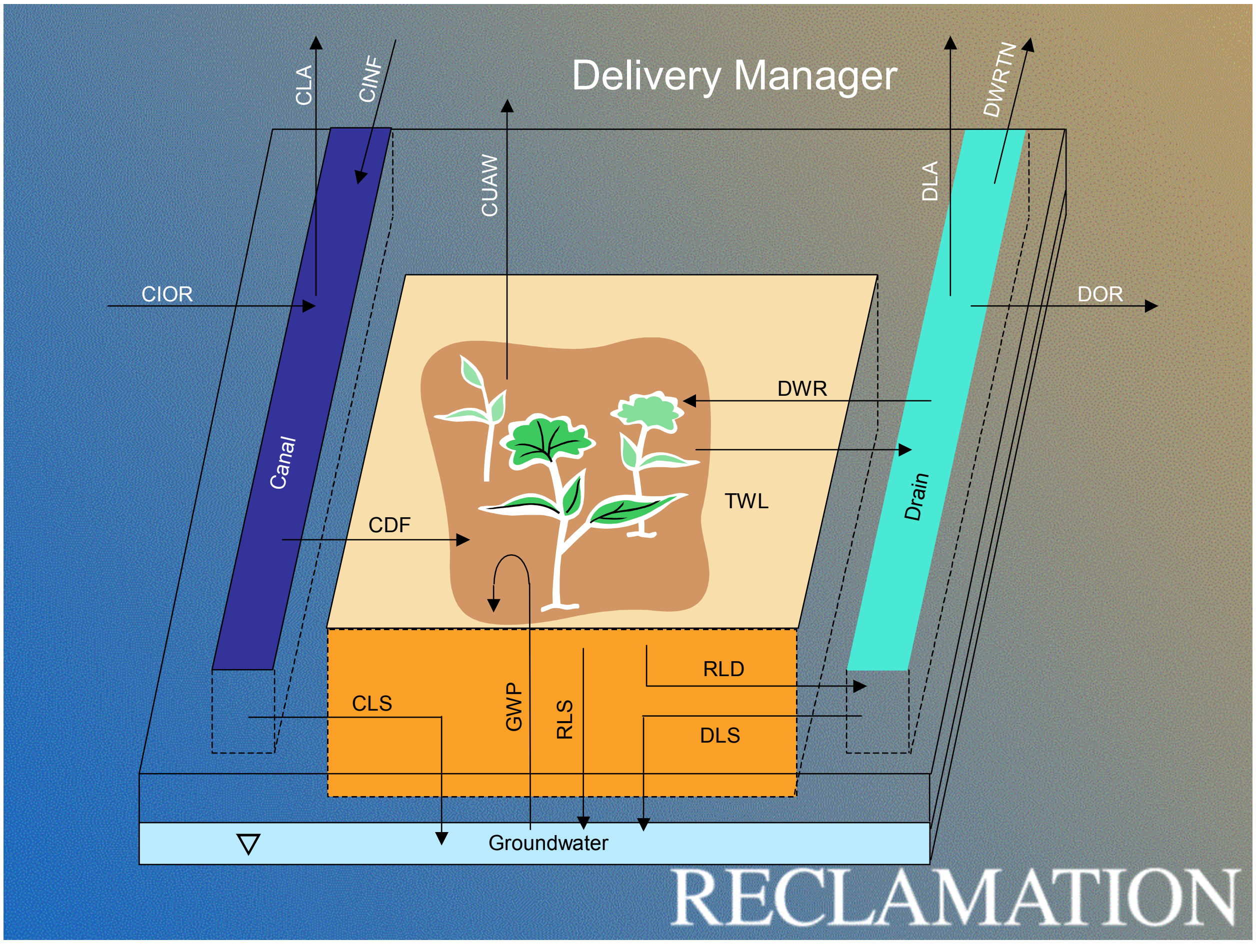


Figure 2.5.4 Delivery Manager Water Budget Components

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 the 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. Thus, the DM must employ the LAWS priority based decision system to determine whether an application request from a particular

LM should actually be delivered. 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, crop condition, moisture stress, and other user defined criteria can be employed in the delivery decision logic.

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. The delivery decision logic is described above and presented on Figure 2.5.3.

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.

2.5.5 LAWS Land Manager

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 relative to particular management targets in effect at various times during the year.

In order to provide flexibility for managing vegetation, the annual cycle is divided into 5 growth stages. These stages include: pre-germination (PG), rapid growth (RG), maturation (M), harvest (H), and post-harvest (PH). The starting and ending dates for each of these periods are specified by starting and ending dates during the calendar year. The PG and PH periods are included in LAWS so that water applications not directly related to crop evapotranspiration can be simulated. Crop evapotranspiration (ETC) is computed as shown on Figure 2.5.5 below during each of the growth stages from the reference crop evapotranspiration (ET0).

