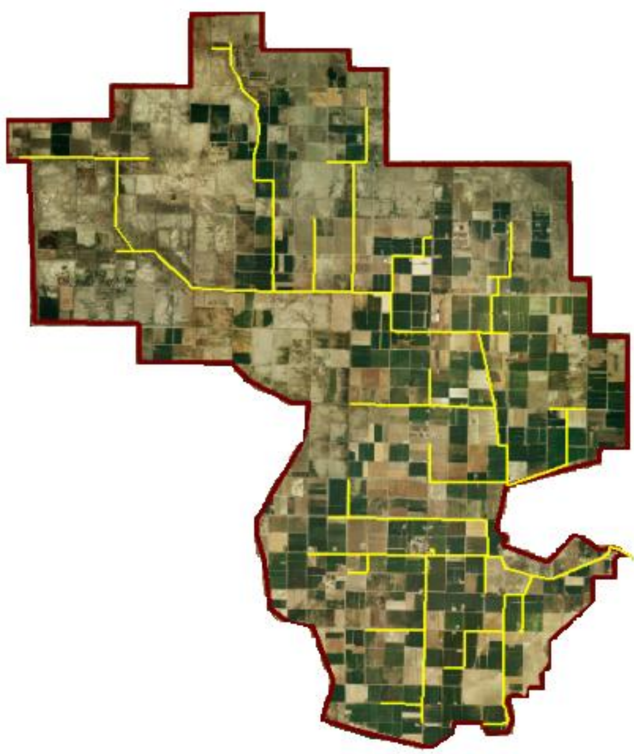
CEE 6440: GIS in Water Resources

Term Project

Better Estimation of ET for Efficient Irrigation in Delta, UT using GIS



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Introduction

As the population grows, the need for more water is increasing worldwide. Then methods to reduce the water use are required especially in irrigated agriculture that is one of the sectors that uses large quantities of water. For this purpose, knowledge about irrigation demand is important, and this can result from better estimation of Evapotranspiration (ET). ET is usually calculated from reference evapotranspiration (ET_o) that expresses the evaporating power of the atmosphere at a specific location and time of the year and does not consider the crop characteristics and soil factors. As it is mentioned by Allen *et al*. (1998), the only factors affecting ET_o are climatic parameters. Consequently, ET_o is a climatic parameter and can be computed from weather data, then by multiplying this ET_o by a crop coefficient (K_c) we can get the actual ET of crops. In general, K_c values are suggested by FAO irrigation and drainage papers for all the crops, but those ones are very general, site specific and differ with climate conditions, so they need to be calculated for each area (usually using lysimeters experiments).

On the other hand, remote sensing and geographic information systems (GIS) studies have evolved in all scientific field, and certainly agriculture and water resources. And those tool can be used to classify crops, estimate the K_c based on reflectance and hence estimating crop water demands. Lots of studies were done on estimating K_c values from vegetation indices such as the soil vegetation index (SAVI), or the normalized difference vegetation index (NDVI)…

For this project, the study area was the agricultural area of Delta, Southern Utah. In this area, water is diverted from Sevier River based on requests from the farmers depending on their water shares. That is why, accurate ET estimation is important for the management of this river. So the objective of this project is to evaluate the irrigation system efficiency of the area irrigated by Canal B of the Sevier River, Southern Utah. This may be accomplished by estimating the crop water requirements in the area using GIS tools to get the evapotranspiration, and compare it to the flow measurements of water diverted to irrigate this area.

Methodology

1. *Study Area*

Delta is a major agriculture area in the Sevier River Basin, UT (Fig. 1). It is irrigated by Sevier River through canal diversions. The main crops that are grown in this area are Alfalfa, Corn, and grains mainly Barley. The study was conducted for the growing season 2008. A weather station is available in

Delta, from which reference evapotranspiration (ET_o)can be estimated. Only part on this agriculture area was considered for this study, and it is an area of study for a project with Utah Water Research Laboratory and the Bureau of Reclamation to help Sevier River Association in river and canals management. The canal B (in yellow, Fig1) was mapped using ArcGIS then the area of study was delineated accordingly. The total area irrigated by this canal is about 10,000 hectares.

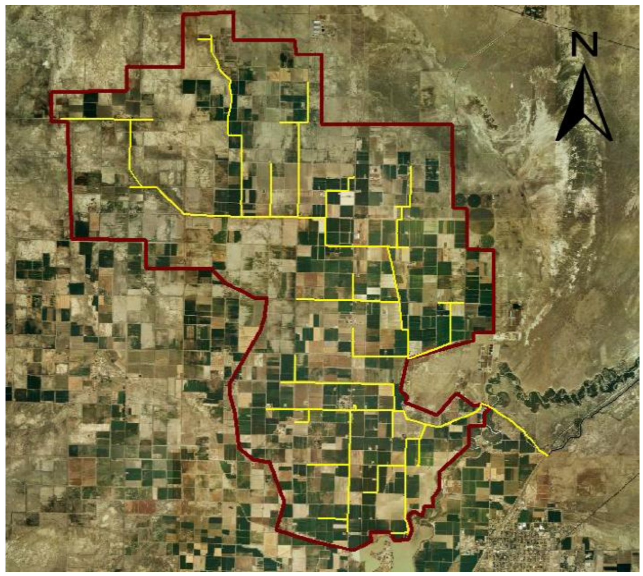


Fig1. Area of Study, Delta, Utah

2. Satellite images

Satellite images from Landsat 5 Thematic Mapper were collected. The dataset in Fig. 2 consisted of reflectance values for channels 3 (0.63-0.69 µm), 4 (0.78-0.90 µm) and 5 (1.55-1.75 µm) with a spatial resolution of 30 meters. Landsat Images with minimal cloud cover (Table 1) over the area were acquired in different dates throughout the growing season (from June 11 till October 1, 2008), and this will allow us to capture most of the growing crops.

