

Optimizing crop water consumption using ET maps in GIS
CEE6640 Term Paper
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Introduction

Water is essential for crop production, and any shortage has an impact on final yields. Since farmers have a tendency to over-irrigate, an approach runs counter to the conservation of scarce resources. Still gains in water use efficiency can be achieved when water application is precisely matched to the spatially distributed crop water demand. Apart from precipitation, the most significant component of the hydrologic budget is evapotranspiration which is studied in this project. As precipitation falls and soaks into the soil, a plant absorbs it and then transpires it through its leaves, stem, flowers, and/or roots. When this is combined with the evaporation of moisture that was not directly absorbed by the soil, a significant amount of water vapor is returned to the atmosphere. Factors that affect evapotranspiration include the plant's growth stage or level of maturity, percentage of soil cover, solar radiation, humidity, temperature, and wind. Evapotranspiration varies regionally and seasonally; during a drought it varies according to weather and wind conditions. Because of this variability, water managers who are responsible for planning and adjudicating the distribution of water resources to increase crop yield, need to have a thorough understanding of the evapotranspiration process and knowledge about the spatial and temporal rates of evapotranspiration to determine final benefits. So determination of crop production functions which describe the relationship between irrigation water and crop yield under the assumption of optimal irrigation scheduling is a major building block for a more efficient and sustainable water management.

Project objective:

By considering planted crops information, and their related evapotranspiration ratio, required amount of water for irrigation would be determined and net benefits for selling the crops would be maximized by regarding to the constraint for cost/price and water resource (share for canal B) which is limited by available stream flow.

Data and Methodology:

The tools for this study were made available through ArcGIS 10 including ArcCatalog 10 and LINGO optimization modeling software. My field of study was Delta which is a city in Millard County, Utah, United States and it is a major agriculture area in the Sevier River Basin. The data were imported to ArcGIS and projected to Lambert_Conformal_Conic and adjusted to the CGS North American 1983 spatial reference. Image classification here, refers to the task of extracting information classes from a multiband (bands 2-3 and 4) raster image. The resulting raster from image classification is used to create thematic maps. The Image Classification toolbar was used to classify a Landsat TM satellite image. The following raw satellite image is a 3-band Landsat TM image of

Delta. In Delta water is diverted based on requests from the farmers depending on their water shares. Below map (figure (1)) shows the field of study and canal B.