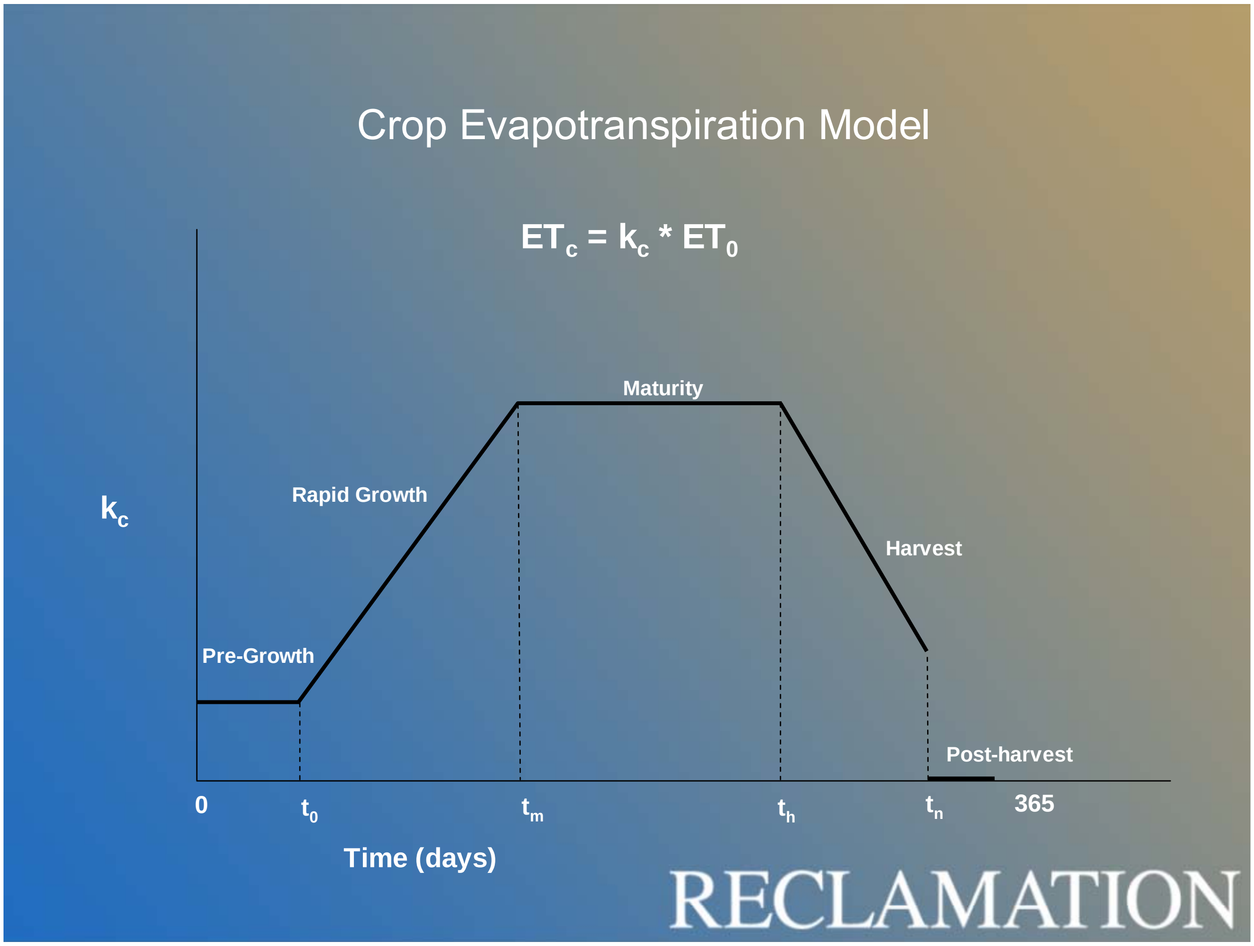


Figure 2.5.5 LAWS Evapotranspiration Model

The daily ET0 values employed in a LAWS simulation can be spatially interpolated to individual fields from data obtained from multiple weather stations such as those operated by the California Irrigation Management Information System (CIMIS) or from ET0 values computed from models such as SIMETAW and CUP[1]

In order to compute soil water content in the root zone, LAWS simulates changes in the depth of roots during the growing season. The maximum root zone depth (RD) for each crop type is simulated on a daily basis using simple linear relationships for each growth stage[2]. The LAWS root zone depth model is shown on Figure 2.5.6.

[1] Add reference for these models
[2] Add reference for this model.

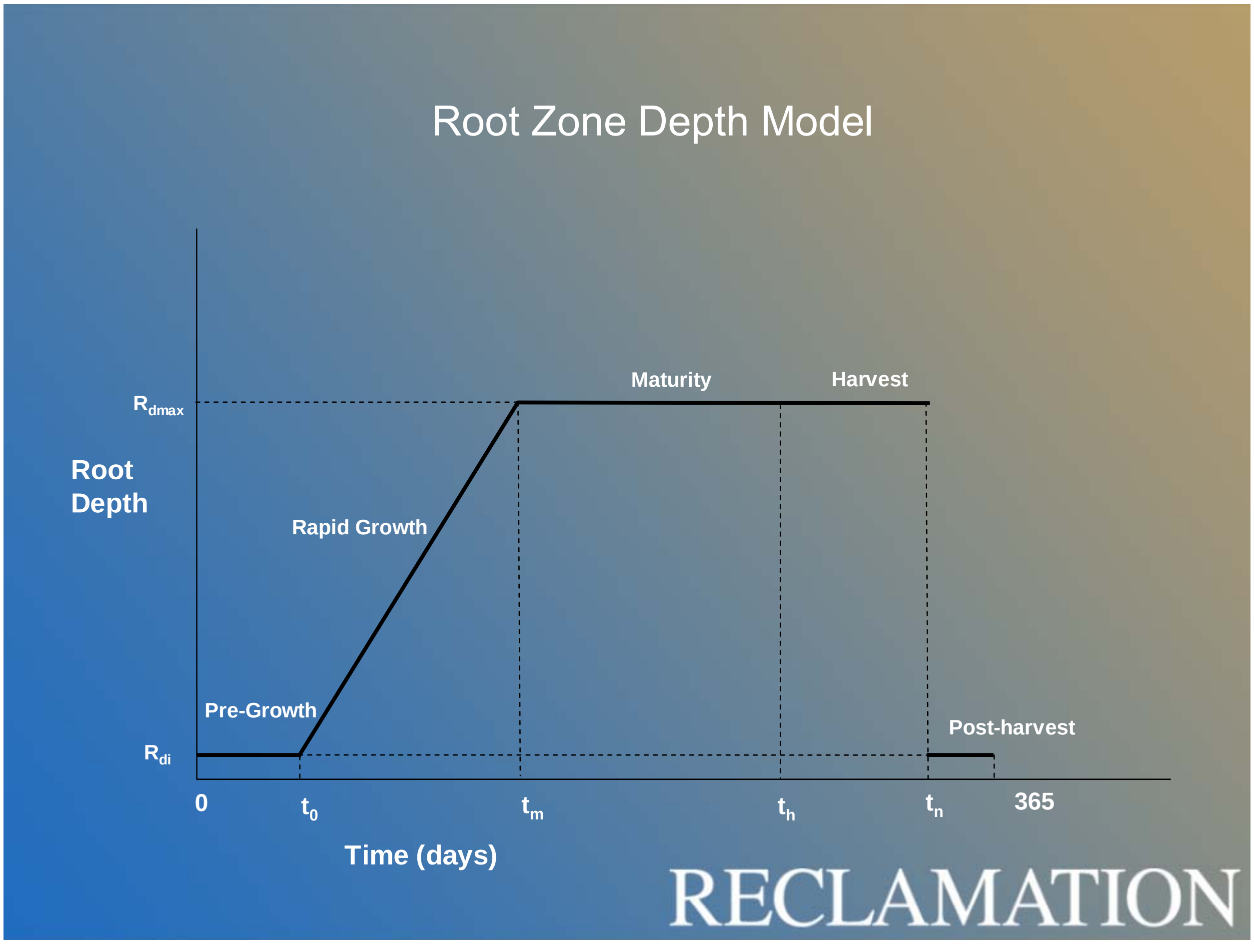


Figure 2.5.6 LAWS Root Zone Depth Model

LAWS simulates the management of irrigation scheduling during the growing season by allowing the user to set specific soil moisture management targets for individual fields. This approach models how irrigators manage their crops water requirements and permits the user to account for differences in soil properties and crop types. These management targets are specified for each of the growth periods. The LM generates a request for water when the root zone soil water content falls below the specified management trigger. The LAWS irrigation management model is shown on Figure 2.5.7 below.