Table 1: Acquired Landsat images

Date (2008)	Day of year	Landsat	Path	Row	Watershed cloud cover (%)
June 11	163	5	38	33	0
June 27	179	5	38	33	4
July 29	211	5	38	33	12
August 14	227	5	38	33	5
August 30	243	5	38	33	41
September 15	259	5	38	33	6
October 1	275	5	38	33	8

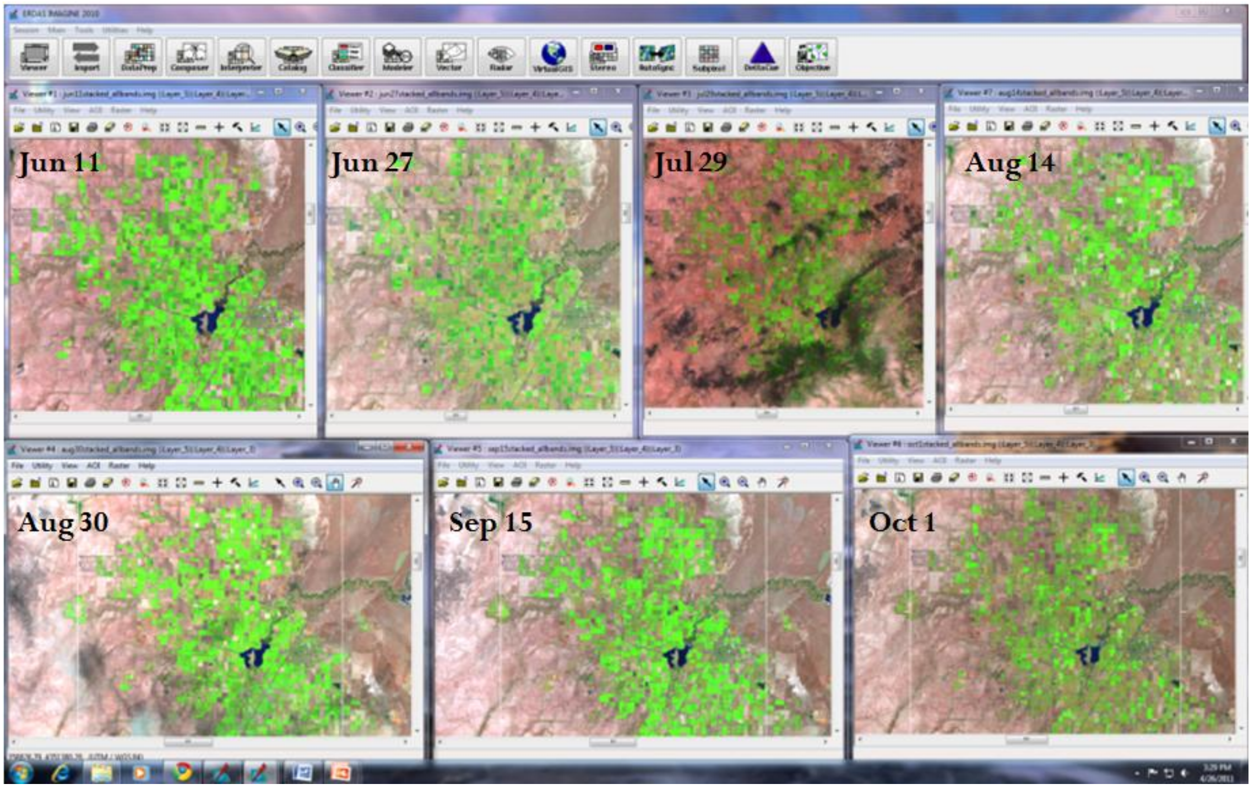


Fig.2. Landsat TM5 images

3. Image Calibration

Atmospheric correction for the images was required, so the satellite images were analyzed and calibrated using ERDAS Imagine software. In order to accomplish this, the COST method (Chavez, 1996) was used. This tool creates a spatial model (.gmd file) that converts digital number (DN) to reflectance. The calibration is done using the following equations:

$$L_\lambda = \left(\frac{LMAX_\lambda - LMIN_\lambda}{Q_{calmax} - Q_{calmin}}\right)(Q_{cal} - Q_{calmin}) + LMIN_\lambda$$

And

$$\rho_\lambda = \frac{\pi . L_\lambda . d^2}{ESUN_\lambda . cos\theta_s}$$

Where,

L_λ = Spectral Radiance at sensor (W $m^{-2}sr^{-1}\mu m^{-1}$)

Q_{cal} = Quantized calibrated pixel value (DN)

Q_{calmin} = Minimum quantized calibrated pixel value (DN)

Q_{calmax} = Maximum quantized calibrated pixel value (DN)

$LMIN_\lambda$ = Spectral at-sensor Radiance scaled to Q_{calmin} (W $m^{-2}sr^{-1}\mu m^{-1}$)

$LMAX_\lambda$ = Spectral at-sensor Radiance scaled to Q_{calmax} (W $m^{-2}sr^{-1}\mu m^{-1}$)

ρ_λ = Planetary TOA reflectance (unitless)

L_λ = Spectral Radiance at sensor (W $m^{-2}sr^{-1}\mu m^{-1}$)

d = Earth-Sun distance (astronomical units)

$ESUN_\lambda$ = Mean exoatmospheric irradiance ($Wm^{-2}\mu m^{-1}$)

θ_s = Solar Zenith angle (degrees)

For this method, a dark value needs to be collected from the statistics of each image using ERDAS IMAGINE. And some of the coefficients needed for the calibration are listed in Table 2.

