NNA07CN10A: Enhancing Water Management Decision Support Systems with High Spatio-temporal Resolution Mapping of Actual Evapotranspiration

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Annual Report – February 2009

Table of Contents

1. **Summary** 1
2. **Benchmarking** 1
3. **Enhancements to Performance of METRIC in Study Areas** 17
4. **Research Extension: Conferences Attended and Papers Written** 24
5. **Issues and concerns** 26
6. **References** 26

1. Summary

ET from agricultural fields is usually estimated by multiplying the weather-based reference ET by crop coefficients (Kc) determined according to the crop type and the crop growth stage. There is typically some question regarding whether the crops grown compare with the conditions represented by the Kc values, especially in water short areas. Riverside Technology, inc. (RTi) is using NASA earth-sun system results and modeling procedures to achieve temporal calibration and refinement of traditional crop coefficients curves in the South Platte River basin using Mapping Evapotranspiration at High Resolution with Internalized Calibration - METRIC™ (Allen et. al 2007). This has potential to enhance existing water DSS, specifically consumptive use models, resulting in better water demand forecasting, water rights management, water resources planning, and water regulation. METRIC, an image-processing model for calculating actual ET as a residual of the surface energy balance, utilizes the thermal band on various satellite remote sensors.

In 2008, RTi has processed NASA imagery for an additional growing season, and has fully developed a tool called ArcGIS ET Server to conduct benchmarking. This application facilitates project stakeholders' involvement in benchmarking at user specific locations, and at the temporal and spatial scales most appropriate for their water management decision-making processes.

In 2008, RTi has continued to work with our research partners at the University of Idaho on a new version of the METRIC model that uses lapse-adjustment to surface temperature. This has been applied to Landsat images for path 32/32 row 32 in NE Colorado. The project team has improved standardization of Land use class nomenclature and associated aerodynamic roughness values that are used in internal calculations within METRIC.

In 2008, the project team have continued development of automated thermal sharpening for satellite images with special emphasis on thermal pixels having mixed water and land information. The sharpening procedure has been transported from ERDAS into ARC-GIS for more efficient development and testing. The sharpening has application to both Landsat and MODIS images.

In 2008, the project team have developed a kriging procedure for producing spatial maps of daily reference evapotranspiration (ET) (based on weather data) to use in developing daily and monthly images of actual ET from the METRIC surface energy balance procedure by multiplying the reference ET maps by the fraction of reference ET as determined by METRIC. We have explored using a better procedure for estimating aerodynamic roughness of tall vegetation such as trees inside METRIC.

In 2008 the project team have prepared numerous conference manuscripts and presentations to present at the 2007 and 2008 AGU, the May 2008 EWRI meeting in Hawaii, the November 2008 Pecora meeting in Denver, and the May 2009 EWRI meeting in Kansas City, and a Drought workshop.

2. Benchmarking

South Platte Decision Support System (SPDSS)

Improvements in the accuracy of ET estimates or in the processing efficiency of consumptive use demand for large irrigated lands and associated verification can greatly benefit core SPDSS capabilities to better understand the temporal and spatial relationships between water demand and water availability, ultimately leading to better water planning decisions and water management. Having complete information on ET is essential to the better understanding of consumptive use and soil moisture availability.

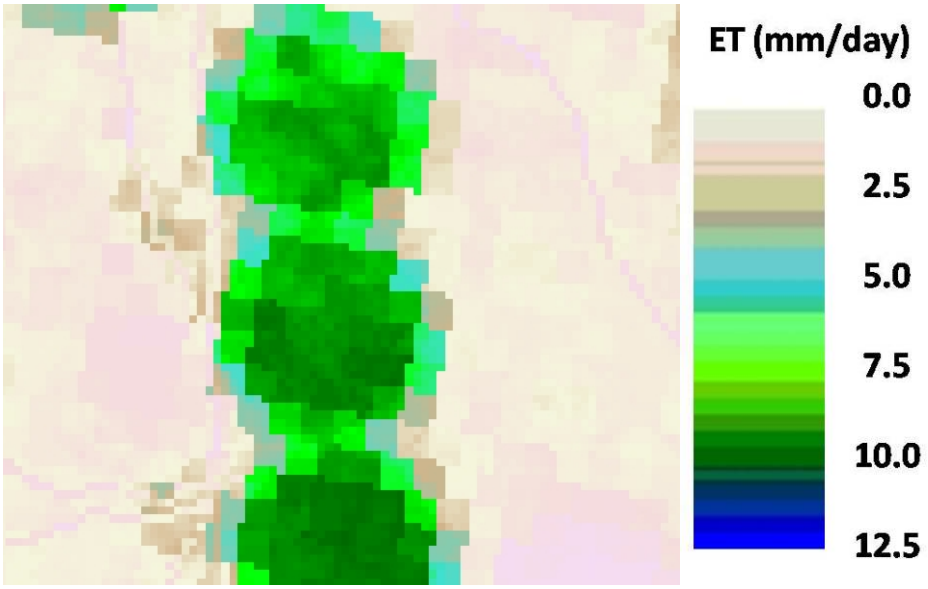


Figure 1. METRIC generated 24-h ET map on July 16 2001 along the South Platte River south of Sterling, CO.

Supported by NASA-ROSES funding, RTi has advanced ET-remote sensing science and applications in the past year with development of an ArcGIS ET-Server application. This benchmarking application, prototyped in YRI, has been fully developed to allow users to select and analyze remote sensing-based ET data in areas-of-interest by digitizing on-screen or by geographic analysis - for example, by selecting all data (pixels) that lie within a specified irrigation service area or crop type. The analysis function calculates and displays total ET for the specific spatiotemporal query as a single date, 24hr ET interpolation, and monthly or seasonal interpolations. User query of seasonal values returns a graph (ET curve) on screen; this ET curve can be co-plotted with ET curves derived from more conventional methods to enable the user to assess and interpret the difference between the two methods, thus facilitating detailed and widespread benchmarking of NASA earth-sun system results from METRIC ET modeling. This ArcGIS ET-Server application is allowing stakeholders to assess the results of the METRIC mapping and compare with results from conventional ET estimation methods. In addition, this ET-Server application provides rapid and transparent access to the data enabling external QA/QC and general assessments by users during the data development stages.

The following figures describe the function of the ET benchmarking application. The web mapping application was developed using ESRI's Web Application development Framework (ADF) for .NET. The development environment is Visual Studio 2005 using ASP.NET with VB.NET and C#. The application implements SOA architecture, using the SOAP protocol to consume ArcGIS Server map and geoprocessing services.

When the application loads, it displays the map at an initial extent of the South Platte basin in Colorado where ET data and parcels, and ditch service area data are available for testing and demonstrating the ET analysis capabilities of the application (***Figure 2***).

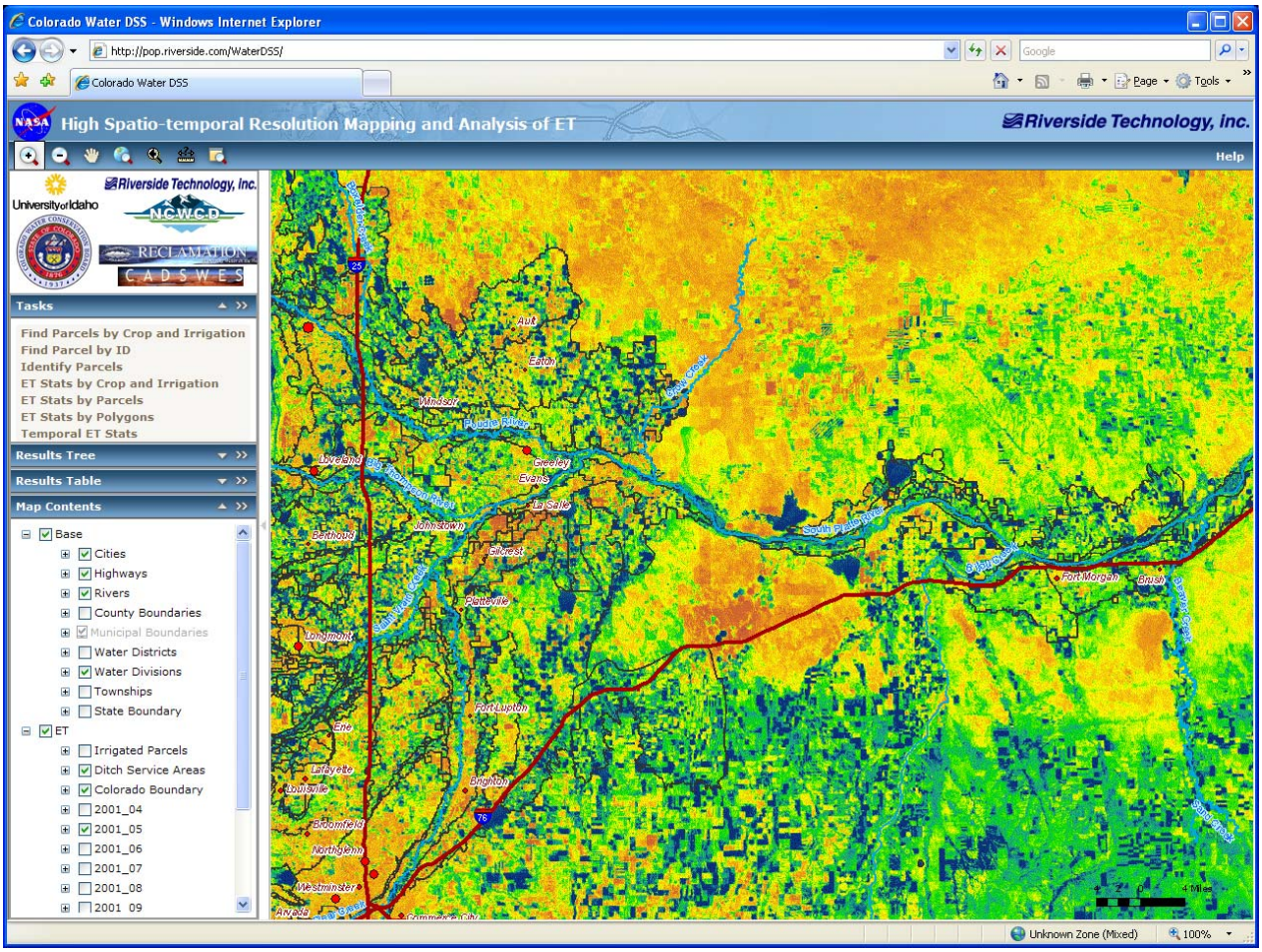


Figure 2

The toolbar below the title banner provides map navigation tools, with the zoom-in set as the initial active tool. Other navigation tools are zoom-out, pan, zoom-to-full-extent, and zoom-to-previous-extent. Additional tools are distance measurement and a magnifying glass. A scale bar is displayed at the right-bottom corner of the map, showing distance in miles. When clicking the zoom to full extent tool in the toolbar, the map will zoom to display the extent of the entire state of Colorado (***Figure 3***).