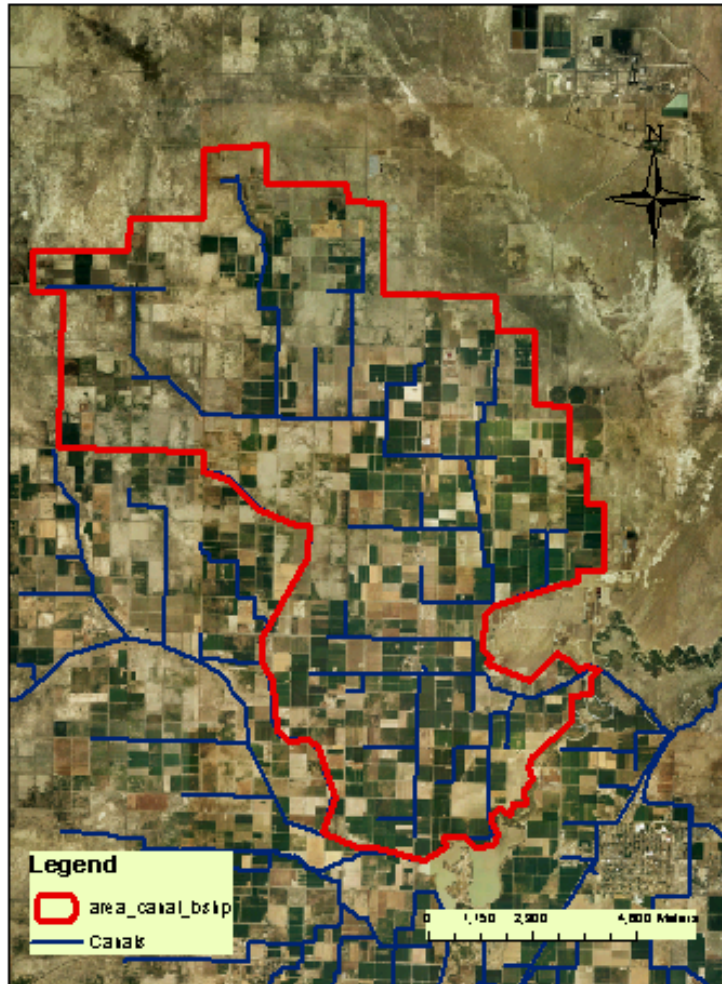


Figure (1): Canal B and its irrigation area in Delta, UT

As was mentioned, in this project, three landsat images (bands 2-3 and 4) were applied to form a new raster which includes all characteristics for three landsats. In this step, combine tool from spatial analyst tools was used that combines multiple rasters so that a unique output value is assigned to each unique combination of input values. Figure (2) shows raw satellite image which is a three-band Landsat TM.

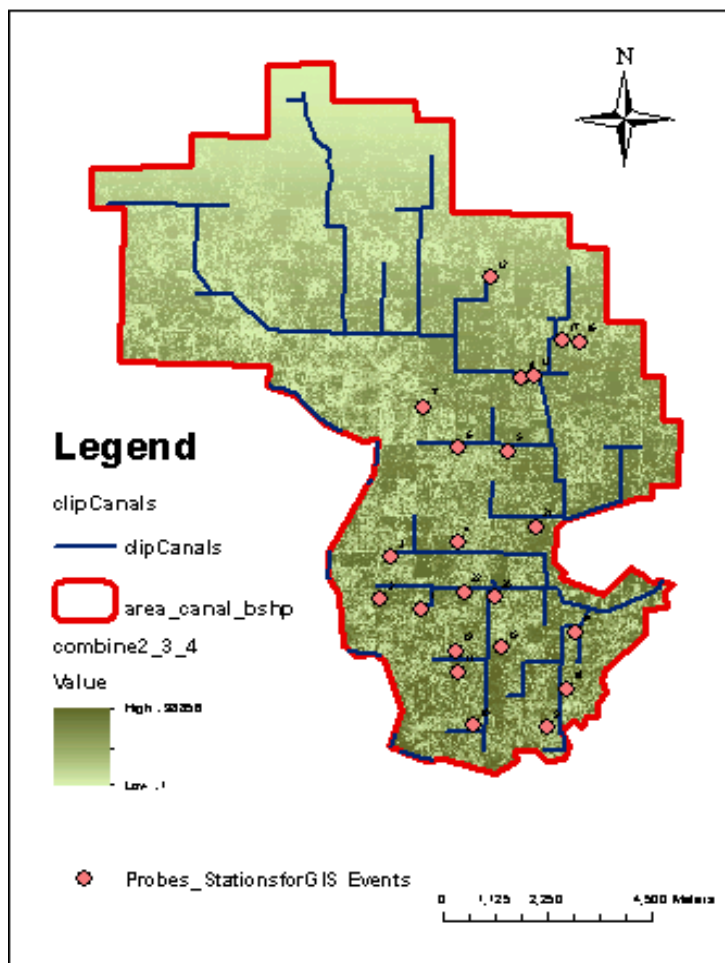


Figure (2): Landsat 4-5 TM, Delta, UT

Classification:

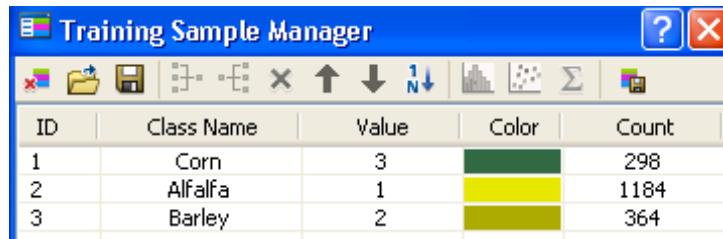
In ArcGIS Spatial Analyst, there is a full suite of tools in the Multivariate toolset to perform supervised and unsupervised classification by using training samples. To create training samples, land cover information in some areas were needed. For the previous studies on Delta, in order to record soil moisture values of some agricultural fields under irrigation by Canal B, 22 sensors were installed. This was performed by the installation of 4 soil moisture sensors at two different deeps 1 and 2 ft So land cover on both sides of these sensors' were know and for this project these farms were applied as training samples.