Table 2: ESUN coefficients for every band of Landsat TM5

Coefficients for every band of Landsat TM5.

TM Sensors (Q_{calmin} = 1 and Q_{calmax} = 255)							
Band	Spectral range	Center wavelength	$LMIN_{\lambda}$	$LMAX_{\lambda}$	$G_{rescale}$	$B_{rescale}$	$ESUN_{\lambda}$
Units	µm		$W/(m^2\ sr\ m)$		$(W/m^2\ sr\ m)/DN$	$W/(m^2\ sr\ m)$	$W/(m^2\ m)$
L5 TM							
1	0.452 - 0.518	0.485	-1.52	193	0.765827	-2.29	1983
2	0.528 - 0.609	0.569	-2.84	365	1.448189	-4.29	1796
3	0.626 - 0.693	0.660	-1.17	264	1.043976	-2.21	1536
4	0.776 - 0.904	0.840	-1.51	221	0.876024	-2.39	1031
5	1.567 - 1.784	1.676	-0.37	30.2	0.120354	-0.49	220.0
6	10.45 - 12.42	11.435	1.2378	15.3032	0.055376	1.18	N/A
7	2.097 - 2.349	2.223	-0.15	16.5	0.065551	-0.22	83.44

Then a model (Fig. 3) was developed in ERDAS IMAGINE to calibrate those images using COST method.

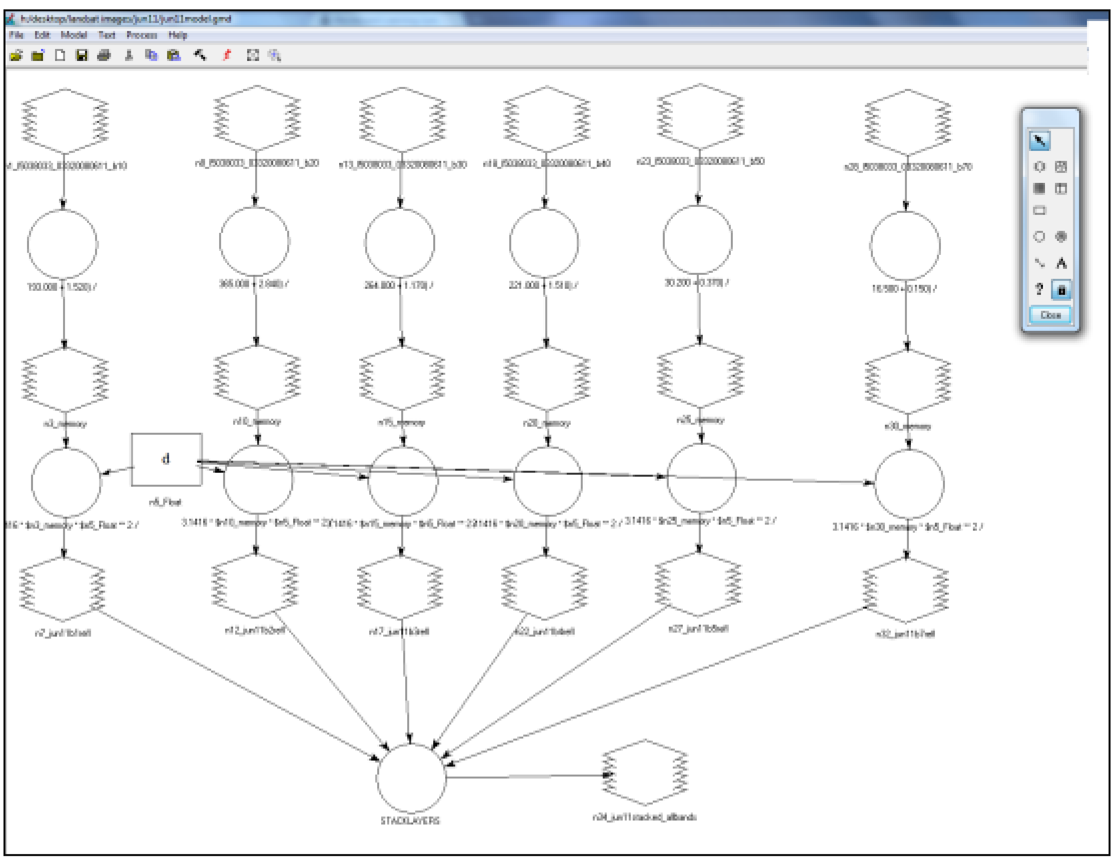


Fig.3. Calibration model (COST method)

4. Unsupervised classification

After correcting the images, a thorough look at all the images, was done to choose three cloud-free images that captures the growing crops, based on our knowledge of the growing cycle for each crop. Then a 6-band image (Fig. 4) was developed in ERDAS Imagine by stacking bands 4 (NIR) and band 3 (RED) of images from June 11, June 27 and August 30. This image was developed to get a better estimate of the crops and avoid misclassification.