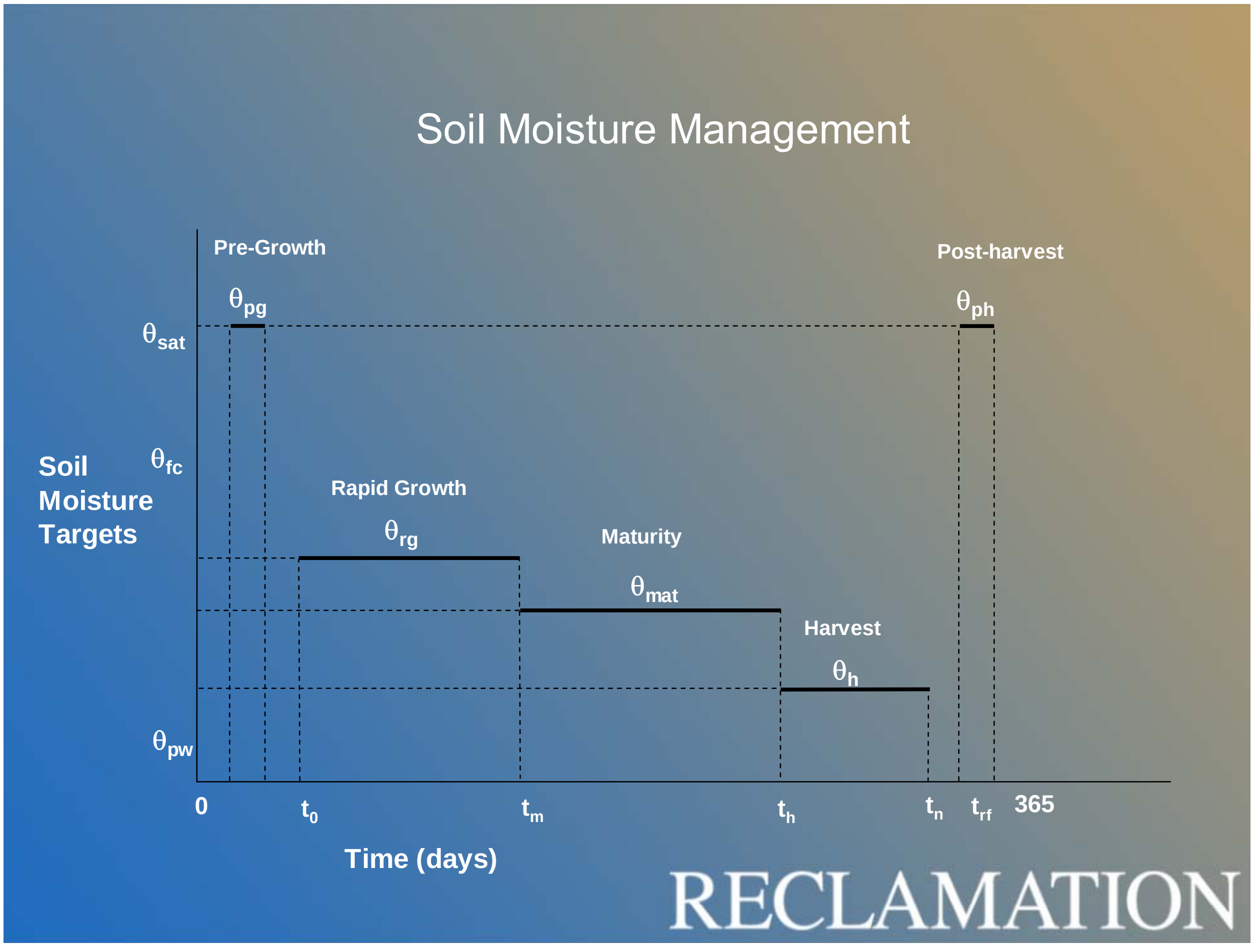


Figure 2.5.7 LAWS Irrigation Management Model

The amount of water requested by the LM is determined by the root zone storage capacity at the time the request is made and the application efficiency of the irrigation system used to apply the water to the land unit. In order to compute the application requirement, LAWS employs soil several properties. The soil water capacity and hydraulic properties used by LAWS are presented on Figure 2.5.8.

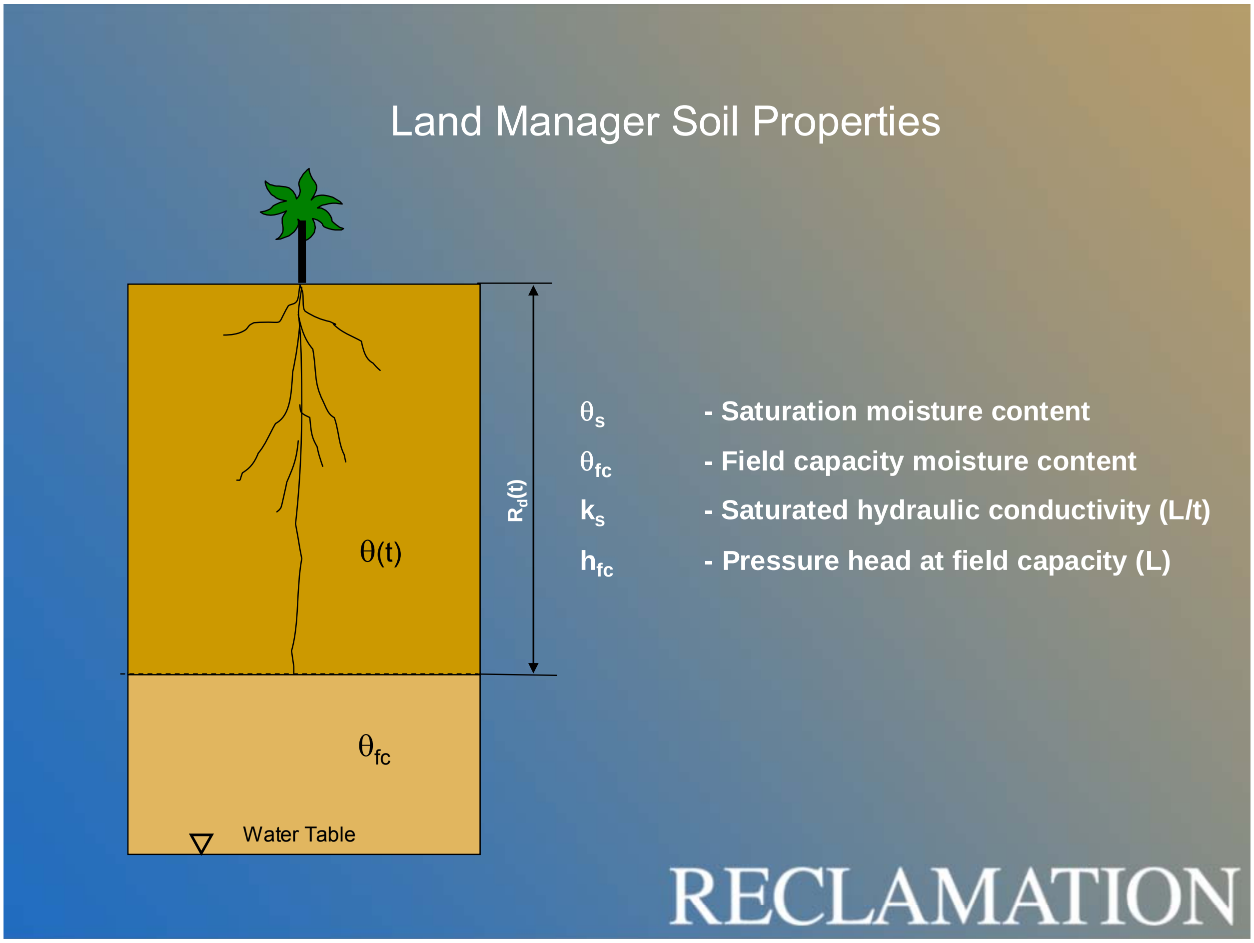


Figure 2.5.8 LAWS Soil Water Capacity and Hydraulic Properties

Since certain crop types and management practices require ponding of water on the soil surface, a provision is made in LAWS to manage water under both ponded and unponded conditions. Components of the LAWS water budget with and without ponding are shown on Figures 2.5.9 and 2.5.10 respectively.