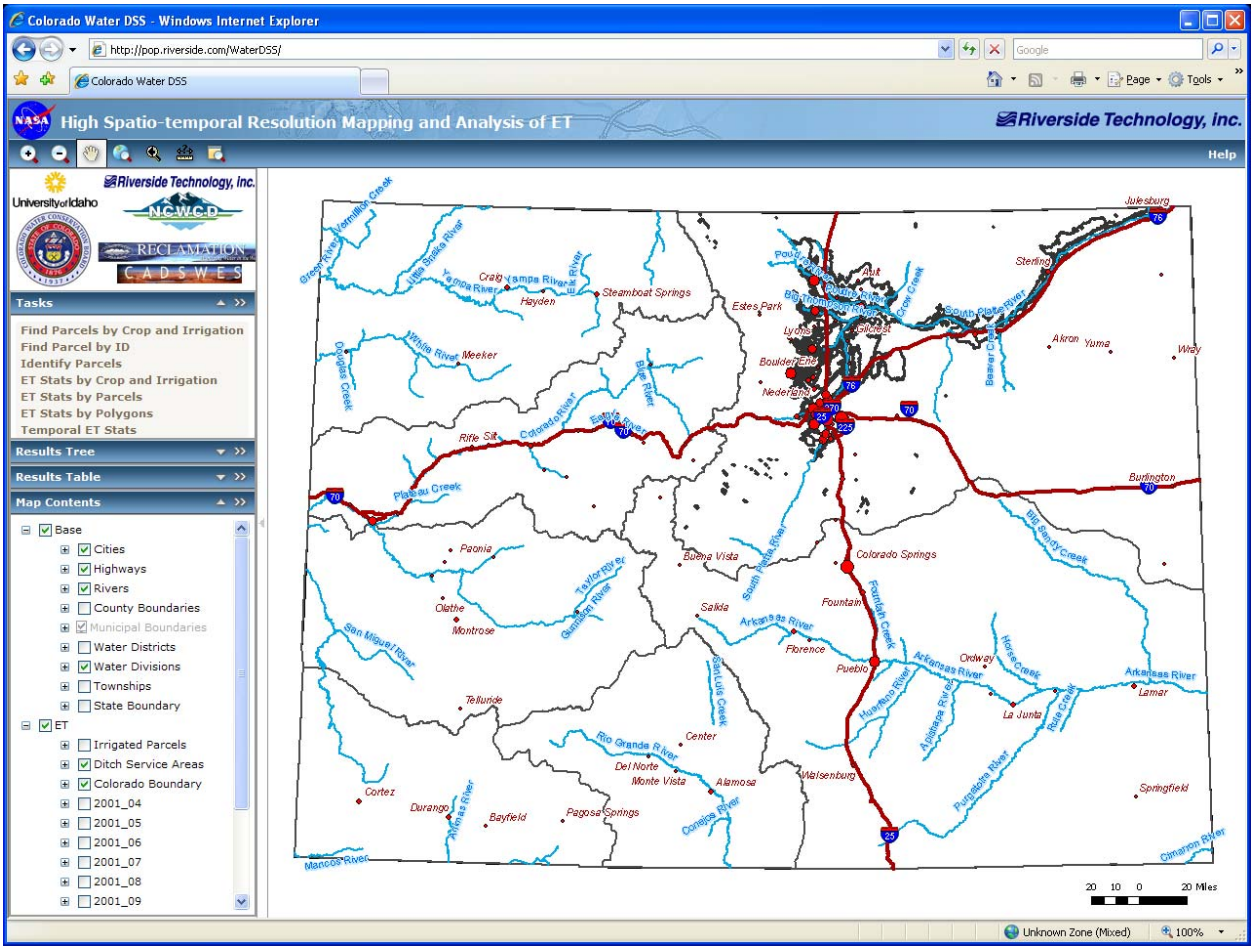


Figure 3

Logos of organizations that partner in this project are displayed in the title of the application window and in the panel below the toolbar. The logo graphics also serve as hotlinks to the corresponding organization's web site; clicking the logo opens the home page of the organization site in a new browser window (***Figure 4***).

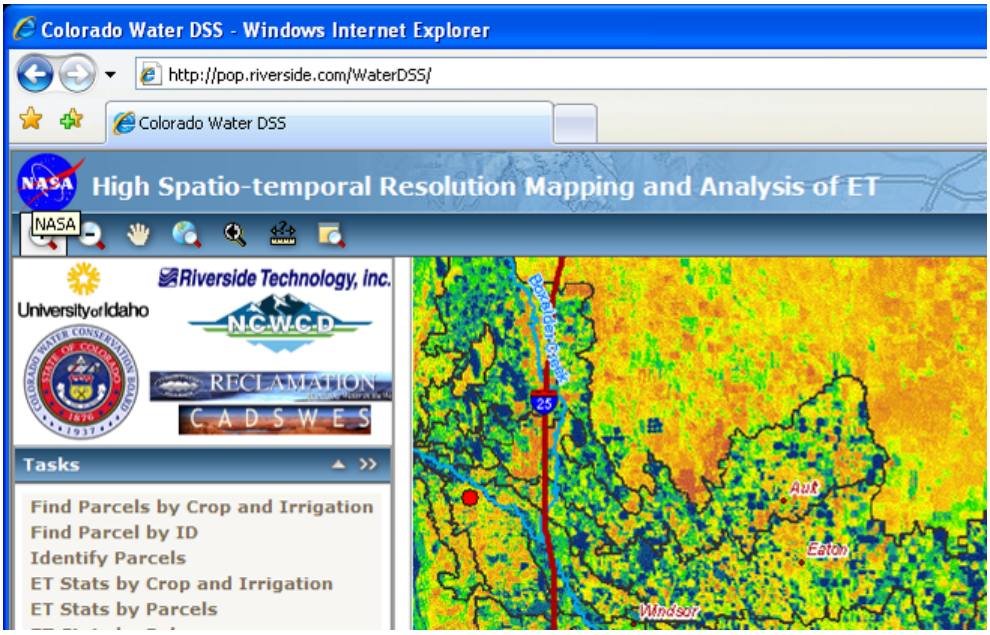


Figure 4

The map contents panel to the left hand side of the map shows the layers that are available for display on the map (***Figure 5***). The layers are organized by subject groups in a tree view. Each of the layer groups is a separate map service. Each map service is based on a map document (.mxd file). The check box to the left of each layer name toggles the visibility of the layer on the map. The check box at the root of each group toggles the visibility of all the layers in the group. Some layers have are scale sensitive and will not display at scales that are too large or too small to provide meaningful information. For example, the Municipal Boundaries layer is grayed out in this slide and a scale bar underlines its check box because it has a scale limit of 1:250,000, while the current scale of the map is 1:500,000. In ***Figure 5***, the ET layer has been turned off to better see the ditch service (water supply) areas.

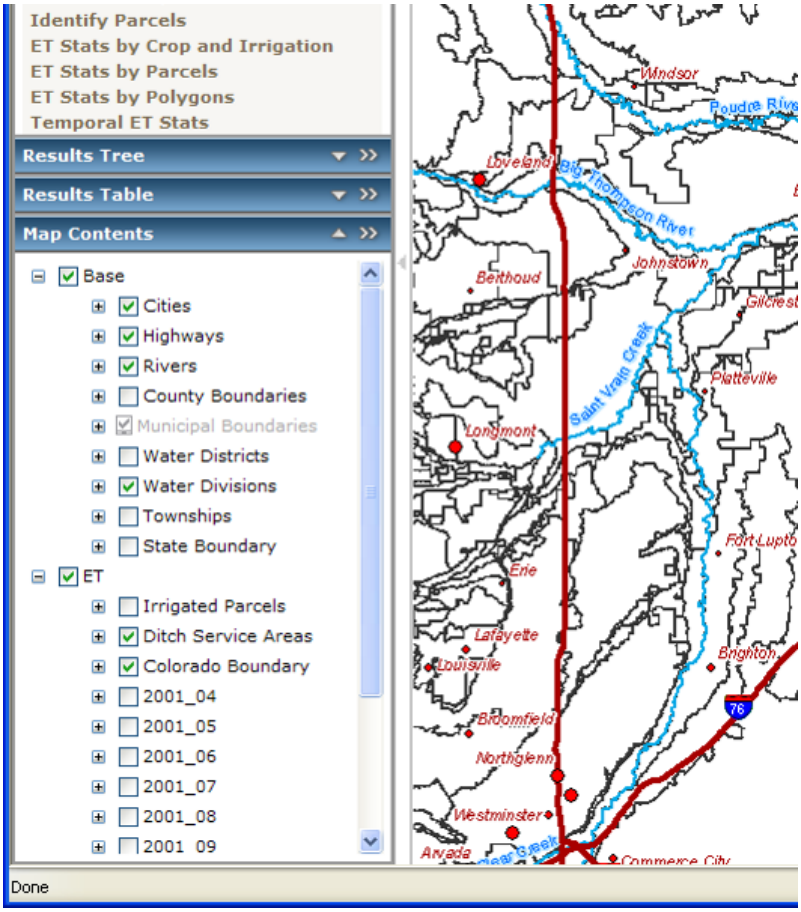


Figure 5

The Map Contents also provides a legend for the map. The +/- box at the left of each layer row toggles the visibility of the symbol used for the display of the layer (***Figure 6***). The panel to the left of the map can be hidden, providing a larger screen area for the map by clicking the arrow in the divider between the map and the panel. Clicking it again restores the left panel and the map to their initial position (***Figure 7***).

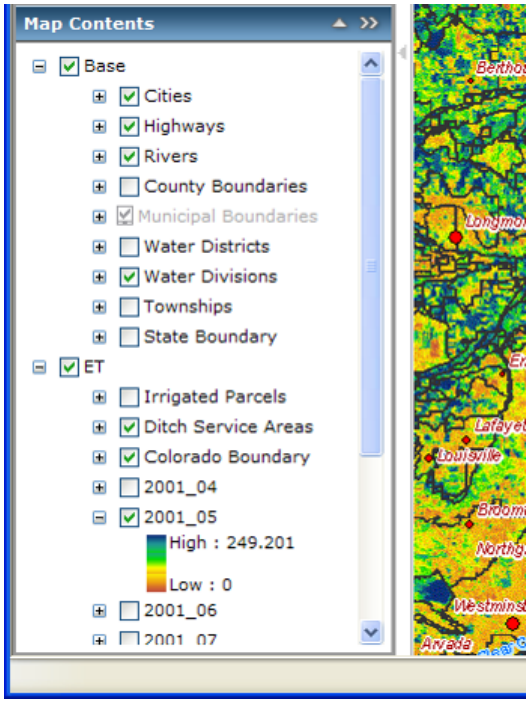


Figure 6

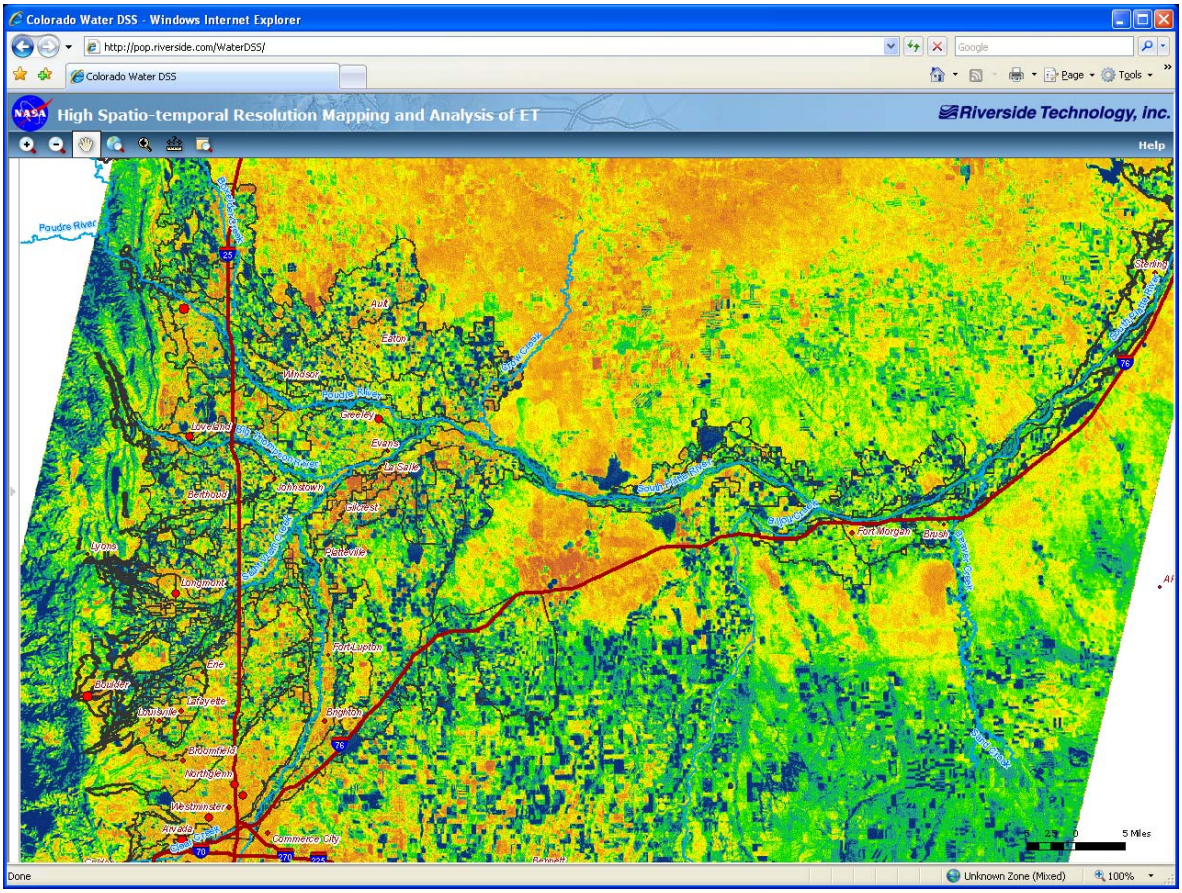


Figure 7

Detailed aerial photographic imagery (NAIP) from the USDA has been added to the web service. Visibility of NAIP is limited to very large scale because this imagery is very data intensive and takes a long time to render at smaller scales. This feature demonstrated the ability of the application to consume web services from different sources. This eliminated the need to acquire the actual data and maintain it locally. ***Figure 8*** shows how the boundaries of our parcels and service areas layer match the imagery.