Crop installed 2010	Field A	B	B	C	B	A	A	A	A	A	B	C	A	A	C	A	A	B	A	A	A	A
	Field B	B	B	C	B	A	A	C	A	A	A	B	C	A	A	C	A	A	A	A	C	A

A: Alfalfa - B: Barley - C: Corn

Table (1): Land –cover at both sides of stations

In this study, unsupervised classification was used which finds spectral classes (or clusters) in a multiband image. The Image Classification toolbar aids in unsupervised classification by providing access to the tools to create the clusters, capability to analyze the quality of the clusters, and access to classification tools. Here the Image Classification toolbar was used to classify a Landsat TM satellite image. Using the toolbar, three land-cover classes were defined from the satellite image: Alfalfa, Barley and Corn. Figure (3) shows these training samples.



ID	Class Name	Value	Color	Count
1	Corn	3	Dark Green	298
2	Alfalfa	1	Yellow	1184
3	Barley	2	Olive Green	364

Figure (3): Training samples

Using the Image Classification toolbar and Training Sample Manager, it was determined the training samples were representative for the area and statistically separate. Therefore, a maximum likelihood classification was performed from the toolbar. The classified image was then cleaned to create the final land-cover map as shown below.

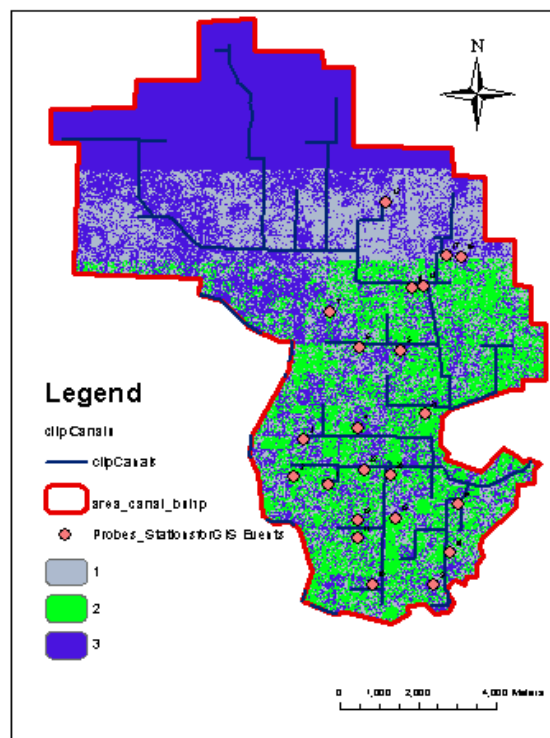


Figure (3): Unsupervised image classification (Land-cover map)

Rowid	VALUE	CROP_NAME	COUNT	ET_MEAN	TOTAL_WATER	AREA
0	1	Alfalfa	28784	3.3023766938	95055.61	25905600
1	2	Barley	29526	3.3470488677	98824.96	26573400
2	3	Corn	57560	3.3491928801	192779.5	51804000

Table (2): Attribute table of classified raster

The next step after classification was finding a correlation between classified land-cover raster and ET map raster. In this stage Zonal Statistic tool from Spatial Analyst tools was used. With the Zonal Statistics tool, a statistic is calculated for each zone defined by a zone dataset, based on values from another dataset (a value raster). A single output value is computed for every zone in the input zone dataset. The Zonal Statistics as Table tool calculates all, a subset or a single statistic that is valid for the specific input but returns the result as a table instead of an output raster which is the choice of this study to have value for optimization calculations. A zone is all the cells in a raster that have the same value, whether or not they are contiguous. The input zone layer defines the shape, values, and locations of the zones. An integer field in the zone input is specified to define the zones. A string field can also be used. Both raster and feature datasets can be used as the zone dataset. The input value raster contains the input values used in calculating the output statistic for each zone. The output data type is determined by both the selected statistic type and the value input type. Here, each crop was defined as a zone and ET map was assumed as zone field with range statistic type.