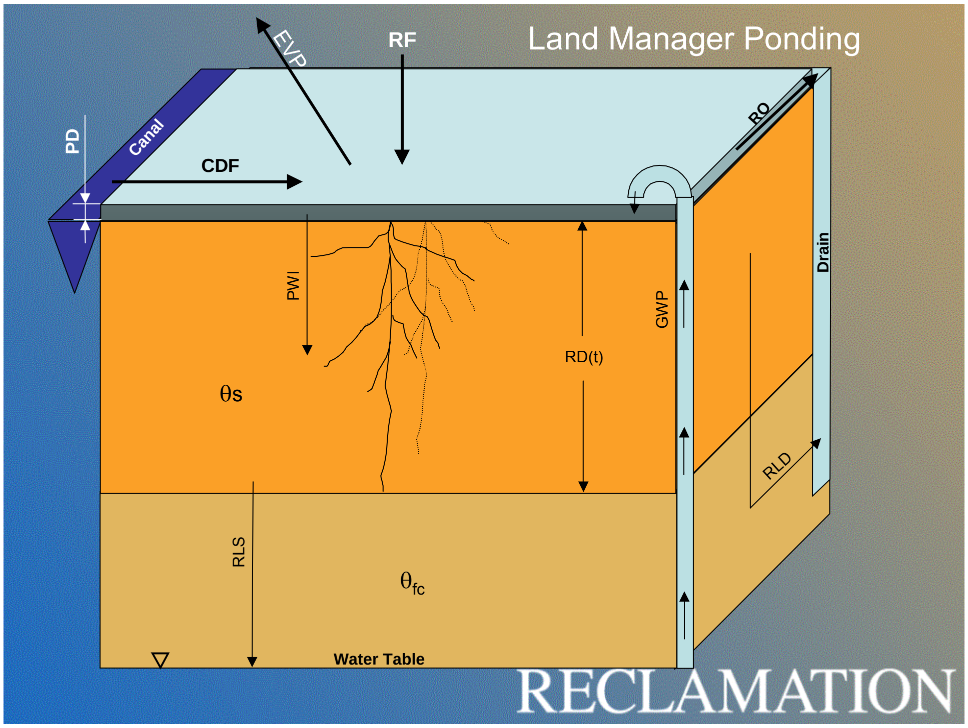


Figure 2.5.9 LAWS Water Budget Components under Ponding

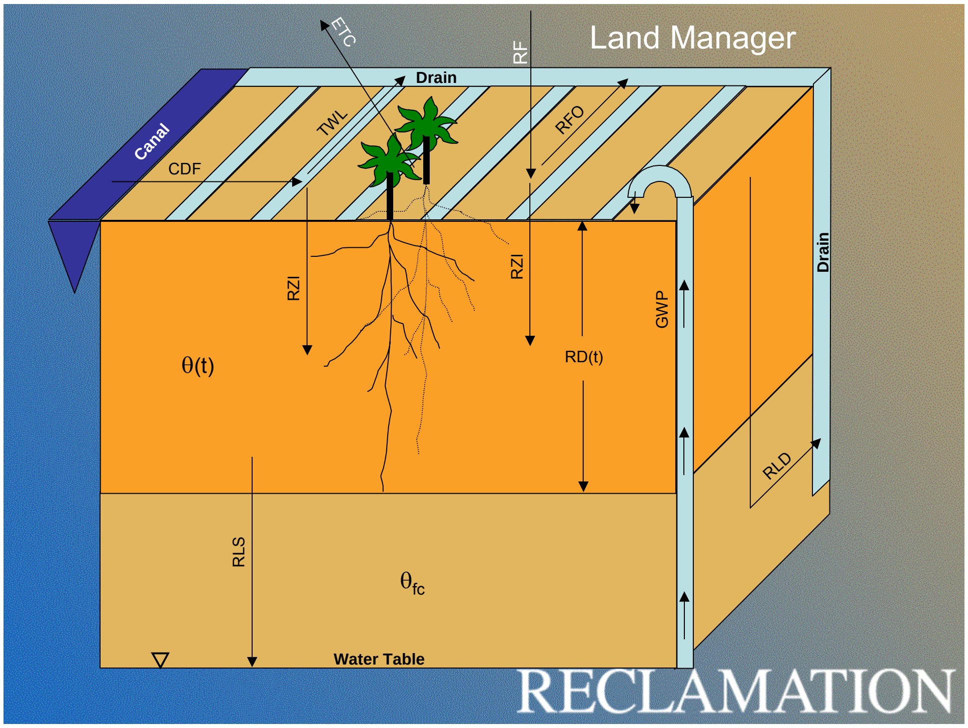


Figure 2.5.10 LAWS Water Budget Components without Ponding

The LM performs several functions on daily basis including updating the root zone depth (RD(t))[3] , soil water content $\theta(t)$, crop evapotranspiration (ETC) , pond evaporation (EVP), runoff from rain and ponds (RFO), pond depth (PD), and consumptive use of applied water (CUAW). If ponded conditions are present, the LM computes the total root zone losses using Darcys LAW with the assumption that the wetting front soil water content is at field capacity (θ_{fc}). Seepage to groundwater (RLS) and drains (RLD) are computed as user specified fractions of the total root zone losses.

If the LM receives water from the DM or rainfall occurs, the LM also computes the root zone infiltration (RZI), tail water losses to drains (TWL) and root zone losses based on the assumption that the root zone immediately drains to field capacity.

When the soil water content drops below a soil moisture management target, the LM initiates a request for water. The amount of the application request includes sufficient water to saturate the root zone plus additional water to account for the efficiency of the irrigation system and this application request is sent to the DM.

Deliverable 2.6 User Interface Module

2.6.1 Graphic User Interface Expertise and Background

The section describes the graphical user interface for the LAWS model. The Graphical User Interface (GUI) was built using a Java based extensible pluggable framework. This framework will be able to accommodate the current LAWS capabilities as well as any future enhancements and will facilitate integration with other models. The application framework provides the basic functionality that is in the LAWS GUI such as geo-referenced map display, advanced tables, plots and animation capabilities summary reports, and the ability to run and compare multiple LAWS alternatives.