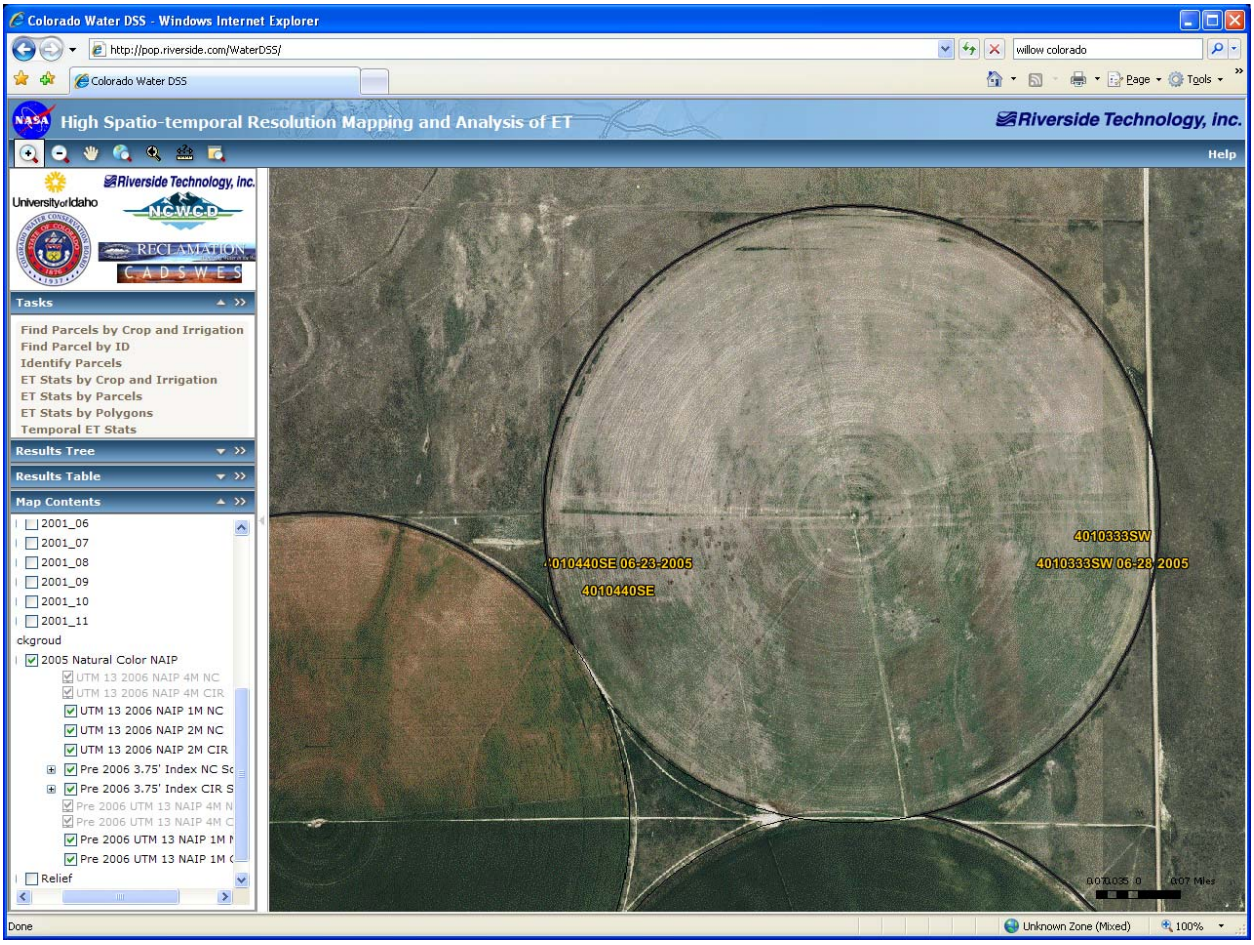
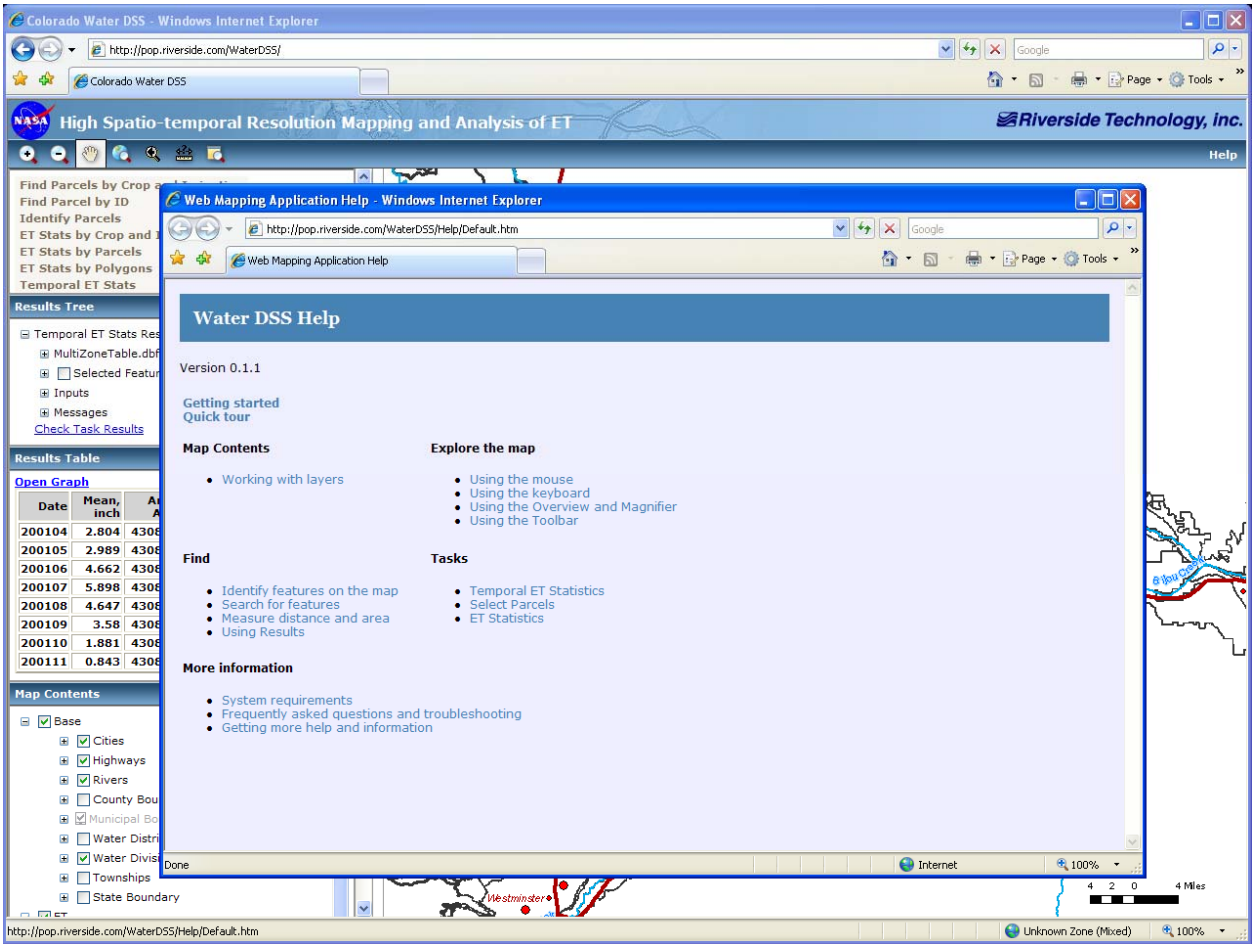


Figure 8

Clicking the Help link on the left side of the toolbar opens the online help system in a new browser window. The main Help page show the revision number of the application and the contents of the help system. The various topics describe the features of the application and provide step-by-step instructions for operating it (***Figure 9*** and ***Figure 10***).


Colorado Water DSS - Windows Internet Explorer
http://pop.riverside.com/WaterDSS/
High Spatio-temporal Resolution Mapping and Analysis of ET
Riverside Technology, Inc.
Help
Find Parcels by Crop
Find Parcel by ID
Identify Parcels
ET Stats by Crop and
ET Stats by Parcels
ET Stats by Polygons
Temporal ET Stats
Results Tree
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Selected Featur
Inputs
Messages
Check Task Results
Results Table
Open Graph
Date
Mean, inch
200104 2.804
200105 2.989
200106 4.662
200107 5.898
200108 4.647
200109 3.58
200110 1.881
200111 0.843
Map Contents
Base
Cities
Highways
Rivers
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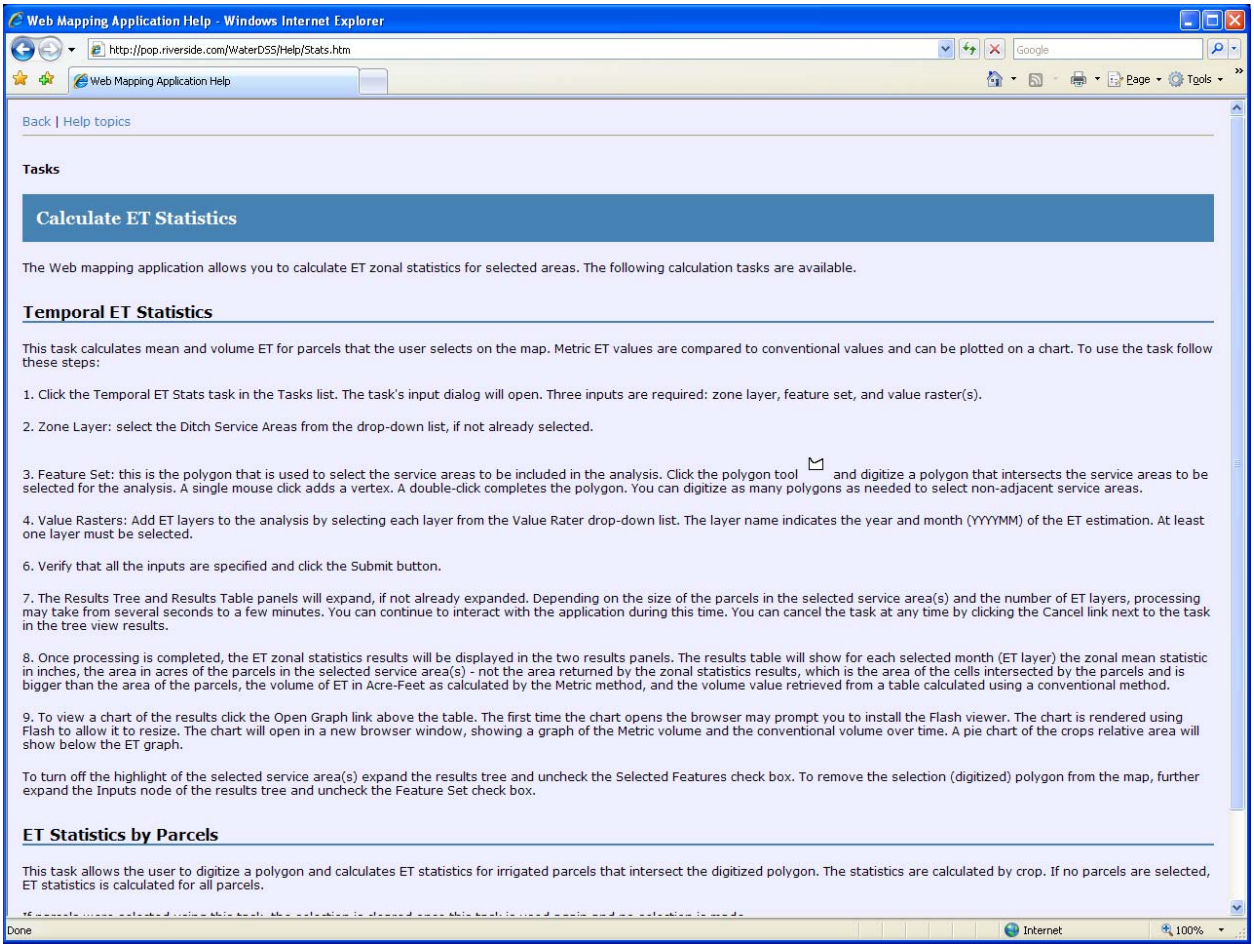
Web Mapping Application Help - Windows Internet Explorer
http://pop.riverside.com/WaterDSS/Help/Default.htm
Water DSS Help
Version 0.1.1
Getting started
Quick tour
Map Contents
Working with layers
Explore the map
Using the mouse
Using the keyboard
Using the Overview and Magnifier
Using the Toolbar
Find
Identify features on the map
Search for features
Measure distance and area
Using Results
Tasks
Temporal ET Statistics
Select Parcels
ET Statistics
More information
System requirements
Frequently asked questions and troubleshooting
Getting more help and information
Done
Internet
100%
Unknown Zone (Mixed)

Figure 9



Web Mapping Application Help - Windows Internet Explorer

http://pop.riverside.com/WaterDSS/Help/Stats.htm

Back | Help topics

Tasks

Calculate ET Statistics

The Web mapping application allows you to calculate ET zonal statistics for selected areas. The following calculation tasks are available.

