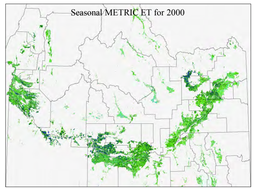
Mapping Evapotranspiration for Water Administration in Idaho



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Introduction

Agriculture in the Western US requires significant quantities of surface and ground water for irrigation because summer rainfall amounts are so low. Southern Idaho only receives about 8 to 12 inches of rainfall per year and most of that occurs in the winter. Idaho's 3.4 million acres of irrigated agriculture accounts for over 90% of the water consumed in the state. Mapping evapotranspiration (ET) is important for water administration because it quantifies the amount and shows the location of water consumed by agriculture.

The Mapping Evapotranspiration program started as a joint effort between the Idaho Department of Water Resources (IDWR) and the University of Idaho (U of I) with initial funding provided by a NASA Synergy Grant. The U of I performed the research and developed the computer models needed to process Landsat data into ET data and IDWR uses the ET data for water administration.

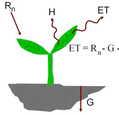
Landsat

IDWR uses Landsat images to compute and map ET because it is the only operational satellite with a high enough resolution thermal sensor to map ET at the field level. Landsat has 16-day repetitive coverage, a large archive of images, and Landsat images are now free. Landsat is managed by NASA and USGS.

The Landsat Data Continuity Mission (LDCM) will launch in December of 2012 with the Thermal InfraRed Sensor (TIRS). TIRS is being built by NASA. The LDCM is a joint NASA and USGS mission.

Developing ET Data

The U of I developed METRIC (Mapping EvapoTranspiration at high Resolution with Internalized Calibration) to compute and map ET. METRIC is a satellite-based energy balance model for computing ET as a residual of the energy balance at the earth's surface using the equation ET = Rn – G - H, where Rn is net radiation, G is sensible heat flux conducted into the ground, and H is sensible heat flux convected into the air. The fundamental principle underlying METRIC is that evaporating liquids absorb heat.



METRIC is a modification and refinement of the Surface Energy Balance Algorithm for Land (SEBAL). METRIC takes advantage of AgriMet weather data to internally calibrate the ET computation. Seasonal and monthly ET images are computed by processing Landsat images throughout a year and using AgriMet data to interpolate ET between image dates. AgriMet is the US Bureau of Reclamation's network of weather stations in the Northwest.

METRIC is a robust model and does not need crop type as input. METRIC computes actual, not potential, ET. METRIC also computes ET for bare soil before planting and after harvest.

METRIC uses two anchor conditions from within an image to fix boundary conditions for the energy balance and to internally calibrate the sensible heat computation, which eliminates the need for in-depth atmospheric correction of temperature or albedo. The internal calibration reduces impacts of any biases in estimation of aerodynamic stability correction or surface roughness.

Accuracy

The accuracy of METRIC ET compares favorably with ET measured in the field. The U of I has found that for a full growing season, METRIC ET is about 90-95% accurate compared to ET measured with a precision weighing lysimeter.

Applications in Idaho

Idaho now uses Landsat based METRIC ET data operationally. Applications include 1) hydrologic modeling, 2) water calls, 3) endangered species protection, 4) land-use/land-cover for planning, and 5) ground water monitoring. METRIC results have been used in legal proceedings and are now part of adjudicated decisions.

The most important feature of using METRIC is that ET is computed for each of Landsat's 900 square-meter pixels, which enables ET to be computed for individual fields where western water and water rights are actually managed. The main limiting factor of using Landsat is that, in some years, not enough cloud free images are available to develop a full season of ET data. Four Landsat satellites collecting data over the same area every 4 days would greatly increase the odds of collecting cloud free images.

Other States

Other states in the west have started to investigate and use satellite-derived ET data including: Nevada, Nebraska, Colorado, Kansas, Wyoming, Oregon, California, New Mexico, and Montana.

References

Allen, R.G., M. Tasumi, and R. Trezza, 2007. Satellite-based energy balance for mapping evapotranspiration with internalized calibration (METRIC)—Model. Journal of Irrigation and Drainage Engineering 133(4):380-394.

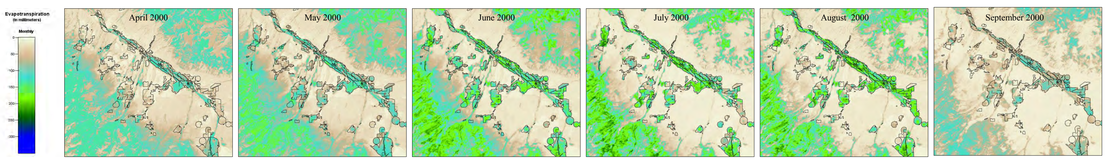
Allen, R.G., M. Tasumi, A. Morse, R. Trezza, J.L.Wright, W. Bastiaanssen, W. Kramber, I. Lorite, and C.W. Robison, 2007. Satellite-based energy balance for mapping evapotranspiration with internalized calibration (METRIC)—Applications. Journal of Irrigation and Drainage Engineering 133(4):395-406.

L. Rocchio, 2007. Precious Resources: Water & Landsat's Thermal Band, http://landsat.gsfc.nasa.gov/news/news-archive/soc_0011.html

IDWR. Mapping Evapotranspiration, http://www.idwr.idaho.gov/GeographicInfo/METRIC/et.htm

U of I. Generation of Evapotranspiration Maps using Landsat Satellite Images, http://www.kimberly.uidaho.edu/water/metric/index.html

Endangered Species



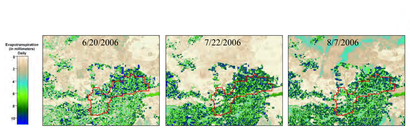
In some basins, there are times of the year when stream flow is low and there is not enough water to meet both the needs of irrigation and stream flow for fish. This is especially true during drought years, and in some areas irrigation can divert all the flow in a stream (photo at left). Most minimum stream flow water rights in Idaho are junior to irrigation water rights. In drought years, this means that stream flows often fall below the amount desirable for fish listed under the Endangered Species Act (ESA).