The framework is designed around the MDI standard with multiple views, dockable views and toolbars, Internationalization, undo, cut/copy/paste, and printing. It also supports multiple language capabilities.

[3] This abbreviation and those following refer to the preceding figures.

2.6.2 Framework

A LAWS example project is shown in Figure 2.6.2. The main window is broken up into several components, the menu bar and toolbar, the Project pane, the Content pane and the Editors and Viewers pane.

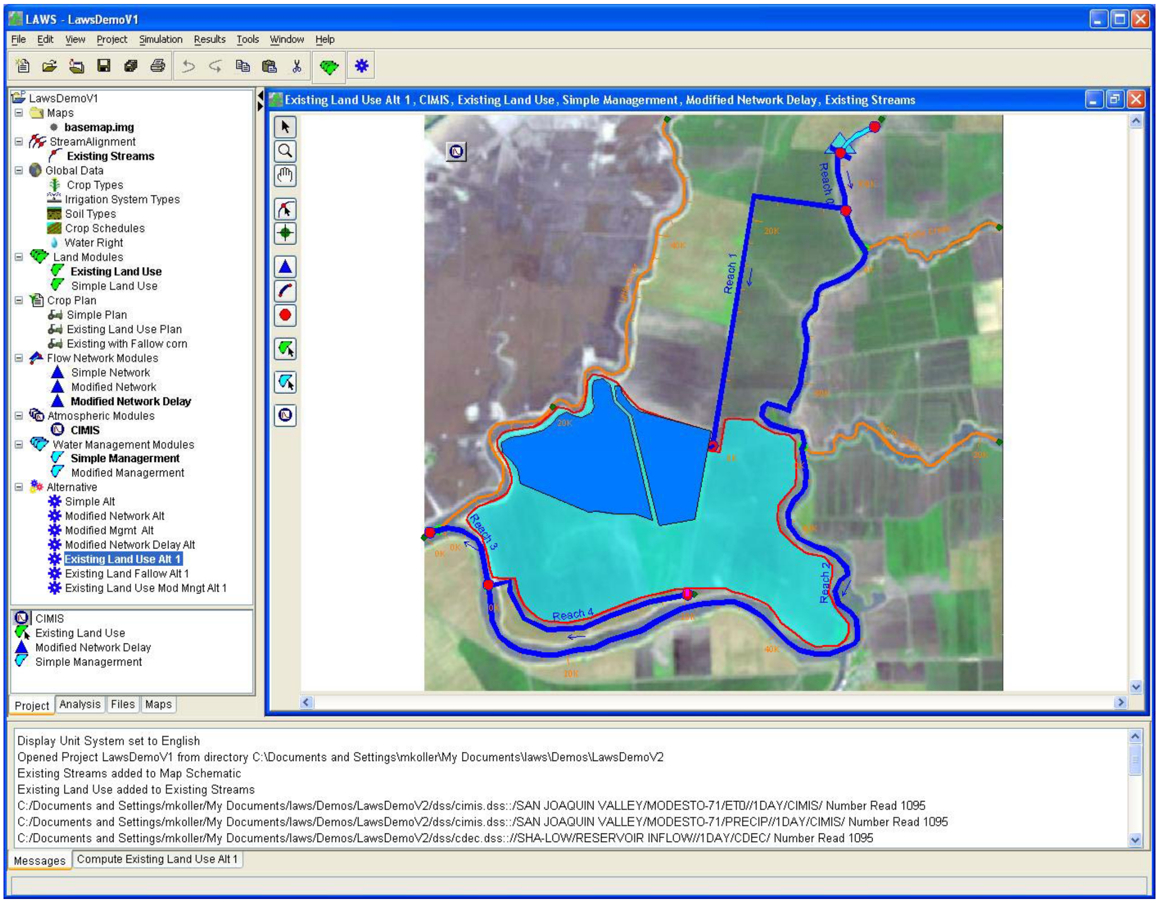


Figure 2.6.2 LAWS main window

Each section of the main window is described briefly below.

Menu Bars and Toolbars

The Menu bar and Toolbar contain the standard set of actions plus additional actions specific to LAWS. The toolbar is docked by default but can also become free floating if the user chooses.

Figure 2.6.3 Menu bar and Toolbar

Project and Content Panes

The Project pane is a tree based view of the contents of the current Project. The lower content pane displays higher-level content, if any, for the selected node in the Project pane. Each node in the Project pane corresponds to a resource in the LAWS project. Each node also has a context sensitive right click menu.
Each node in the Project or Content Pane has a label, icon, and a description associated with them. The description shows as a tool tip when the mouse is hovered over the node. Each node in the Project pane can have a viewer/editor associated with it. Every node in the Content pane must have a viewer/editor associated with it.

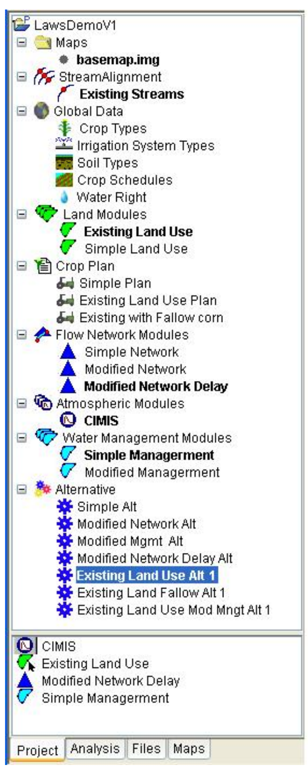


Figure 2.6.4 Project and Content Panes

Editor and Viewers Pane

The Viewers and Editors pane displays the viewer or editor for the selected node. It also displays the Map Schematic. The Map Schematic is a geo-referenced map display that is capable of displaying various map formats, image files, as well as displaying the LAWS river segments.