Temporal ET Statistics

This task calculates mean and volume ET for parcels that the user selects on the map. Metric ET values are compared to conventional values and can be plotted on a chart. To use the task follow these steps:

1. Click the Temporal ET Stats task in the Tasks list. The task's input dialog will open. Three inputs are required: zone layer, feature set, and value raster(s).

2. Zone Layer: select the Ditch Service Areas from the drop-down list, if not already selected.

3. Feature Set: this is the polygon that is used to select the service areas to be included in the analysis. Click the polygon tool and digitize a polygon that intersects the service areas to be selected for the analysis. A single mouse click adds a vertex. A double-click completes the polygon. You can digitize as many polygons as needed to select non-adjacent service areas.

4. Value Rasters: Add ET layers to the analysis by selecting each layer from the Value Rater drop-down list. The layer name indicates the year and month (YYYYMM) of the ET estimation. At least one layer must be selected.

6. Verify that all the inputs are specified and click the Submit button.

7. The Results Tree and Results Table panels will expand, if not already expanded. Depending on the size of the parcels in the selected service area(s) and the number of ET layers, processing may take from several seconds to a few minutes. You can continue to interact with the application during this time. You can cancel the task at any time by clicking the Cancel link next to the task in the tree view results.

8. Once processing is completed, the ET zonal statistics results will be displayed in the two results panels. The results table will show for each selected month (ET layer) the zonal mean statistic in inches, the area in acres of the parcels in the selected service area(s) - not the area returned by the zonal statistics results, which is the area of the cells intersected by the parcels and is bigger than the area of the parcels, the volume of ET in Acre-Feet as calculated by the Metric method, and the volume value retrieved from a table calculated using a conventional method.

9. To view a chart of the results click the Open Graph link above the table. The first time the chart opens the browser may prompt you to install the Flash viewer. The chart is rendered using Flash to allow it to resize. The chart will open in a new browser window, showing a graph of the Metric volume and the conventional volume over time. A pie chart of the crops relative area will show below the ET graph.

To turn off the highlight of the selected service area(s) expand the results tree and uncheck the Selected Features check box. To remove the selection (digitized) polygon from the map, further expand the Inputs node of the results tree and uncheck the Feature Set check box.

ET Statistics by Parcels

This task allows the user to digitize a polygon and calculates ET statistics for irrigated parcels that intersect the digitized polygon. The statistics are calculated by crop. If no parcels are selected, ET statistics is calculated for all parcels.

Figure 10

'Tasks' provide functionality that is generally more involved than 'tools' on the toolbar. Available tasks are listed in the Tasks panel to the left of the map, below the logos panel. The main task added recently is the Temporal ET Stats task, which is described in detail in the Help system. The following figures describe the use of this task.

Clicking the task opens its dialog. In 2008, the system supporting the application was upgraded from ArcGIS 9.2 to 9.3. The new version enabled the improvement of the task dialog. The new dialog is shown on the right. It explicitly list the available ET layers, and allows toggling their inclusion in the analysis using a check box rather than having to select each one from a drop-down list, which is less convenient (***Figure 11***).

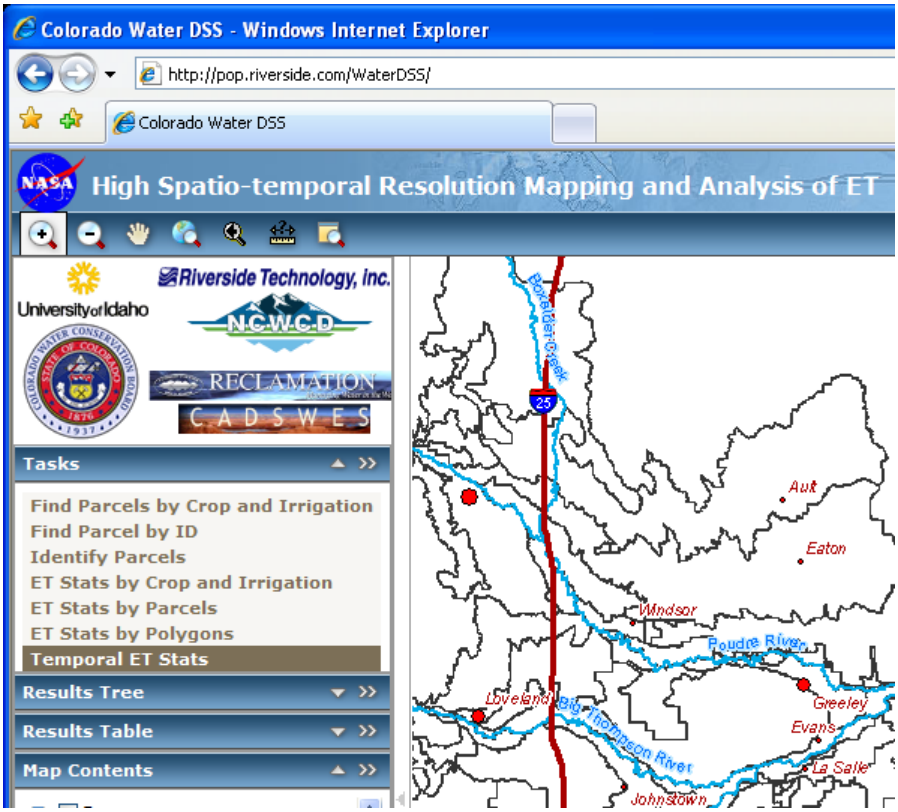


Figure 11

The task is executed asynchronously. The user can interact with the application during processing, and can cancel the task before it is complete (***Figure 12*** and ***Figure 13***).

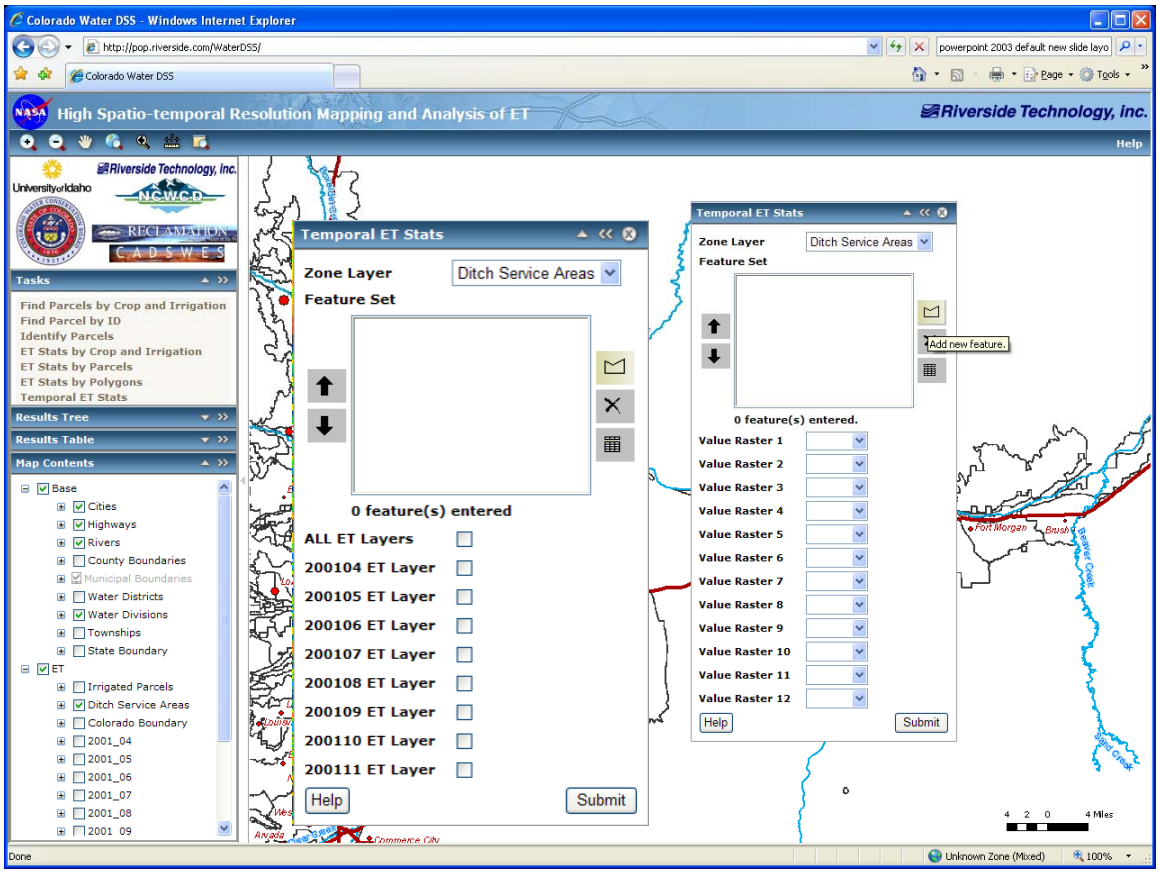


Figure 12

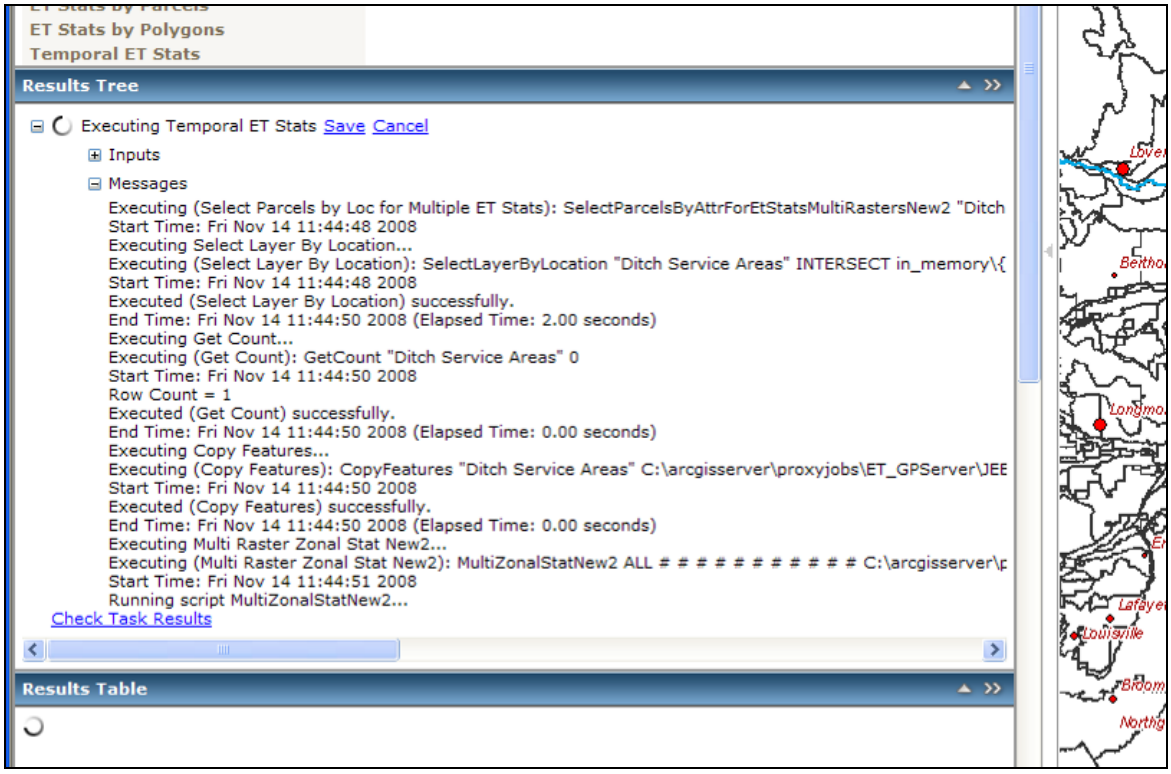


Figure 13

The new version of ArcGIS has enabled the removal of the digitizing polygon. The map resulting from the improved task displays the polygon that was digitized to select the parcels or service areas to be included in the analysis, as shown in the map insert on the bottom-right of the slide (with the selected service area highlighted in yellow) (***Figure 14***).