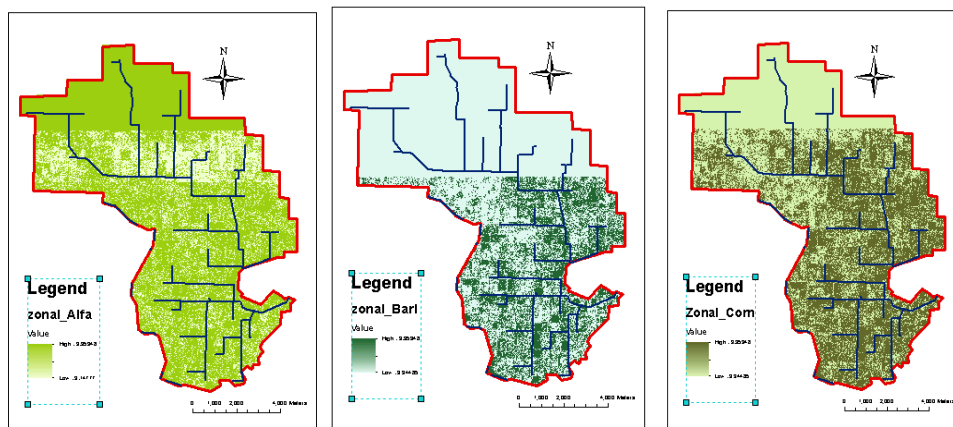


Figure (4): Zonal Statistics results for each crop

Optimization:

When water supply does not meet crop water requirements, actual evapotranspiration (ET_a) will fall below maximum evapotranspiration (ET_m) or ET_a < ET_m. Under this condition, water stress will develop in the plant which will adversely affect crop growth and ultimately crop yield. The effect of water stress on growth and yield depends on the crop species and the variety on the one hand and the magnitude and the time of occurrence of water deficit on the other. The effect of the magnitude and the timing of water deficit on crop growth and yield are of major importance in scheduling available but limited water supply over growing periods of the crops and in determining the priority of water supply amongst crops during the growing season. Because of above reasons finding a way to minimize decrease in yield will conclude to maximize benefits from selling the crops. In this study LINGO optimization software is used to maximize benefits by using yield function basis as an objective function.

Yield function is a linear crop-water production function which was introduced in the FAO Irrigation and Drainage Paper No33 to predict the reduction in crop yield when crop stress was caused by a shortage of soil water:

$$\left(1 - \frac{Y_a}{Y_m}\right) = K_y \left(1 - \frac{ET_{cadj}}{ET_c}\right) \quad \text{Equation (1)}$$

Where: Y_a = Actual Yield, Y_m = Maximum Yield, ET_{cadj} = Actual ET, ET_c = Maximum ET and K_y = Yield Response factor

ET_{cadj} = Actual ET and ET_c = Maximum ET can be derived from table(2) and figure (5) and K_y is obtained from FAO No.33 as below.

Crop	Maximum Yield ton/acre	Maximum ET mm/day	Actual ET mm/day	Yield Response Factor -	Cost \$/ton	Area acres
Alfalfa	20	3.35348	3.302376694	0.9	99.79	6401.41
Barley	5	3.35348	3.347048868	1.07	158.38	6566.43
Corn	8.5	3.35348	3.34919288	1.25	186	12801.05

Table (3): Required parameters for optimization

Optimization using LINGO

```
! Solving problems by LINGO;
Model:
! Objective Function;

!cost(dollar per ton)
!Cost_Alfalfa = 99.79;
!Cost_Barley = 158.38;
!Cost - Corn = 186;
```