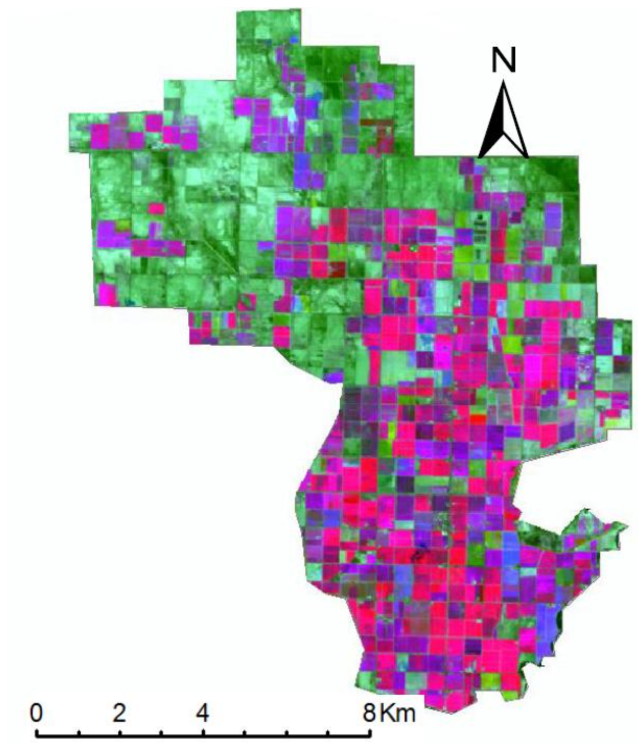


Fig.4. The 6-bands image

a) Classification using ArcGIS

After stacking the 6-band image, it was imported to ArcGIS as a raster in order to be classifed. Prior to that, the area outside Canal B irrigation was left out using the Clip function of ArcGIS.

Since no signature files are available (ground points), it was decided to run an unsupervised classification that will take the input raster and classify it depending on different reflectance of each pixel of the image. to accomplish this, the "Iso Cluster Unsupervised Classification" was used from ArcGIS. It takes as input the 6-band image (Fig 4), 10 classes were chosen to classify this image. The output of this tool is a classified raster image that was recolored depending on each crop (Fig. 5).

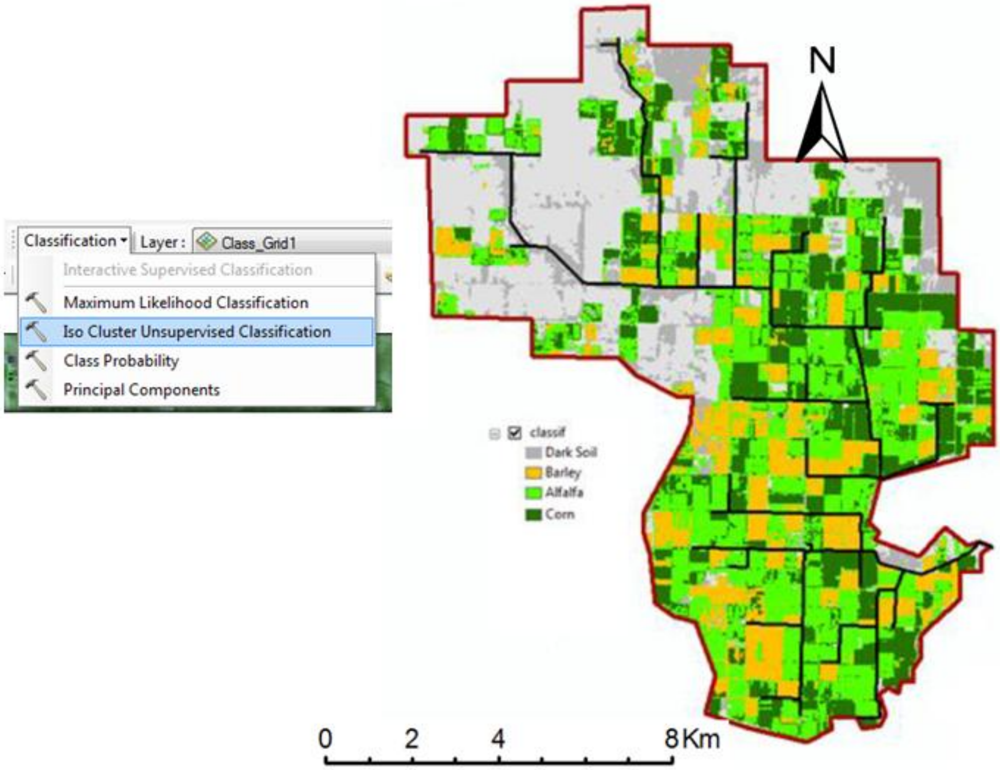


Fig.5. Recolored classified image (unsupervised classification using ArcGIS)

The classification using ArcGIS resulted in the areas for each crop as follows: 3,346 ha of Alfalfa, 1,972 ha of Corn and 1,543 ha of Barley, and the rest of the area was classified as fallow (or bare soils) with an area of 3,924 ha.