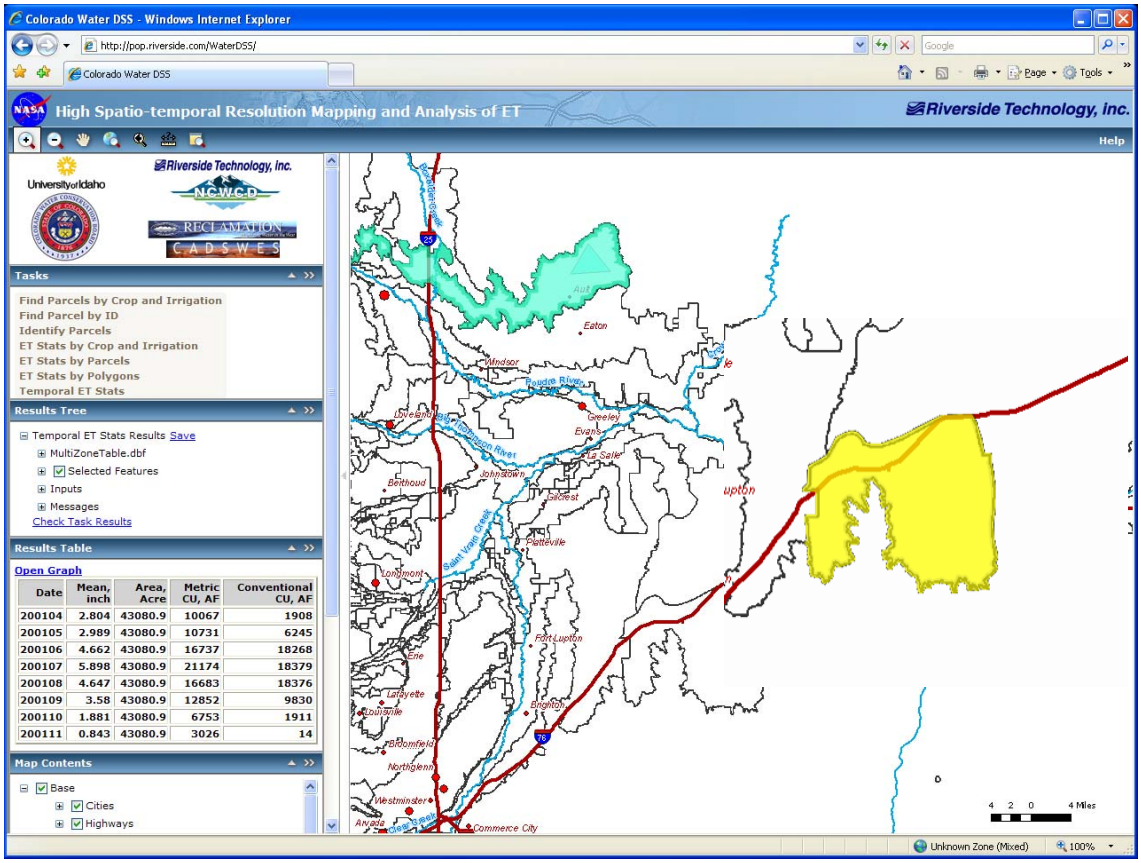


Figure 14

The results are displayed in a table. The selected area can be turned on and off in the results tree view (***Figure 15***).

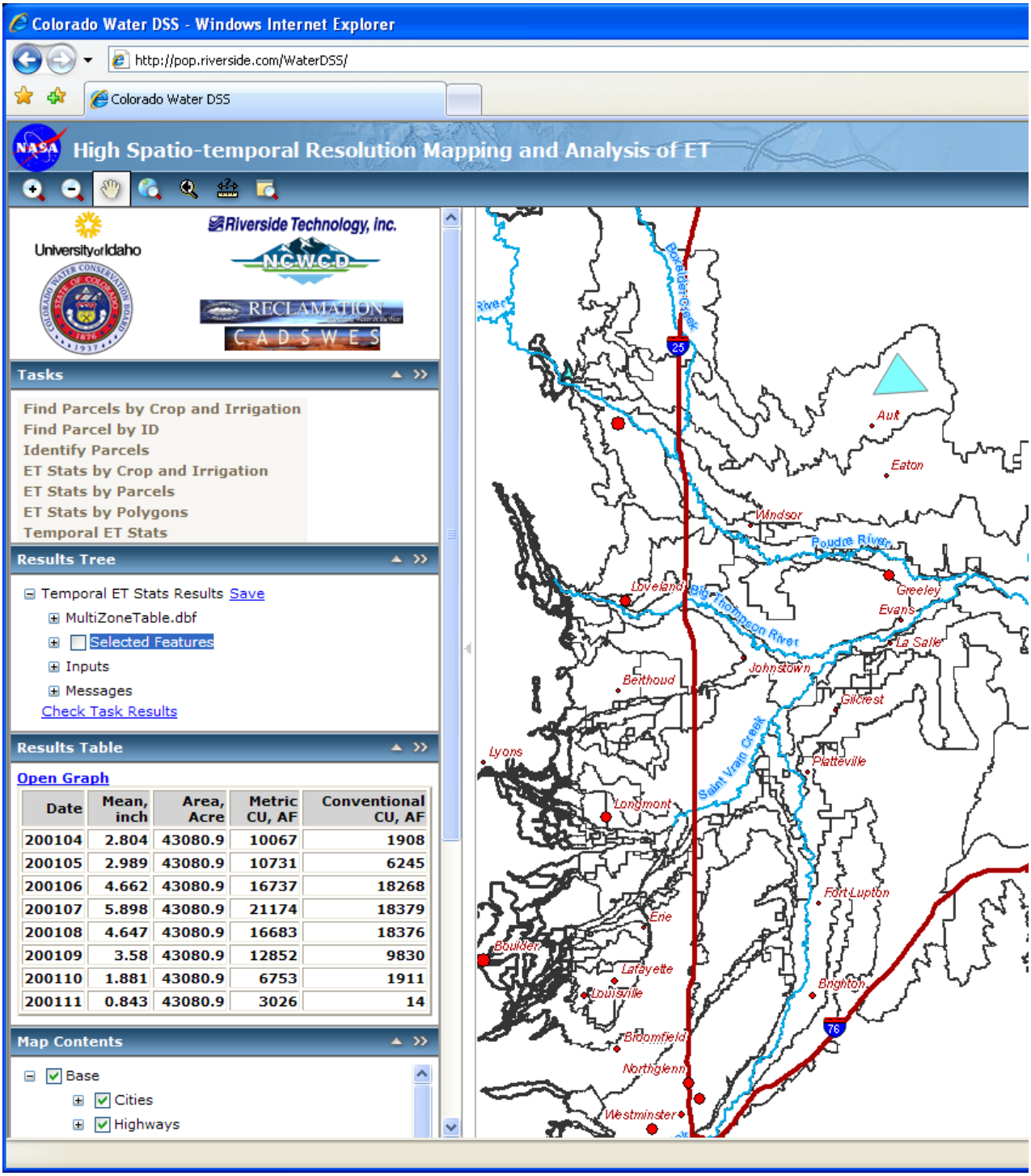


Figure 15

Clicking the Open Graph link above the results table shows a graph of the results in a new browser window (***Figure 16***). The graph was implemented using c# with a component library called Dundas Chart for ASP.NET. It is rendered as a Flash object, which allows for chart to resize with the window. The main graph shows the variation of ET volume in Acre-Feet with time for the Metric and conventional methods, and the different of the values between the two methods. The pie chart shows the proportions of crop area and the total acreage of irrigated crops in the selected service area(s). This further facilitates

benchmarking analysis by providing a greater understanding of the influence of various crop types on total ET being compared for each method.

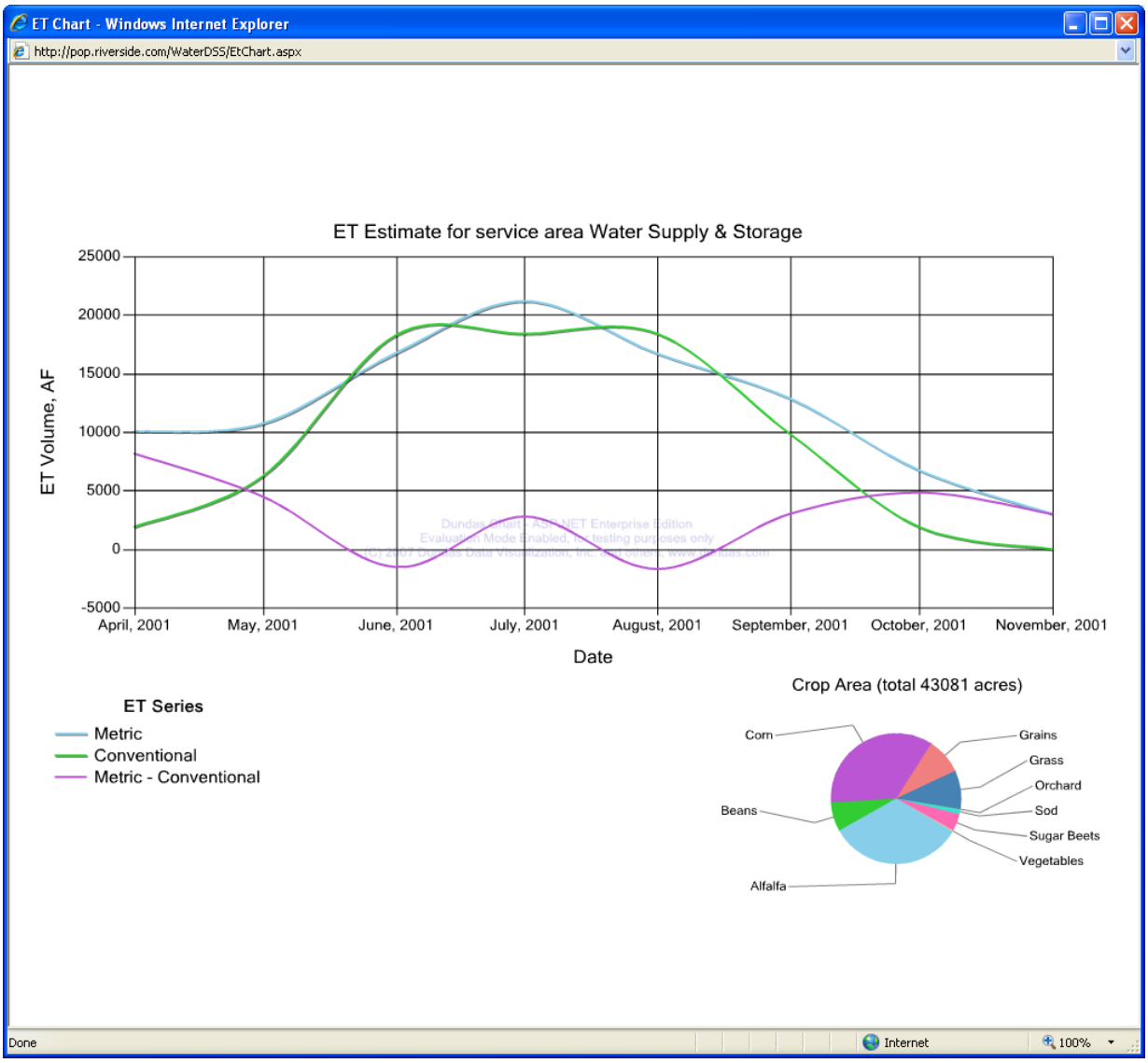
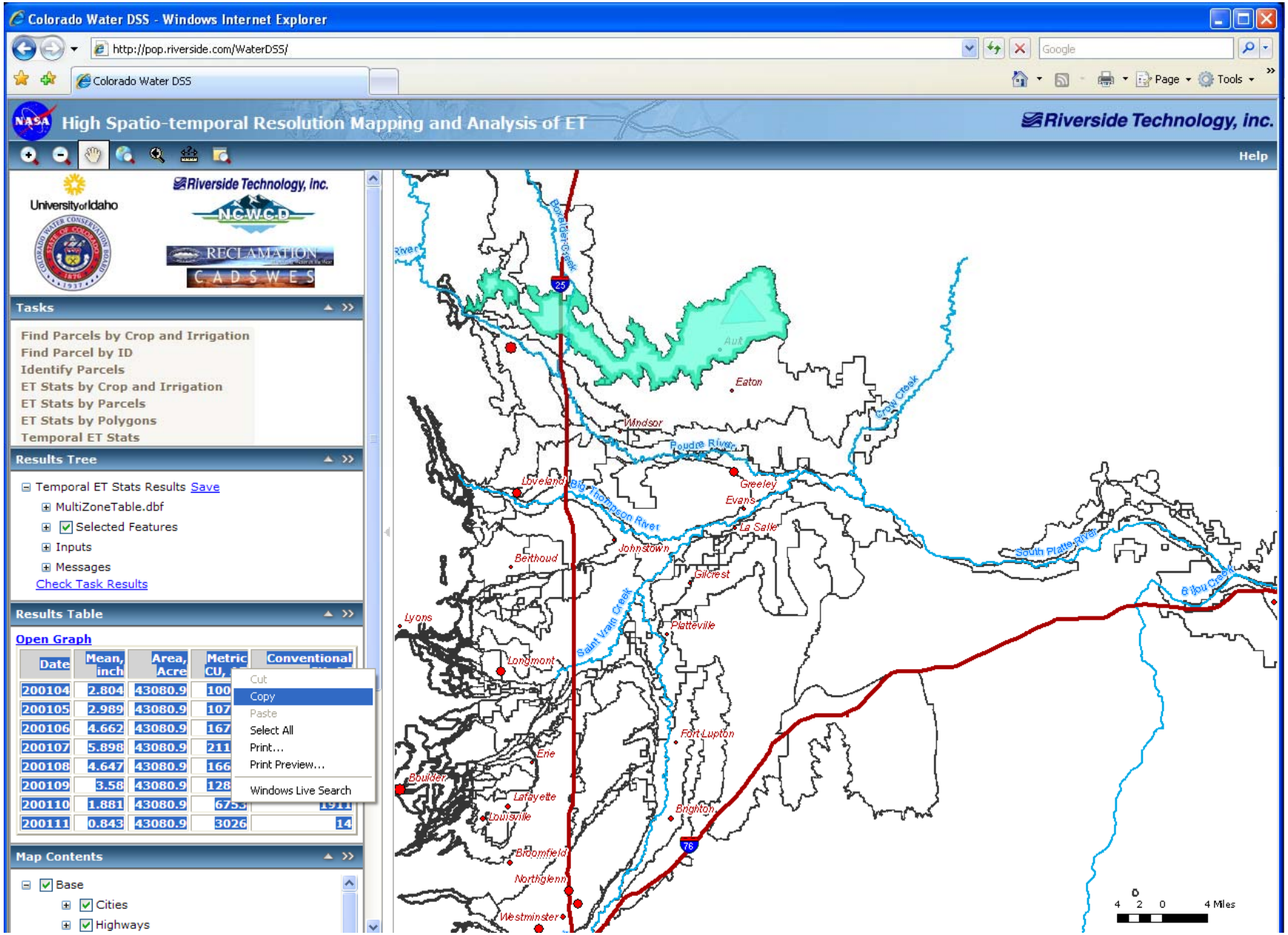