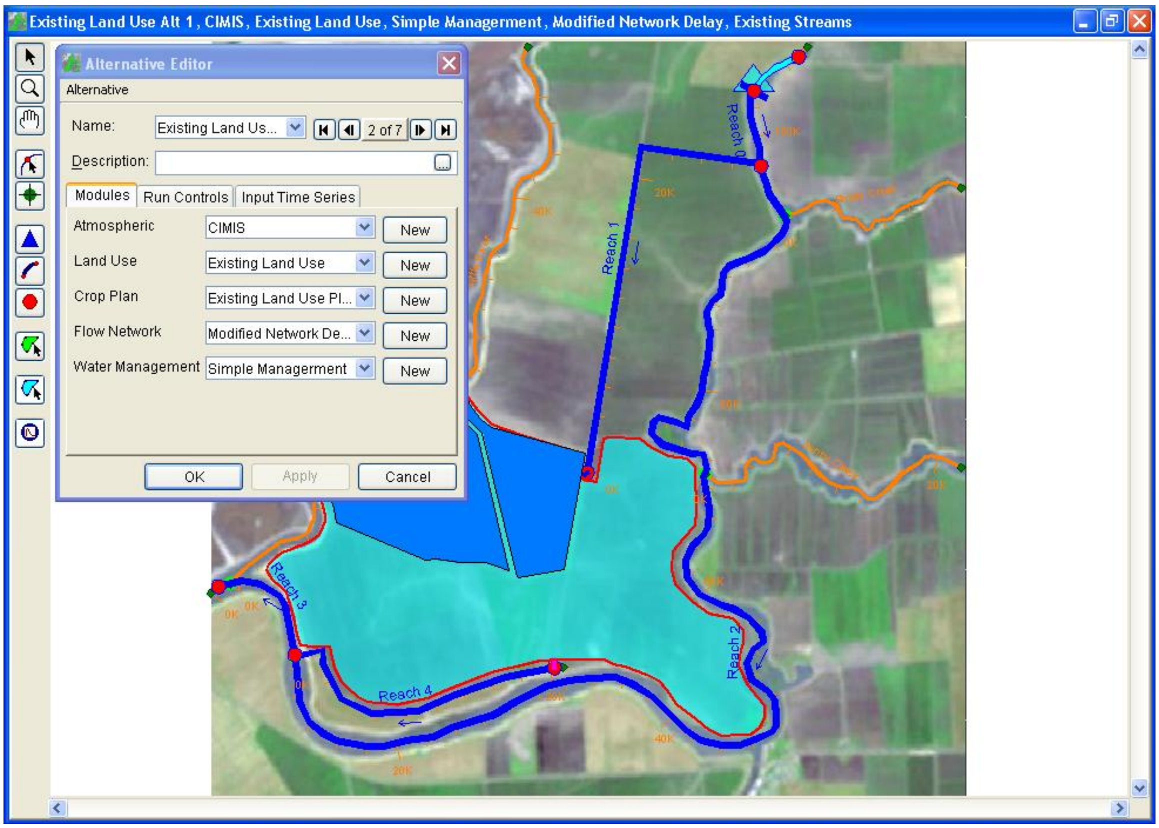


Figure 2.6.5 Viewers and Editors

2.6.3 Map Schematic

The Map Schematic, used by the LAWS application, uses the US Army Corps of Engineers Hydrologic Engineering Center (HEC) Java map libraries. The Map Schematic frame, shown in Figure 2.6.6, is a JInternalFrame that contains a Toolbar down the left side of the frame and a Map panel that occupies the majority of the frame. The Map panel has full panning and zooming support. There are three standard tools, the Select tool, the Zoom tool and the Pan tool. There can be any number of additional application specific toolbar tools added to the toolbar.

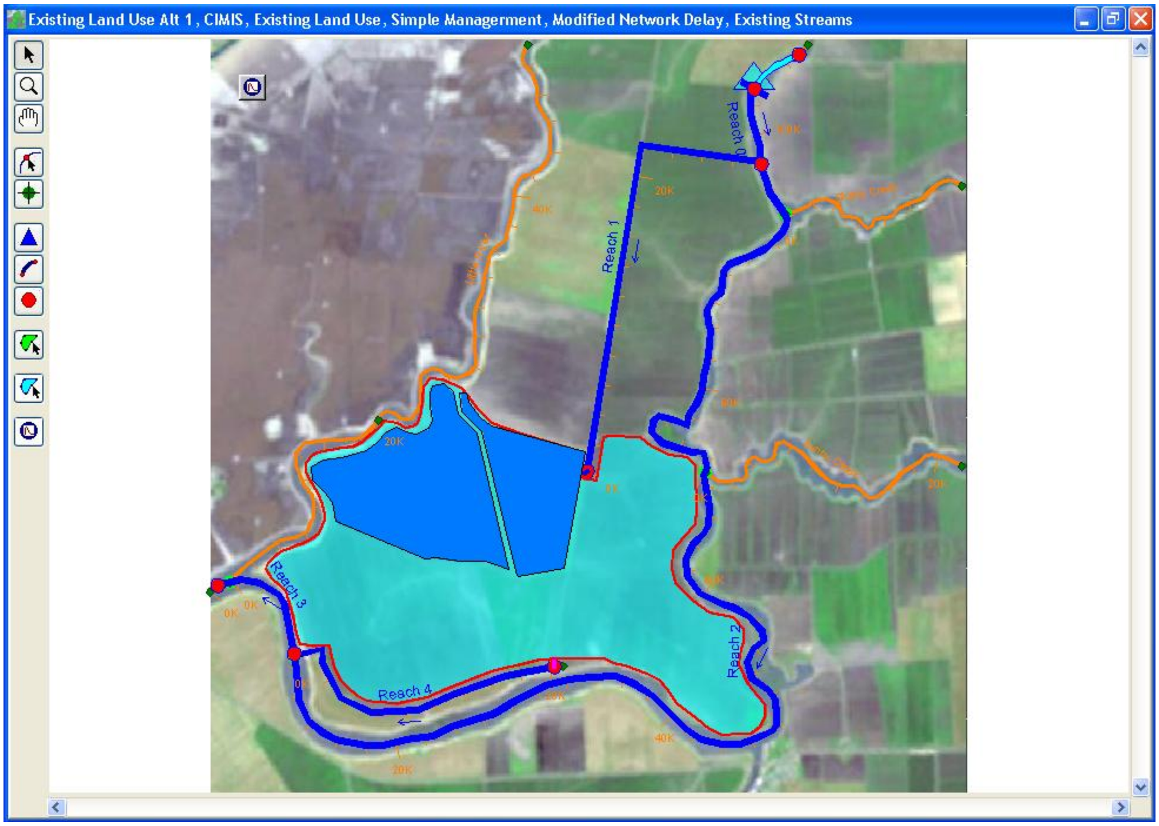


Figure 2.6.6 Map Schematic Frame

The Map Schematic supports a wide variety of GIS formats including:

- USGS DLG
- Autocad DXF
- ArcInfo Shape file
- USGS DEM
- ArcInfo DEM
- NetTin
- Ascii NETTIN
- Geo-referenced Image files

The Map schematic supports right click menus on different elements displayed in it as well as full Geo-referenced editing of model data.

Figure 2.6.7 Map Schematic right click menu

The Map Schematic has a Layer Selector dialog, shown in Figure 2.6.8, which allows adding, removing, and rearranging of the various map layers displayed in the Map Schematic.