Since we were not sure of the accuracy of the classification in ArcGIS, and since we had no experience with this tool, some validation or comparison would make the resulting classification more robust. For that reason, we decided to run and compare an unsupervised classification for the same 6-band image in ERDAS Imagine that is a software used in remote sensing especially for classifications.

b) Using ERDAS Imagine

The 6-band image that was developed earlier was used in ERDAS Imagine for an unsupervised classification, it was done with 70 classes, 20 iterations. The resulting images was recolored for the different crops, and a final recoded image with 7 classes only was developed (Fig. 6) to serve for comparisons with the ArcGIS classification results.

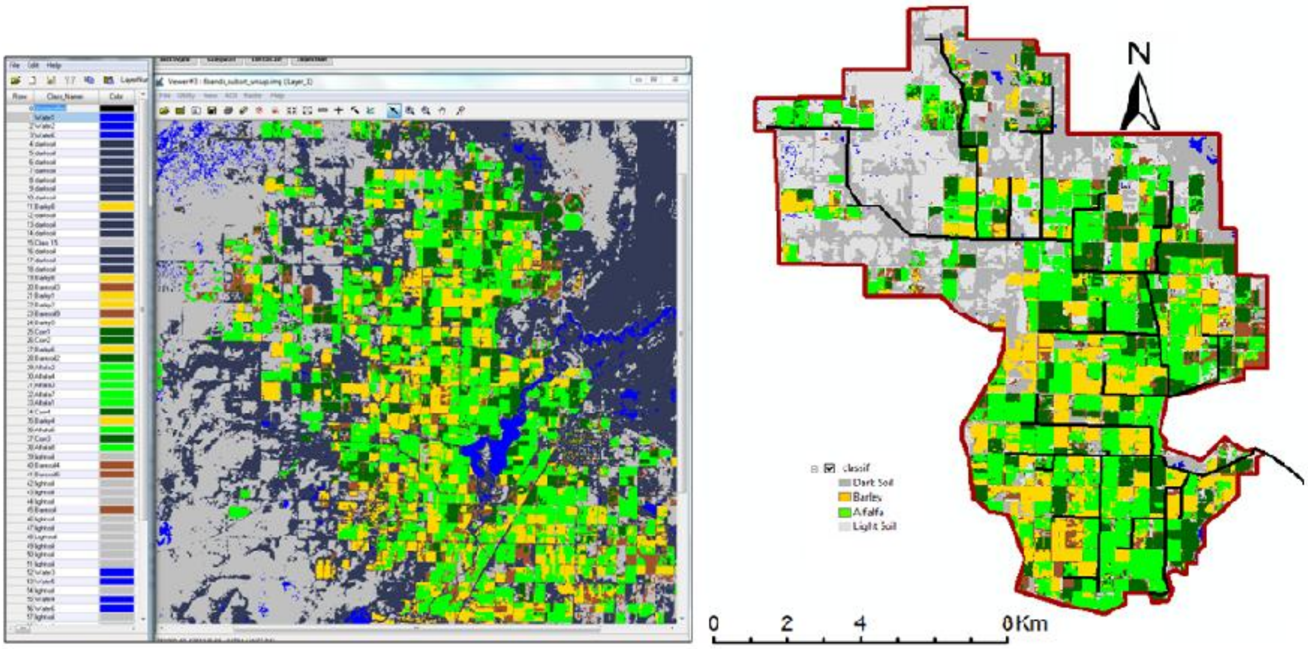


Fig.6. Recolored classified image (unsupervised classification using ERDAS Imagine)

The classification results are shown in Table 3, where it is noticed to have two additional classes (Water and Baresoil) that ArcGIS was not able to detect. We also notice that ArcGIS estimated more corn and barley than ERDAS, and less fallow vegetation. This will lead to an overestimation of the crop water requirements, but it will still be used in this project to estimate the irrigation system efficiency. Results of classification for the same area and same year were also done by Torres *et al.* (2011) using a MATLAB code to classify image, those results are very close to the ones from ERDAS Imagine.

Table3 : Areas of different classes of classification

VALUE	CLASS_NAME	Area (ha)		
		ArcGIS	ERDAS Imagine	Torres *et al.* (2011)
1	Barley	1,543	1,566	1,505
2	Corn	1,972	1,346	1,578
3	Alfalfa	3,346	2,627	2,783
4	Water	-	68	72
5	Baresoil	-	679	741
6	Fallow	3,924	4,661	4,253
Total		**10,785**	**10,947**	**10,938**

5. Crop water requirements

The crop water requirement (CWR) is usually equivalent to the crop evapotranspiration (ET_c) minus the effective rainfall. since the study was done during the growing season (May-September) it was assumed that the precipitations are negligible. But, since during the presentation there was a question about this issue, the precipitation for this season was extracted from Delta weather station and results are plotted in Fig. 7, and then the results were taken into consideration while computing the CWR.