Figure 16

To copy the results to Excel, the user just needs to select the cells with the mouse, right-click and select Copy. Open Excel and paste (***Figure 17*** and ***Figure 18***).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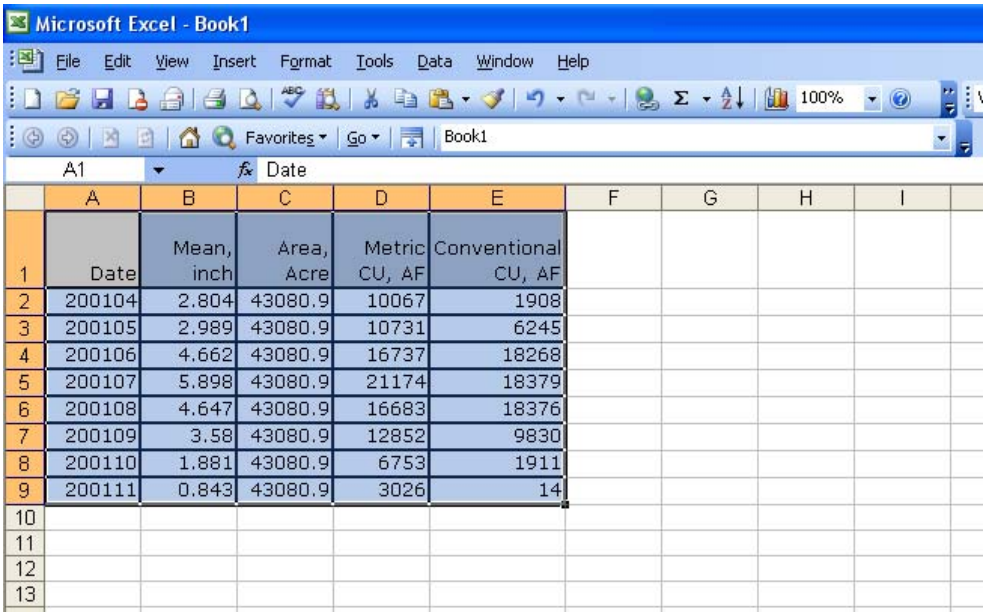
High Spatio-temporal Resolution Mapping and Analysis of ET
Riverside Technology, inc.
Help
University of Idaho
Riverside Technology, inc.
N.C.W.C.D
RECLAMATION
C A D S W E S
Tasks
Find Parcels by Crop and Irrigation
Find Parcel by ID
Identify Parcels
ET Stats by Crop and Irrigation
ET Stats by Parcels
ET Stats by Polygons
Temporal ET Stats
Results Tree
Temporal ET Stats Results Save
MultiZoneTable.dbf
Selected Features
Inputs
Messages
Check Task Results
Results Table
Open Graph
Date
Mean, inch
Area, Acre
Metric CU
Conventional
200104 2.804 43080.9 100
200105 2.989 43080.9 107
200106 4.662 43080.9 167
200107 5.898 43080.9 211
200108 4.647 43080.9 166
200109 3.58 43080.9 128
200110 1.881 43080.9 6753 1911
200111 0.843 43080.9 3026 14
Cut
Copy
Paste
Select All
Print...
Print Preview...
Windows Live Search
Map Contents
Base
Cities
Highways
Eaton
Windsor
Poudre River
Greeley
Evans
Loveland
Big Thompson River
La Salle
Johnstown
Berthoud
Gilcrest
Platteville
Lyons
Longmont
Saint Vrain Creek
Fort Lupton
Erie
Boulder
Lafayette
Louisville
Brighton
Broomfield
Northglenn
Westminster
South Platte River
Crow Creek
4 2 0 4 Miles

Figure 17



Date	Mean, inch	Area, Acre	Metric CU, AF	Conventional CU, AF
200104	2.804	43080.9	10067	1908
200105	2.989	43080.9	10731	6245
200106	4.662	43080.9	16737	18268
200107	5.898	43080.9	21174	18379
200108	4.647	43080.9	16683	18376
200109	3.58	43080.9	12852	9830
200110	1.881	43080.9	6753	1911
200111	0.843	43080.9	3026	14

Figure 18

3. Enhancements to Performance of METRIC in Study Areas

Thermal Sharpening

Figure 19 illustrates the loss of fidelity in T_s, compared to vegetation indices, when the thermal band has lower spatial resolution than the short wave spectral bands. While an NDVI map derived from the 30 m resolution bands 3 and 4 of Landsat 5 TM allows identification of features such as individual fields, cities and roads, a T_s image derived from the 120 m resolution of the Landsat 5 thermal band tends to mix surface features with a loss of detail. This mixing of surface characteristics translates into error and loss of resolution in the estimates of energy balance fluxes including ET. ***Figure 20*** shows how the coarse resolution thermal data degrades the resolution of the final ET estimation, producing a net resolution somewhere between 30 and 120 m resolution.

The use of NDVI or some other vegetation index for sharpening T_s is effective because of the close correspondence between evaporative cooling of vegetated surfaces and the amount of vegetation. Applications of satellite-based energy balance have demonstrated the close correspondence between surface temperature and vegetation amount, where full leaf cover under high levels of soil moisture tends to function similar to a wet bulb pyschrometer (Allen et al. 2007, Bastiaanssen, 1998a, b) and approach a near equilibrium surface temperature that is a function of energy availability and vapor pressure deficit of the air. On the other extreme, dry, bare soil surfaces tend to approach a nearly constant temperature that is in near equilibrium with available energy, surface albedo and general, effective radiative and thermal temperatures of the atmosphere.

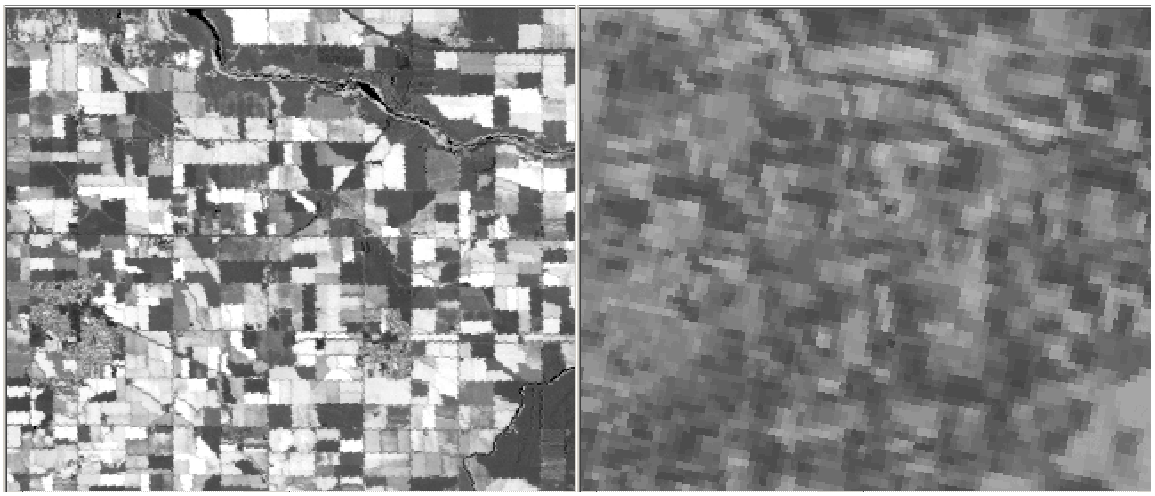
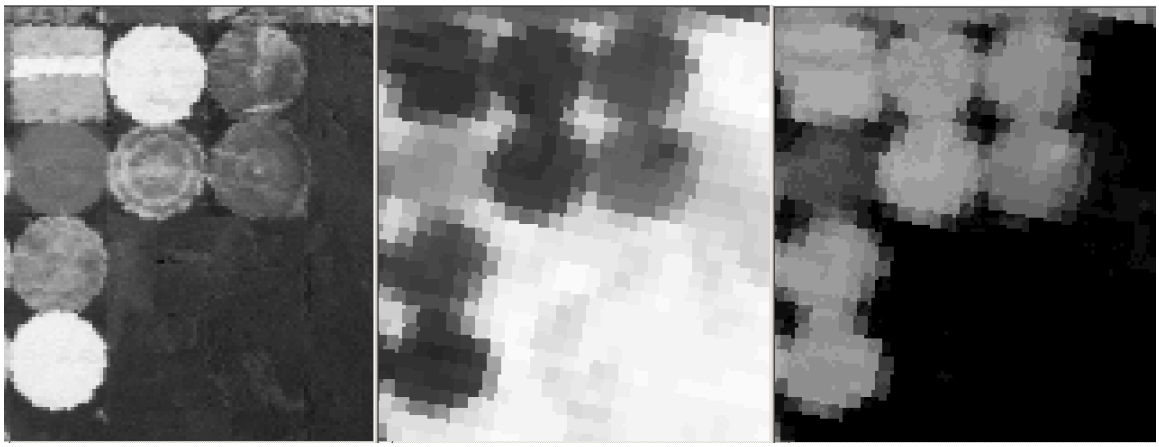


Figure 19. Left: NDVI image from southern Idaho derived from Landsat 5 TM at 30 m spatial resolution. Right: T_s values corresponding to the NDVI image, where warmer areas are brighter. The right image is clearly less sharp due to the 120 m resolution of the thermal infrared band. Both images were orthocorrected to 30 m using nearest neighbor resampling.



(a) (b) (c)

Figure 20. (a) NDVI map derived from Landsat 5 TM at 30 m spatial resolution for path 40, row 30 (07/23/1989), with higher values bright, lower values dark, (b) Corresponding thermal band (band 6), (c) Daily ET map derived by energy balance via METRIC. The impact of band 6 resolution on final ET estimates is pronounced.

Exceptions to the relationships between T_s and NDVI exist for moist, bare soil that experiences evaporative cooling and for open water. In these situations, the sharpening of T_s using NDVI or any other vegetation index may incur substantial error. The association of a vegetation index such as NDVI with surface temperature is somewhat congruent with some energy balance calibration processes, such as that used within the METRIC (Mapping evapotranspiration at High Resolution with Internal Calibration) (Allen et al., 2007) and SEBAL (Surface Energy Balance Algorithms for Land) (Bastiaanssen, 1995, 1998a, 2005).

The NDVI has the advantage over e.g. soil adjusted vegetation index (SAVI) and some other indices because NDVI tends to 'saturate' at about the same amount of ground cover by vegetation as the

evapotranspiration rate. This is due to the tendency of NDVI to reach maximum levels at about 80% ground cover (by vegetation) or at leaf area indices of about 3.0 and for ET to reach maximum levels at these same levels. In comparison, the SAVI index tends to extend past 90 to 95% ground cover. Because the impact of evaporative cooling on T_s is largely proportional to the latent heat flux, and because ET is generally found to be linearly proportional to NDVI, the relationship between T_s and NDVI is considered to be more linear and monotonic than that for SAVI.