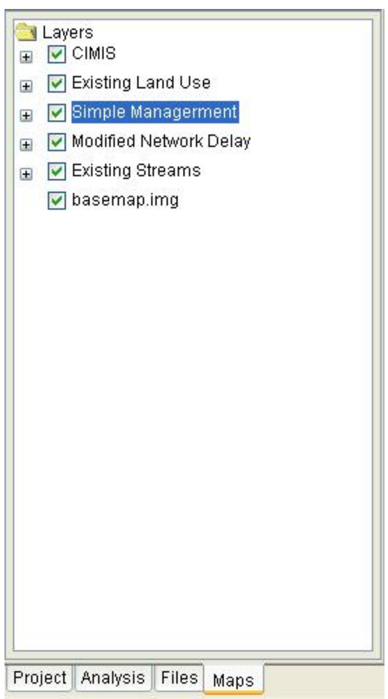


Figure 2.6.8 Layer Selector dialog

Stream Alignment

The Map Schematic provides a Geo-referenced stream alignment which the LAWS' river segments and cross sections would automatically overlay onto. The stream alignment represents the centerline of the river system being modeled. The stream alignment has a river stationing coordinate system assigned to it so that one-dimensional river data (cross-section locations identified by river station) can be mapped onto the two dimensional geo-referenced map.

2.6.4 Data Management

Data in memory is governed by a Manager. The Manager is responsible for reading/writing the data to disk and holding the data in memory. Every file in the project will be associated with a single Manager.

Scripting

The LAWS framework supports the Python language for scripting. The user interface contains a scripting editor, which allows the user to create scripts, which can control all aspects of the application.

Undo, Cut, Copy, Paste

The application framework provides basic user interface support and clipboard access for common editing functions. Specific application modules provide the detailed implementation of undo, cut, copy, and paste functions.

Help

The application framework provides the user interface and calling structure to access context sensitive help.

Internationalization

The LAWS framework supports Internationalization with initial development being in US English. Internationalization is the process of designing an application so it can be adapted to various languages and regions without engineering changes.

2.6.5 DSS File Support

The LAWS framework has full DSS file support utilizing HEC's DSS Java libraries.

2.6.6 Model Execution and Output

The LAWS numerical engine is run through the Runtime Manager. The Runtime Manager provides a platform independent method of executing external programs. A progress dialog will be displayed to the user during the numerical engine's execution. At the end of the execution the output will be available to use the user to view.

Plotting

The LAWS framework utilizes the HEC Java 2D plotting libraries.

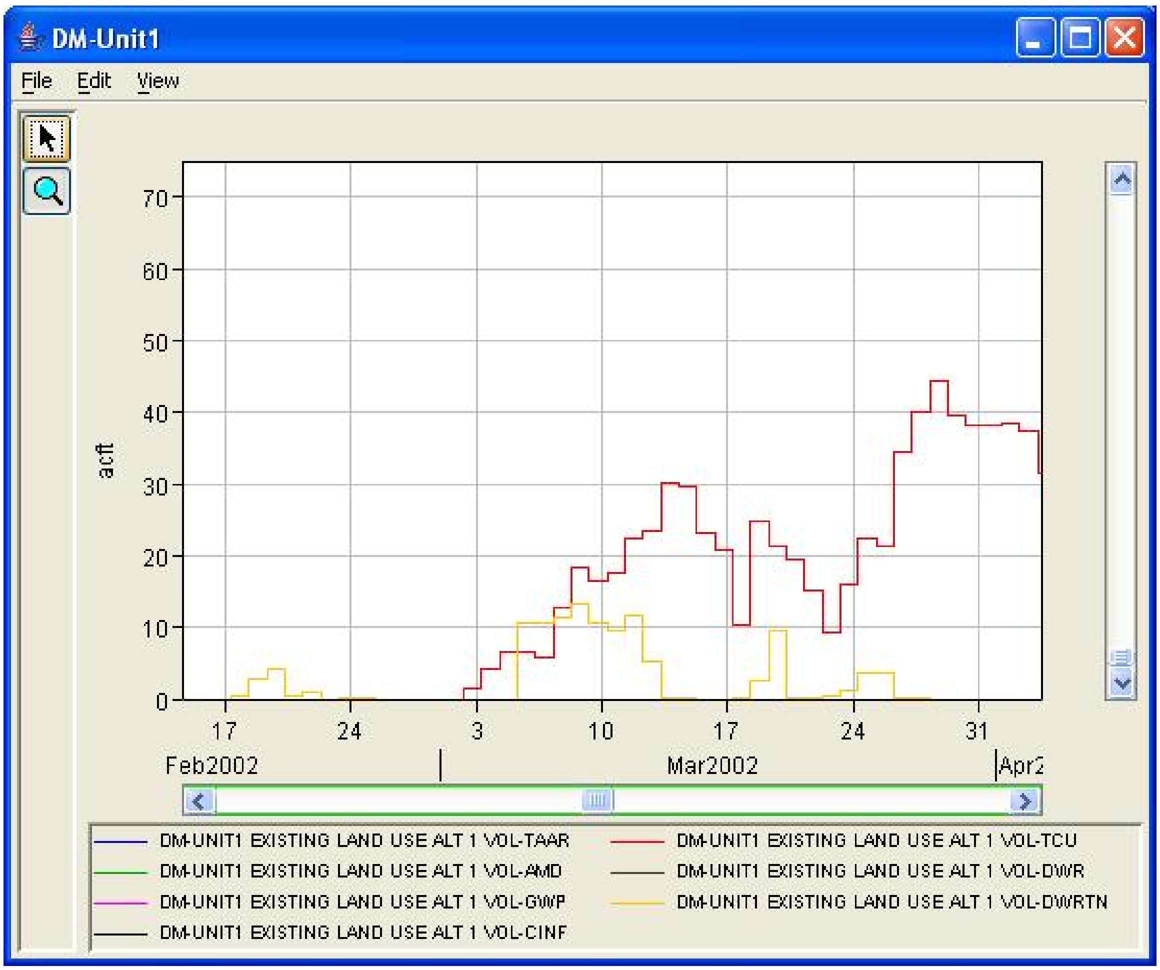


Figure 2.6.9 Example Output Plot s

Support for both Time Series data as well as Paired Data is built in. All the plot properties can be set through either by the programmer through a set of Java APIs as well as interactively by the user through various dialogs. Plots support:

- zooming
- panning
- printing
- saving to files
- tabulating
- line and point styles and colors
- multiple viewports
- copying to the system clipboard
- SI and Imperial unit systems

Animation

LAWS also provides support for displaying animations of key spatial information over a simulation period.