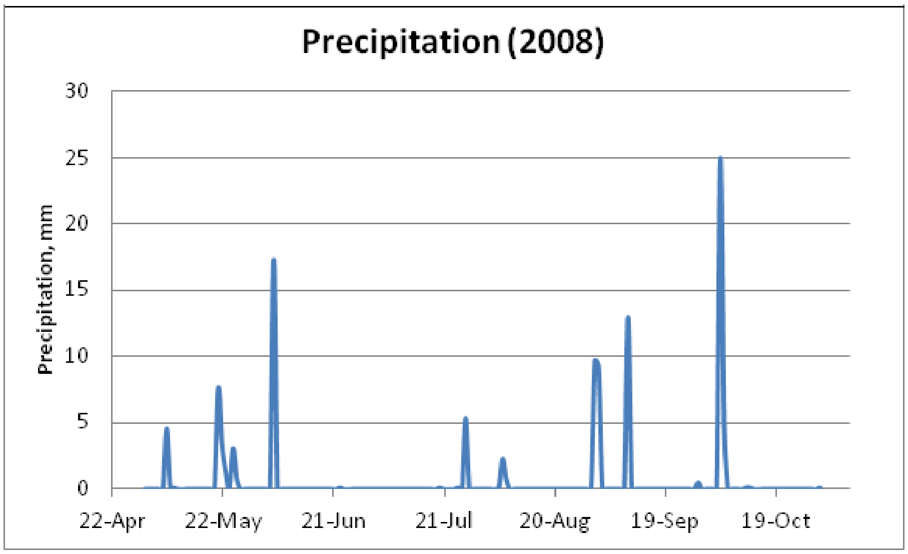


Fig.7.: Rainfall data for 2008 growing season

The crop evapotranspiration (ET_c) can be computed using the following equation:

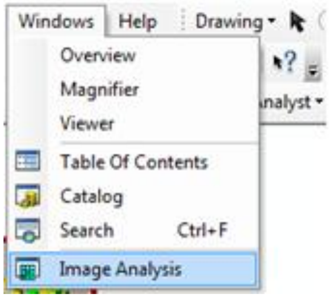
$$ET_c = ET_o * K_c$$

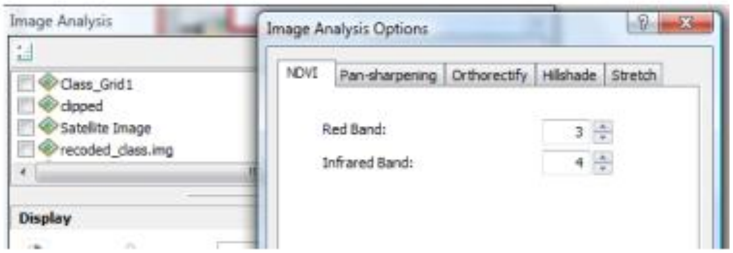
where, ET_o is the reference evapotranspiration that we get from the weather station (Annex 1) and K_c is the crop coefficient.

In general K_c is given in the literature for each crop, but it is site specific and is sometime not very accurate. On the other hand, studies showed that K_c values can be obtained by a linear relationship with the normalized difference vegetation index (NDVI). The NDVI is given by the following equation as suggested by Huete *et al.* (1988) relating NDVI to the near infrared (NIR) and Red bands reflectance of an image:

$$NDVI = \frac{NIR - Red}{NIR + Red}$$

The image analysis tool in ArcGIS provides an option to calculate NDVI for a raster image as shown below:





in order to get the crop coefficient, satellite image for each date was analyzed for seperately, and an NDVI image was developped. Then we selected 5-6 pixels for each crop, from which we got an average of the NDVI for that date. And we were able to get the K_c values for each crop using the equations developed by (Rocha *et al*., 2010):

- K_c (corn) = 1.37*NDVI – 0.017
- K_c (alfalfa) = 1.36*NDVI – 0.031
- K_c (Barley) = 1.25*NDVI – 1.37

Results and discussion

After getting the K_c for each crop, they were plotted against the values from literature (Fig. 8). it is obvious from this figure that the actual values of K_c are different from those in the literature but follow the same trend. So the Kc from NDVI will be used to calculate the crop water requirement. It is noticed that Barley had a peak K_c in June then dropped down after harvest. While Corn starts growing in June to reach a peak in late August when the K_c gets close to 1, and then drops down after senescence. On the other hand, Alfalfa, that is being cut several times during the season, shows a fluctuating K_c curve.