The basic sharpening philosophy and procedure followed here is based on the application of an established T_s vs. NDVI relationship to produce a first estimate of T_s at every short wave pixel (referred to as $pixel_{sw}$), assuming a linear relationship and correspondence between NDVI and T_s. Later, to preserve original T_s information, this first estimate of T_s is adjusted so that T_s averaged over all $pixel_{sw}$ lying within an original thermal pixel (referred to as $pixel_{th}$) matches the original average T_s of that thermal pixel. In some cases, the redistribution of the bias between the original $pixel_{th}$ and the resampled $pixel_{th}$ is an iterative process. Our process sharpens T_s rather than total thermal radiance, where radiance is proportional to the product of surface emissivity and T_s^4 for several reasons. One, a relation between NDVI and T_s can sometimes be better defined than for radiance. Two, the use of T_s allows one to use a lapse corrected T_s when defining NDVI vs. T_s relationships for use in areas having variable terrain and elevation. Three, the uncertainty in the overall sharpening and final product is much larger than differences caused by targeting the conservation of the original T_s of a thermal pixel rather than conservation of the original radiation of the pixel. Future research will explore the sensitivity and impacts of sharpening temperature over radiance. Details of the sharpening procedure, which requires image-by-image determination and iteration of a T_s vs. NDVI relationship and iterative bias correction within each thermal pixel to preserve the original T_s value, is described in detail in Allen et al. (2008).

To perform the sharpening analysis, it is necessary to 'identify' the locations and outlines of original thermal pixels (having dimensions of 120 m for Landsat 5 and 60 m for Landsat 7). Therefore, during orthocorrection of the satellite images, it is necessary that nearest neighbor (NN) resampling be employed when resampling the thermal pixels to a 30 m equivalent. The resampled 30 m thermal image is overlain on the shortwave image layers (bands) during the sharpening process to determine which shortwave pixels are contained in the original thermal pixel. Because the 'shape' of a thermal pixel is often contorted from the original square shape (4 x 4 for LS5 and 2 x 2 for LS7) during orthocorrection, it is necessary to use a clumping program in an image processor or GIS system that can identify contiguous 30 m resampled thermal pixels that have a common value (digital number) and were therefore part of an initial 120 (or 60 m) thermal pixel. In ERDAS, the Clump tool can be used and in ArcGIS, the Region Group tool can be used. Future work will be to determine whether images that have been resampled using cubic convolution during georectification and terrain correction can be sharpened to a similar extent as with NN.

Sharpening Thermal Images Containing Open Water. Surface temperature for water cannot be sharpened using NDVI using the T_s vs. NDVI process, because NDVI takes on negative values for water. We propose two procedures for sharpening thermal pixels containing water. A simple procedure is based on an apparent NDVI. Using a T_s vs. NDVI relationship for the image, we find the value of NDVI that reproduces the average temperature associated with major water bodies in an image. This apparent NDVI is used during sharpening for all $pixel_{sw}$ identified as being water. This method is generally sufficient to produce satisfactory sharpening of $pixel_{sw}$ near shorelines of water bodies larger than about 1 km^2. In the case of streams that are narrower than the dimension of $pixel_{sw}$ and /or where the $pixel_{sw}$ is comprised of a mixture of land and water, the sharpened temperature can become higher than actual for the water, but in these cases, the sharpening process is complicated and perhaps impossible, because NDVI values are contaminated from different surface types. A second procedure that is somewhat more complicated uses a surface temperature that is assigned to water. This procedure works well on medium to larger water bodies and somewhat better than the simple approach for small or narrow water bodies such as streams.

Figure 21 shows two sub-image areas illustrating results of applying the sharpening procedure to Landsat 5 imagery (path 40, row 30 of southern Idaho). The image had previously been orthocorrected, with the 120 m thermal pixels resampled to 30 m using nearest neighbor resampling. Visually, the effect of the sharpening procedure improved resolution of T_s between surfaces having different NDVI characteristics. The original average T_s of each thermal pixel was preserved in the sharpened image for all $pixel_{th}$. Definition of field shapes was much improved, even for field sizes smaller than the 120 m thermal pixel size. Roads and residential areas in ***Figure 21*** are significantly better defined. The T_s along the diagonal highway in ***Figure 22*** (top) is relatively uniform along the highway, which indicates relatively unbiased sharpening. The original 120 m pixels, often no longer square following resampling using NN and orthocorrection.

Figure 22 and ***Figure 23*** show sharpened T_s in central Spain and in New Mexico. In the New Mexico image, the T_s for narrow riparian systems along the Rio Grande became much more concise following the sharpening to 30 m.

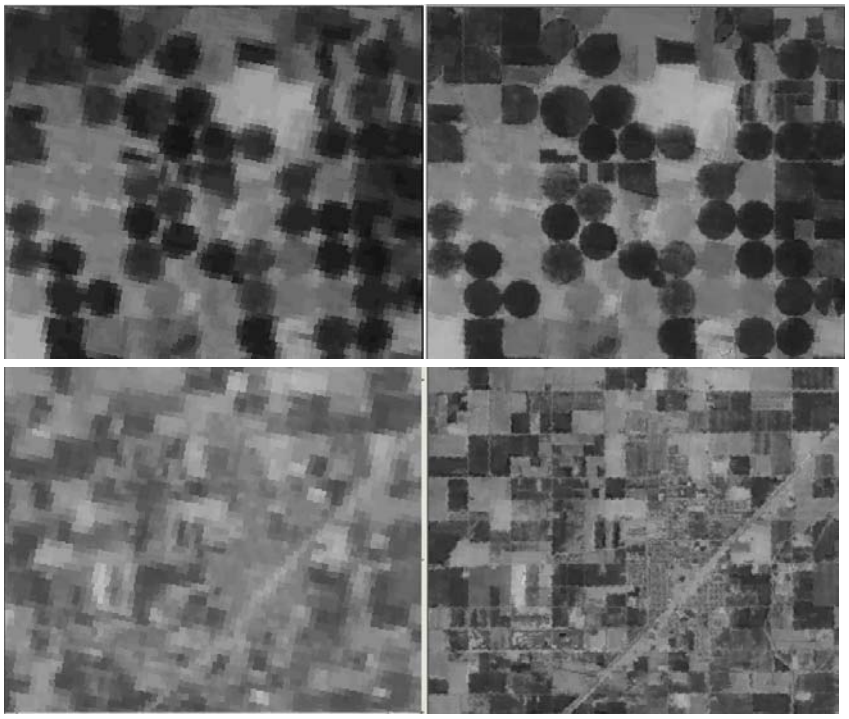


Figure 21. Original T_s (left) and sharpened T_s (right) for an irrigated area in S. Idaho on 07/23/1989 (top) and for an irrigated area containing a small town on 08/22/2000 (bottom) for Landsat 5 images, path 40, row 30.

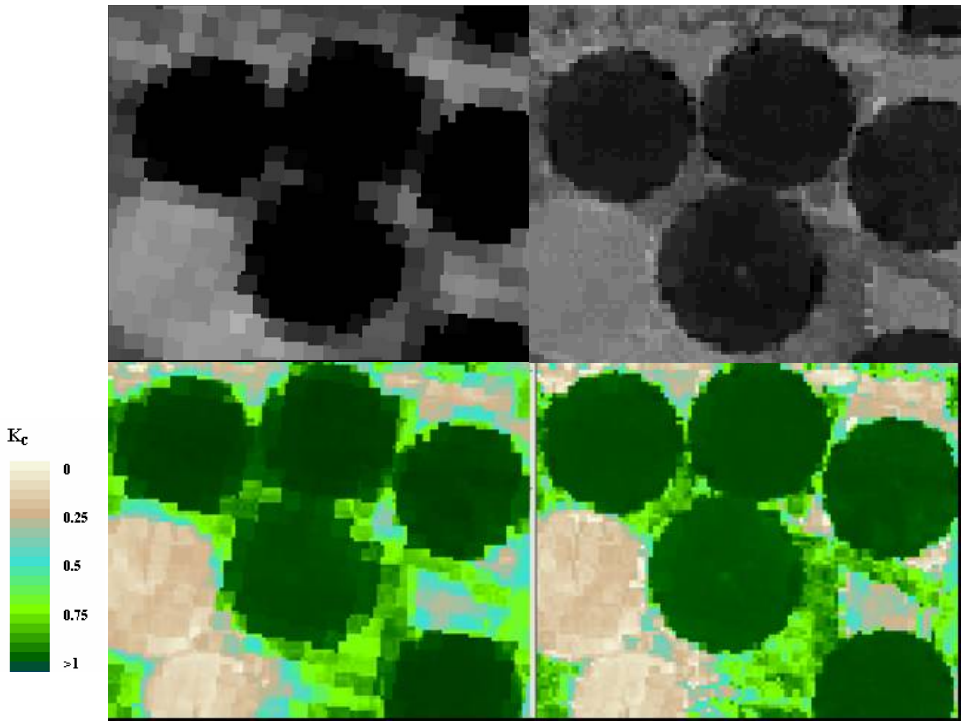


Figure 22. Original T_s (upper left), sharpened T_s (upper right), ET_rF (i.e., $K_c = ET/ET_r$) before sharpening (lower left) and ET_rF after sharpening (lower right) for an area west of Albacete, Spain during 2002 (Landsat 5 image).

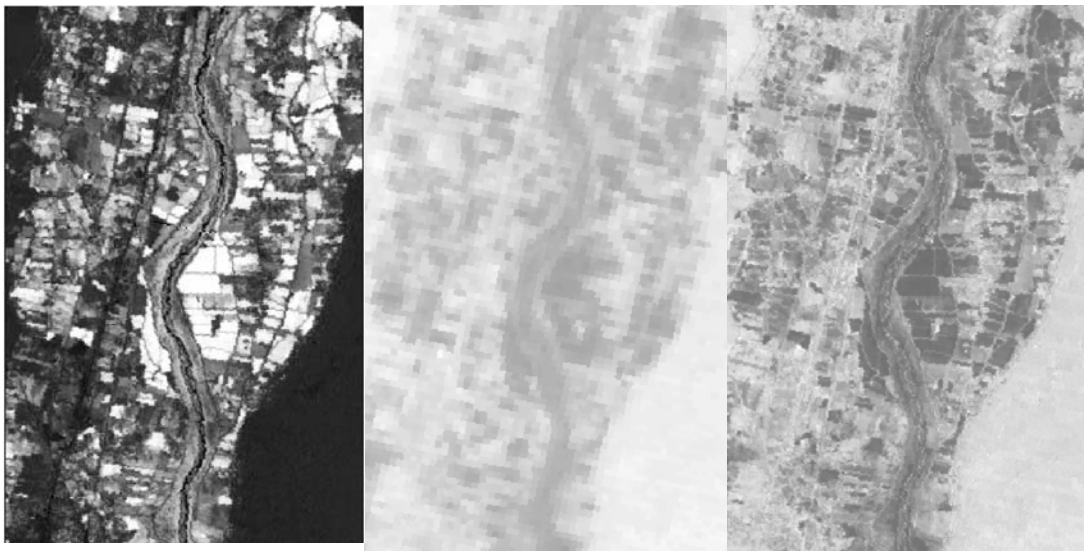


Figure 23. NDVI (left), unsharpened T_s (middle) and sharpened T_s (right) along the Rio Grande just south of Albuquerque, NM for a Landsat 5 image taken in 2002.

Fine Tuning Components in METRIC

Estimation of momentum roughness length. The internalized calibration of sensible heat flux requires a measure of the momentum roughness length (z_{om}) as input to estimate the stability conditions of the atmosphere. A value for z_{om} was assigned for each land use class, other than irrigated agriculture, based on land use maps of the study areas. Initially the z_{om} values were assessed based on the metadata description for the land use maps. However, a field trip to the study areas proved invaluable in refining z_{om} values, as the generalized vegetation descriptions of the land use maps only poorly represented the study area. For some areas with natural rangeland vegetation, this resulted in vales for z_{om} being more than halved. Roughness lengths for irrigated agriculture were estimated using leaf area index estimates that were based on reflectance bands from the Landsat images.

Reduction of soil heat flux for desert areas. The functions used in METRIC estimate soil heat flux (G) for irrigated fields in Southern Idaho well (Tasumi, 2003). The upper soil layers in the cropped fields have usually been disturbed by tillage, emerging plants and plant roots and application of relatively large amounts of water. This has promoted a somewhat uniform vertical soil structure within the upper 20 – 30 cm. For undisturbed, dry desert soils, where vegetation is sparse and the upper soil layer are largely undisturbed, a thin crust often forms at the soil surface. This crust may be partially delaminated from the soil below by an air gap. Frost-thaw cycles, swelling clay minerals, compaction from snow pack and traffic (e.g. animals) may also cause a layering with differences in texture, structure, and bulk density in the upper soil layers. The delamination will likely reduce G, as energy transfer by conduction from the crust to the immediate underlying soil layers is reduced. In addition, the dryness of the soil also reduces G, as water increases the thermal conductivity of the soil. As a result, the G function derived for irrigated conditions likely overestimates the energy flux in desert areas. During the processing this caused desert areas to have negative values of K_c. Reducing the G for pixels in the desert as a function of T_s using a now routine procedure in METRIC reduced negative values K_c for desert areas.

Selection of anchor pixels. Selection of representative anchor pixels is crucial for the accuracy of the ET estimations from METRIC. The cold anchor pixel should represent an agricultural field with full vegetation cover, having near minimum surface temperature and is assigned an ET equal to 1.05 times ET_r. The hot anchor pixel should represent a bare, dry agricultural field having a relatively high temperature. The field should have only very little vegetation residue cover and an albedo similar to other bare fields nearby. The location of the anchor pixels is preferably toward the center of a population of other pixels having similar properties (temperature, albedo, vegetation). The high resolution of Landsat 5 and 7 (30 m for shortwave reflectance, 120 and 60 m for surface temperature, respectively) allow sampling within individual fields.