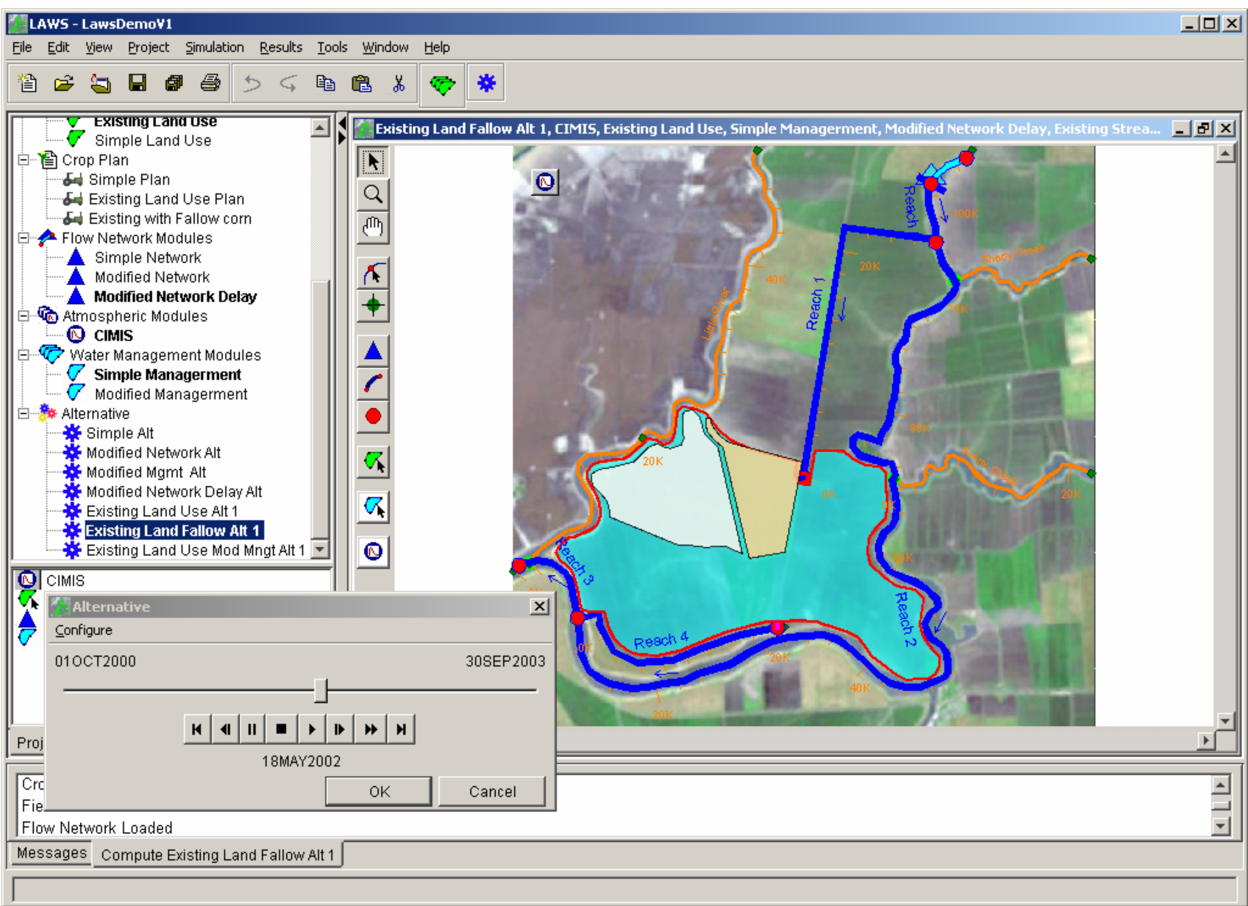


Figure 2.610 Example of Animation

Alternatives

Multiple LAWS projects can be opened simultaneously; this allows the comparison of reports and plots from different LAWS alternatives side by side. Once multiple LAWS projects are loaded, the interface allows the selection of which alternatives are to be displayed in output reports and plots.

When a LAWS plot or report is displayed, all selected alternatives that have been successfully computed will display in the plot or report.

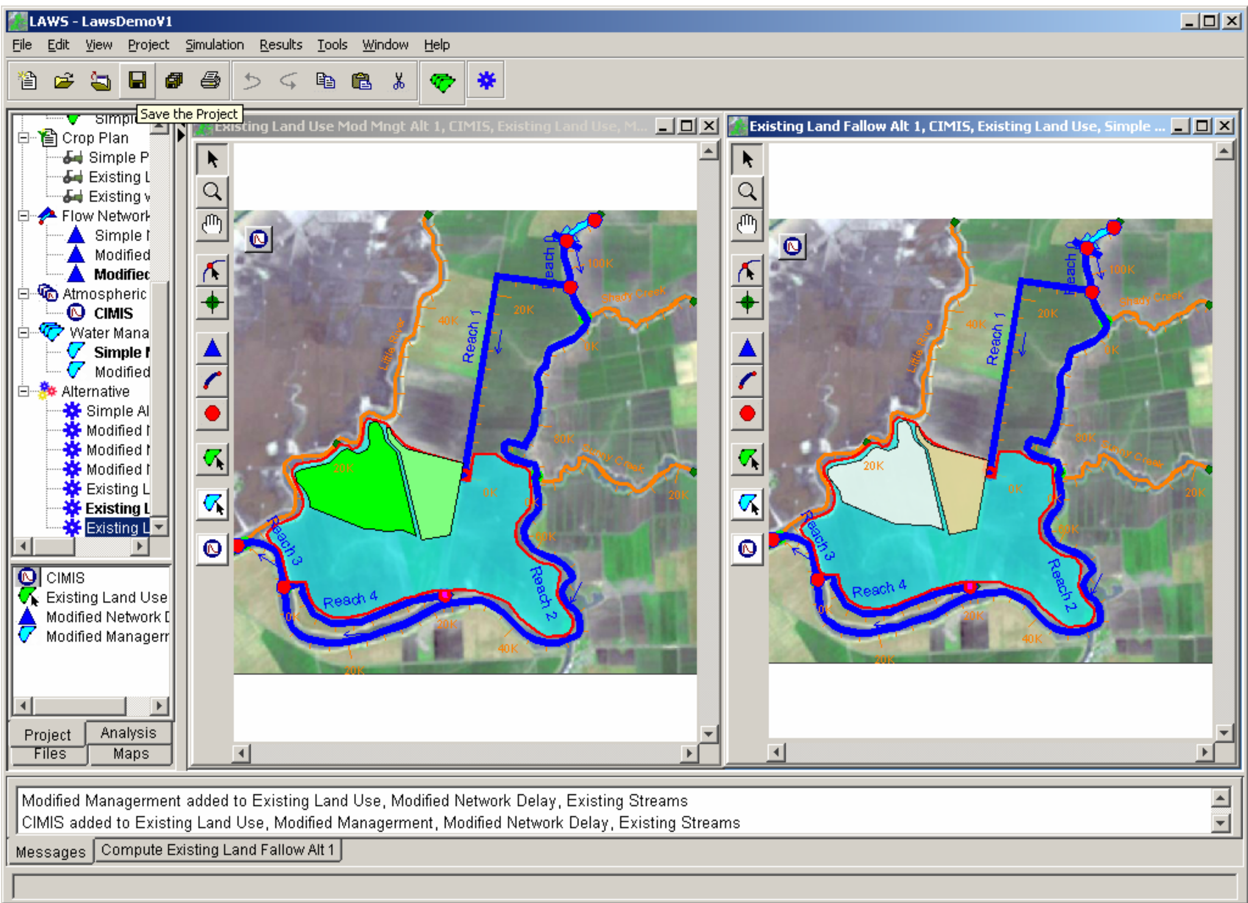


Figure 2.6.11 Example of Multiple Alternatives