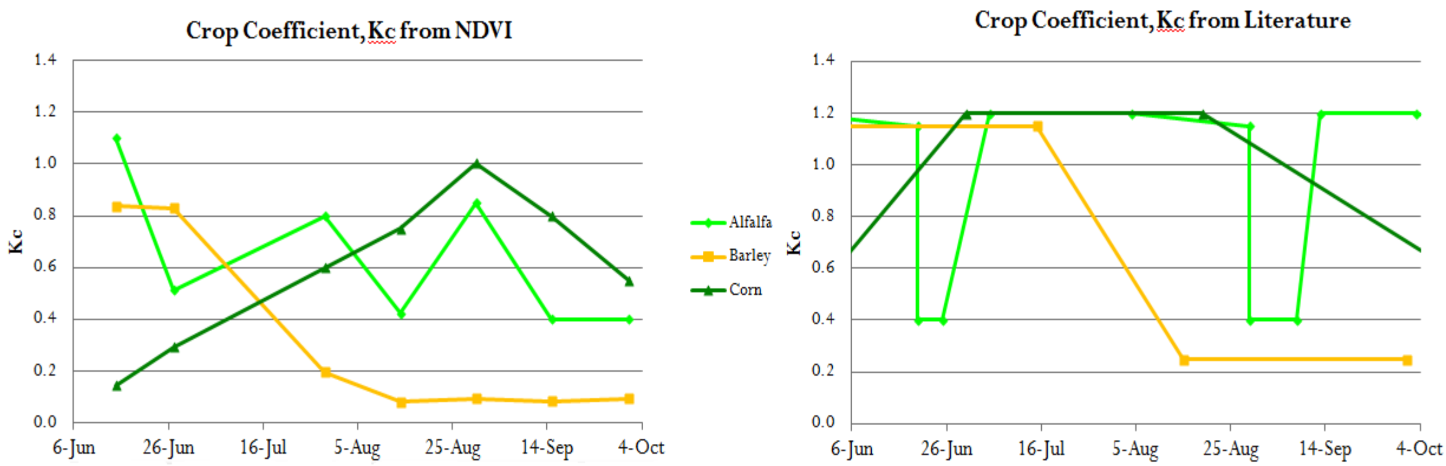


Fig.8. Crop coefficient curves for each crop

From the K_c values, and after getting the potential ET_o for those dates, we calculated the actual ET_c for each crop as plotted in Fig.9. The ET_c shows the same trend as the K_c curves. Those results (Annex 1) were used to calculate CWR (biweekly averages) then the total crop water demand was estimated for the total irrigated area as 30,689,092 m^3 (about 31 million cubic meters MCM).

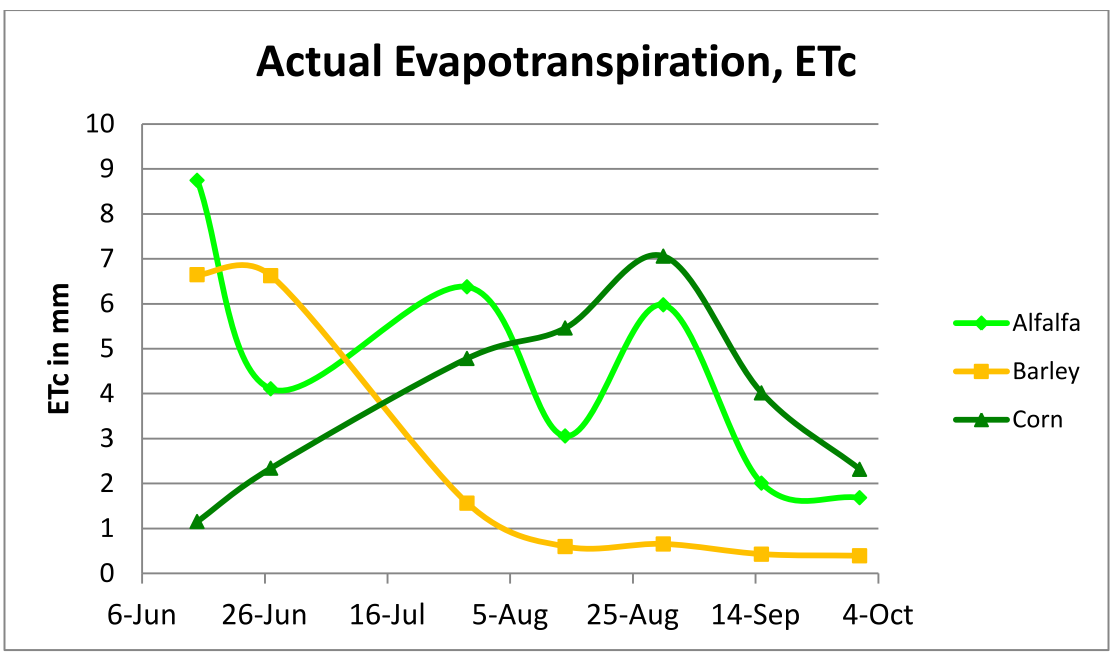


Fig.9. Actual evapotranspiration for each crop

On the other hand, the Sevier River water users association provides a webpage from where the real-time flow data can be downloaded. Those flow measurements are recorded by a USBR gaging station located at the canal B diversion. The flow of canal B for the 2008 season is shown in Fig.10, where the drop in flow during the season corresponds sometime to a period following a rainfall event or it occurs after cutting alfalfa which will results in no-irrigation for few days.