The selection of the anchor pixels must be done manually by the user and is typically an iterative process. The selection may be aided by viewing the Landsat scene in specific band combinations, such as 4, 5 and 7 (C. Schneider, personal communication), colorize vegetation indices and temperature maps based on general criteria for selection of the anchor pixels, use ArcMap to aggregate data and use zonal statistics to output possible candidates (M. Hattendorf, personal communication) and identify fields with little or no residue cover based on other indices.

At the hot anchor pixel, it is assumed that little or no evaporation is taking place if there has been a long period since rainfall. Otherwise, the surface soil water balance and evaporation estimation shown in ***Figure 20*** is used to assign an ET_rF to the hot pixel. The dT function is calibrated for any possible residual evaporation.

Testing Impact of User on Calibration Bias

One of the major caveats in the current design of METRIC is that results are somewhat user dependent. Inter comparisons between ET maps produced using identical versions of METRIC by different users on the application teams illustrated that systematic differences of up to 10 % in the final ET maps are

possible. It was also found, however, that at least half of this difference was caused by inexperience in running the model, insufficient weather quality control, incongruent application of the soil water balance model, lack of communication, missing updates of input parameters between model runs and lack of familiarity with the study area. The group studies have underlined the necessity of users to follow the same general guidelines and procedures for processing, and that the greatest care is used when setting up and running the model. It is also important that users review all intermediate results (such as maps of R_n, G, H, albedo, vegetation indices, temperature etc).

Automatic calibration process. As part of the continuing efforts to improve the predictions of the METRIC model, work is currently being done to develop an automated selection of a population of anchor pixels. This may reduce the user dependency of the final ET maps further. Another issue that is being addressed is the interpolation from daily ET maps to seasonal or annual ET. With Landsat image capture dates being 8, 16, 32 days or more apart (depending on sensor availability and cloud cover) the interpolation method must be able to reproduce the trend between images dates as completely as possible. Unless there is a high frequency of image dates during growing season, a spline type interpolation method should be applied rather than e.g. linear interpolation. In addition, local precipitation events may have a temporal and spatial occurrence that are not registered by the soil water balance or are largely evaporated at the time of the next image capture causing an underestimation of predicted ET. To minimize this error, efforts are being made to expand the daily soil water balance to the entire study area.

4. Research Extension: Conferences Attended and Papers Written

AGU 2007

RTi presented a poster based highlighting our NASA-ROSES Research in the poster session for Hydrology, Agricultural systems, Remote sensing. The poster, titled *"Enhanced monitoring of the temporal and spatial relationships between water demand and water availability"* is included below.

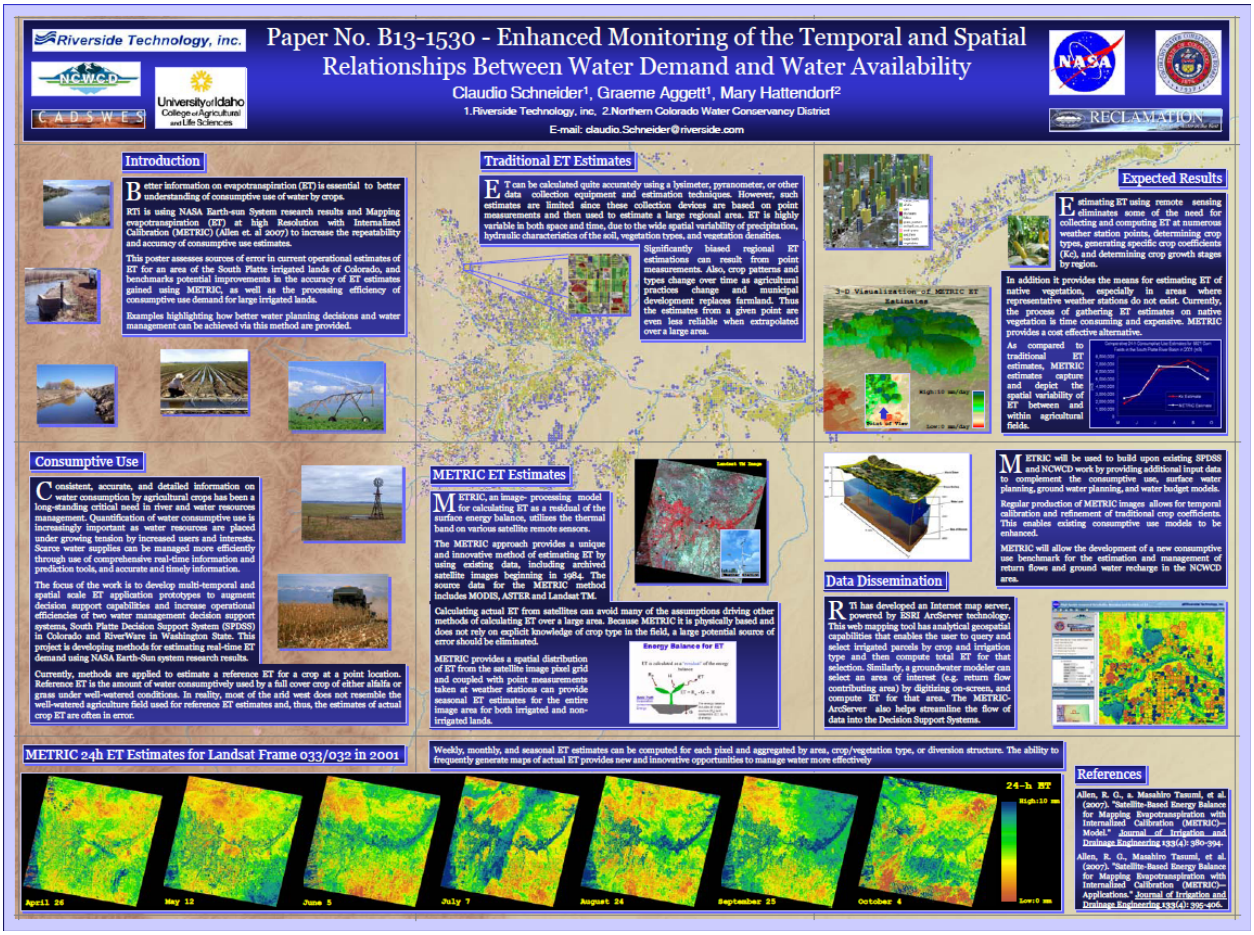


Figure 24

NIDIS Drought Workshop

RTi contributed a presentation of our NASA-funded research at a National Integrated Drought Information System (NIDIS) workshop, "Contributions of Satellite Remote Sensing to Drought Monitoring," held on February 6-7, 2008 in Boulder, Colorado. The workshop consisted of over thirty natural resource managers, researchers, and scientists representing a variety of universities and federal, state, and local agencies. The workshop provided participants with an overview of available satellite remote sensing technologies and products for cross-sector applications in drought monitoring, management, and planning in the United States. In turn, participants provided recommendations regarding the utility and presentation of remote sensing technologies, including input for near-term modifications to operational products and ideas for future development and research. RTi presented on the utility of NASA earth-sun system results for drought and related water management decision support. The RTi presentation is available at Western Water Assessment's web site:

http://wwa.colorado.edu/current_projects/nidis_rs_wrkshp_presen.html

A report on the workshop, including a contribution from RTi, is available at Western Water Assessment's web site:

http://wwa.colorado.edu/forecasts_and_outlooks/docs/WWA_May_2008_feature_standalone.pdf

PECORA ASPRS Conference, Denver 2008

RTi presented a paper at the American Society for Photogrammetry & Remote Sensing (ASPRS) PECORA conference in Denver. The paper, titled *Comparison, calibration and refinement of traditional crop coefficient curves in the South Platte basin using METRIC*, focuses on our benchmarking activities.

AGU 2008

RTi presented a poster based highlighting our NASA-ROSES Research in the poster session for Hydrology, Evapotranspiration, GIS, Modeling, and Remote sensing.

The poster, titled *A Web Application for Validating and Disseminating Surface Energy Balance Evapotranspiration Estimates for Hydrologic Modeling Applications*, highlighted the tools and methods for benchmarking NASA earth-sun system results.

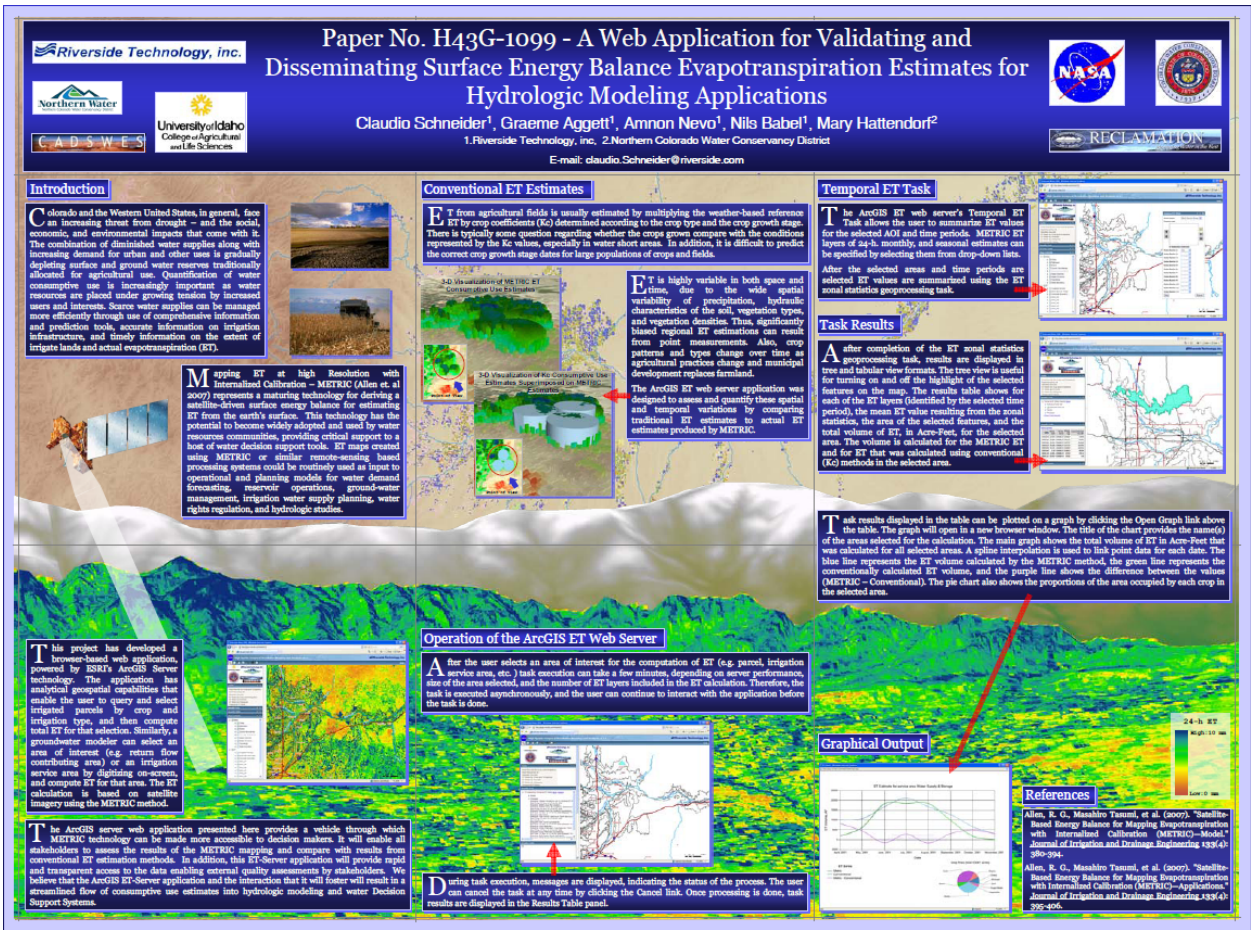


Figure 25

Members of our project team from the University of Idaho also prepared conference manuscripts to present at the May 2008 EWRI meeting in Hawaii, the November 2008 Pecora meeting in Denver, and the May 2009 EWRI meeting in Kansas City.

5. Issues and concerns

The lead contact from the USBR-UCAO in Washington State, Warren Sharp, has moved from Yakima (WA) to Albuquerque (NM). The PI, Dr. Aggett, has discussed with Dr. Dave Toll (NASA) the possibility of moving YR3 benchmarking of the USBR RiverWare DSS from the Columbia river to the Middle Rio Grande (MRG), this because Warren Sharp's role is very important in this testing. By testing on the MRG, we can maintain Mr. Sharp's role in the project. Dr. Toll has agreed to this strategy.

6. References

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