These prices are derived from Utah Department of Agriculture and food web site for year 2010.

```
!water_cost_alfa =0.0000836;
!water_cost_barl =0.0000836;
!water_cost_corn =0.0000836;
```

This price is derived from Utah Division of water rights web site for year 2010.

```
! water_volume_alfa = ET_a_alfa(mm/day)* growing season(day)*
area_alfa(square meter);
! water_volume_barl = ET_a_barl(mm/day)* growing season(day)*
area_barl(aquare meter);
! water_volume_corn = ET_a_corn(mm/day)* growing season(day)*
area_corn(square meter);
```

These equations are used to change the amount of required water for crops, to volumetric units in order to fit with unit for canal capacity.

```
max = y_a * 6401.41 * 99.79
      + y_b * 6566.43 * 158.38
      + y_c * 1281.05 * 186
      - 3.3023766 *30*8* 25905587 * 0.0000836 *0.001
      - 3.3347048 *30*5* 26573399 * 0.0000836 *0.001
      - 3.3491929 *30*5* 51804011 * 0.0000836 *0.001;
```

```
!water_volume_alfa + water_volume_barl + water_volume_corn <= canal
capacity;
```

```
(y_a-2)/5.3683 *0.001 * 25905587
+ ((0.2*y_b)-0.07)/0.319 *0.001 * 26573399
+ ((y_c/8.5)+0.25)/0.3728*0.001 * 51804011<=85631;
```

```
y_a<=20;
y_b<=5;
y_c<=8.5;
```

end

Decision Variables	Optimal value	Optimal solution
Y_a	1.210863	2971397
Y_b	1.656710	
Y_c	2.014230	

Table (4): optimization result

It can be concluded that, maximum benefits from selling crops in Delta, is about 3million dollars.

The screenshot shows the 'Lingo 13.0 Solver Status [1]' dialog box. It contains the following information:

- Solver Status:**
 - Model Class: LP
 - State: Global Opt
 - Objective: 2.9714e+006
 - Infeasibility: 0
 - Iterations: 0
- Extended Solver Status:**
 - Solver Type: . . .
 - Best Obj: . . .
 - Obj Bound: . . .
 - Steps: . . .
 - Active: . . .
- Variables:**
 - Total: 3
 - Nonlinear: 0
 - Integers: 0
- Constraints:**
 - Total: 8
 - Nonlinear: 0
- Nonzeros:**
 - Total: 12
 - Nonlinear: 0
- Generator Memory Used (K):** 22
- Elapsed Runtime (hh:mm:ss):** 00:00:00

At the bottom, there is an 'Update Interval' set to 2, and buttons for 'Interrupt Solver' and 'Close'.

Global optimal solution found.

```

Objective value:                2971397.
Infeasibilities:                 0.000000
Total solver iterations:         0

Model Class:                     LP

Total variables:                  3
Nonlinear variables:              0
  
```



```

Integer variables:           0
Total constraints:          8
Nonlinear constraints:      0

Total nonzeros:            12
Nonlinear nonzeros:        0

```

	Variable	Value	Reduced
Cost			
0.000000	Y_A		1.210863
0.000000	Y_B		1.656710
0.000000	Y_C		2.014230
	Row	Slack or Surplus	Dual
Price			
1.000000	1		2971397.
132.3750	2		0.000000
0.000000	3		18.78914
0.000000	4		3.343290
0.000000	5		6.485770
0.000000	6		0.2108632
1165435.	7	0.000000	-
1925811.	8	0.000000	-

Recommendations for future studies:

By using remote sensing methods, it is possible to get thorough information of evapotranspiration which helps water managers to forecast ET for future, so it helps farmers to estimate their crop water demands to avoid over irrigation.

References

<http://glovis.usgs.gov/>

<http://en.wikipedia.org/wiki/Evapotranspiration>

<http://www.fao.org/landandwater/aglw/cropwater/parta.stm>

<http://help.arcgis.com/en/arcgisdesktop/10.0/help/index.html#//00qp0000000v000000.htm>

<http://ag.utah.gov/news/publications/reports.html>

<http://www.waterrights.utah.gov/>