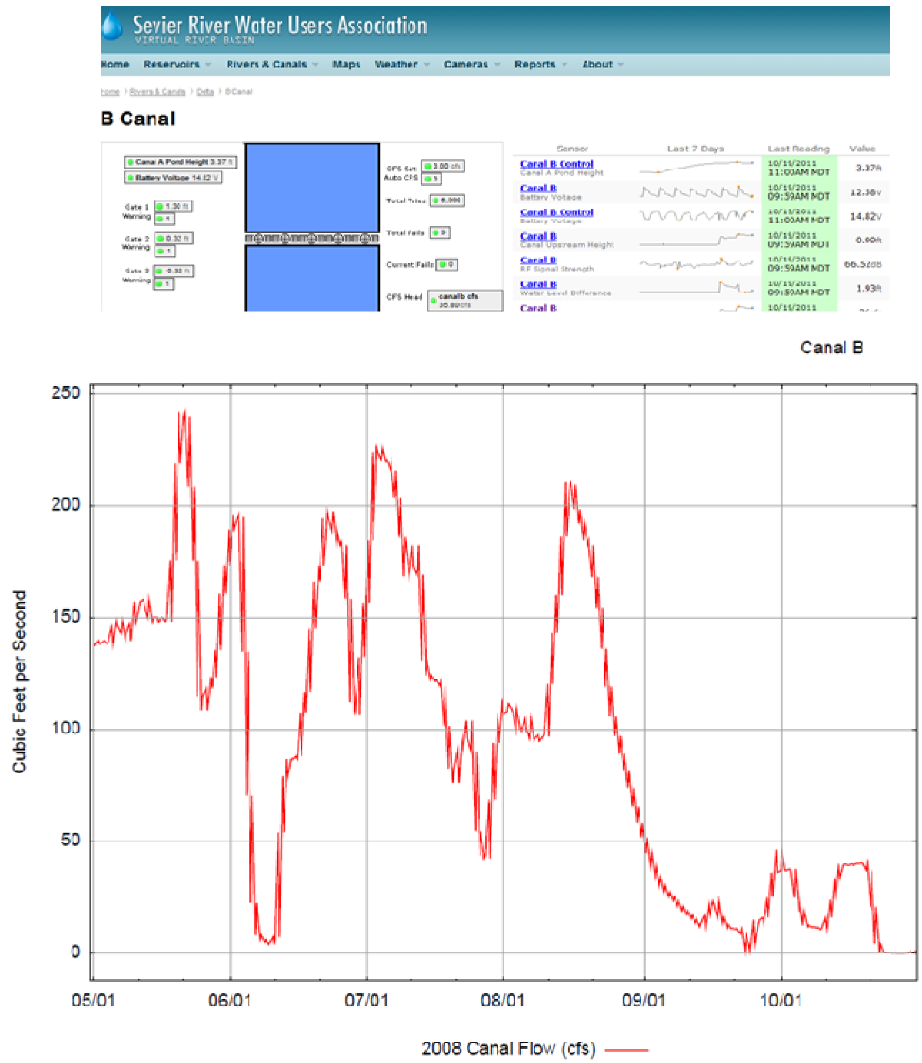


Fig. 10: Canal B flow measurements

Total flow (Q) from canal B for the irrigation season was calculated (Annex1) and it was about 49 MCM, and the calculations showed that the total Crop Water Requirement (CWR) for the irrigated area is about 31 MCM. this results in a System Efficiency of: Eff = CWR/Q = 63%.

This efficiency is considered low for irrigation systems, but there are many factors that contribute to this low value that should be analyzed in further studies.

Conclusion and recommendations

In conclusion, it was obvious that ArcGIS is a very useful tool in irrigation management. It can be used to perform a rough crop classification, generate the crop coefficient based on some image analysis, and estimate the crop water demand accurately.

This study showed that the irrigation efficiency is very low, even though we used the classification from ArcGIS that was overestimating the areas of the crop, hence estimate more water demand. And this can be due to poor irrigation application since it is mainly surface irrigation, or due to conveyance efficiency (some of the canals are earthen canals with lots of weeds in them), etc... But it is clear that the farmers are using more than the crops needs and by better estimating the CWR we can achieve better efficiency and probably expand the irrigated area.

Future work can be done to complete this study, for example, looking through the piece of the system efficiency and evaluate each component. On the other hand, perform a supervised classification using ArcGIS which might result in better classification especially that it will take into consideration real data from the field. And to be more practical and helpful for farmers, a method to forecast CWR spatially and few days in advance should be developed for better management of irrigation in the Sevier river basin.

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Annex

Annex 1: Crop water requirements calculation, flow measurements and efficiency of the system

Date	ETo (mm/day)	Kc			ETc (mm/day)			ETc (m^3/total area/day)			Total CWR (m^3)	Canal B flow	
		Corn	Alfalfa	Barley	Corn	Alfalfa	Barley	Corn	Alfalfa	Barley		cfs	m^3/2weeks
May 1-15	4.85	0.10	0.40	0.35	0.49	1.94	1.70	6,530	50,988	26,600	1,261,765	146	5,353,108
May 16-31	5.78	0.10	0.70	0.55	0.58	4.05	3.18	7,777	106,274	49,785	2,621,363	165	6,456,351
Jun1-15	6.15	0.16	1.10	0.85	0.98	6.76	5.23	13,238	177,664	81,852	4,091,299	76	2,806,223
Jun 16-30	8.36	0.29	0.50	0.80	2.42	4.18	6.69	32,622	109,799	104,742	3,707,435	150	5,521,922
Jul 1-15	8.01	0.45	0.60	0.35	3.60	4.80	2.80	48,490	126,214	43,896	3,278,993	186	6,816,161
Jul 16-31	7.94	0.60	0.80	0.20	4.77	6.36	1.59	64,143	166,958	24,886	4,095,778	89	3,474,138
Aug 1-15	7.13	0.75	0.40	0.15	5.35	2.85	1.07	71,938	74,899	16,746	2,453,744	123	4,496,807
Aug 16-31	6.52	1.00	0.85	0.09	6.52	5.54	0.59	87,770	145,642	9,194	3,881,710	132	5,179,401
Sept 1-15	4.73	0.80	0.65	0.10	3.78	3.07	0.47	50,878	80,699	7,402	2,084,689	26	961,504
Sept 16-30	4.68	0.70	0.40	0.10	3.27	1.87	0.47	44,052	49,141	7,325	1,507,768	15	557,819
Oct 1-15	2.77	0.55	0.40	0.10	1.52	1.11	0.28	20,507	29,116	4,340	809,448	25	919,913
Oct 16-31	2.61	0.50	0.50	0.10	1.31	1.31	0.26	17,565	34,290	4,089	895,100	32	1,252,647
										Total:	30,689,092		48,490,994
												Efficiency	0.63