The State of Idaho developed a draft ESA Section 6 Conservation Plan for the Upper Salmon River Basin with the National Marine Fisheries Service and the US Fish and Wildlife Service. The Section 6 Conservation Plan will put in place measures that increase stream flow for endangered fish and is intended to address long-term low flow streams. Data about the consumptive use of irrigated land is needed in the process.

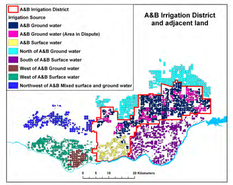
Monthly METRIC ET data were developed for the Lemhi Valley within the Upper Salmon River basin for the year 2000. The data showed that irrigation consumed 33,520 acre-feet (11 billion gallons) of water.

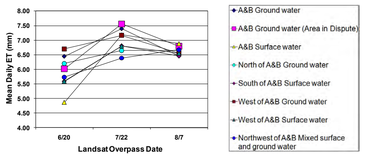
The ET data were also used to assess consumptive use of water rights that may be leased under the Columbia Basin Water Transactions Program (CBWTP). The CBWTP is a Bonneville Power Authority-funded, National Fish and Wildlife Foundation-managed program to improve instream flows in the Columbia River Basin. IDWR identifies stream reaches that would benefit from flow enhancement in the Upper Salmon River basin, and works with willing irrigators to increase instream flow through leases, agreements not to divert, and other transaction methods.

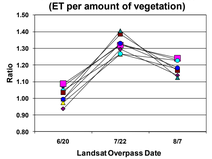
Water Delivery Call



METRIC ET images for three days during summer of 2006.







Idaho water law is based on the prior appropriation doctrine, –first in time is first in right". A water right is the authorization to use water and it includes a priority date. When a senior water right holder experiences a water shortage he may place a –call" against junior water right holders. If the state finds the senior holder has experienced a shortage, the state can respond with a curtailment order, which defines how the junior water right holders must respond so that the senior holder can get their water.

The A&B Irrigation District filed a formal –water call" with the Director of IDWR demanding the curtailment of junior water users. METRIC ET data were used to compute and map consumptive water use for the A&B Irrigation District and adjacent land for 2006. ET data were analyzed from three Landsat image dates by comparing the mean ET for the A&B area where it was claimed to be experiencing a shortage with surrounding areas where no shortage was experienced. The analysis showed that the mean ET for the area in dispute was not lower than surrounding areas that were not claimed to be short of water. Further analysis normalized the ET data using NDVI (Normalized Difference Vegetation Index) to adjust for any differences caused by cropping pattern and the results did not vary. The ET information was used as a –legal finding of fact" in the Director's final order denying the delivery call.

Curtailment Order

Idaho Business *News*

Water curtailment ordered in Magic Valley

POSTED: 11:13 MDT Thursday, July 23, 2009
By IBR Staff

Idaho Department of Water Resources Interim Director Gary Spackman on July 22 issued a curtailment order to about 250 holders of 315 junior water rights in south central Idaho's Magic Valley. The curtailment order is part of a continuing response to a water delivery call made in 2005 by senior water right holder Clear Springs Foods.

Groundwater outflows at Thousand Springs supply water to fish farms that produce 70% of the trout raised in the US. Clear Springs Foods, Inc., is the largest fish farm in the area.

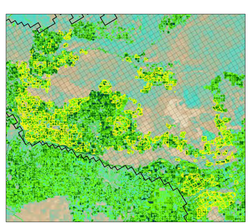
State goes ahead with first large-scale well closure of more than 300 water rights in M.V. 7/31/2009
Water districts have limited options, could file a stay
By Nate Poppino
Times-News writer
The Idaho Department of Water Resources will go forward this morning with a plan to shut off more than 300 water rights irrigating just less than 9,000 acres of Magic Valley farmland, the first wide-scale well curtailment to actually be carried out by the state.

Curtailment on hold for now
By Nate Poppino 8/24/2009
Staff writer
The well closures currently imposed on about 150 water rights in the Magic Valley were lifted today, when 5th District Judge John Melanson conditionally granted a stay sought by two area groundwater districts.

The closures, known as "curtailment," were put in place last month by Idaho Department of Water Resources Interim Director Gary Spackman when he concluded the districts had not followed through with part of an agreement to provide water to Clear Spring Foods in Buhl.

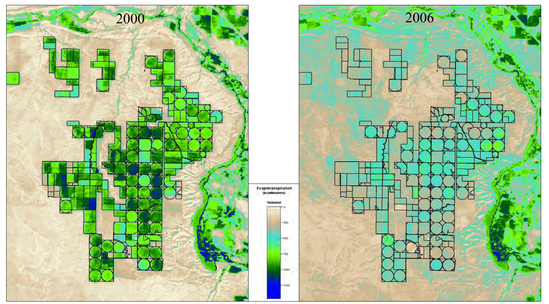
Attorneys for the various parties shared their thoughts on the proposed stay at a hearing Friday in Twin Falls. Melanson, who previously denied a temporary stay of the closures, wrote in today's decision that he would grant the stay as long as the districts follow through with proposed late-season recharge.

IDWR used METRIC ET data to calibrate the Eastern Snake Plain groundwater model and to select the junior water rights to curtail. The initial curtailment order impacted 9,000 acres of land irrigated by ground water. On March 24, 2011, the Idaho Supreme Court ruled in favor of senior water right holder Clear Springs Foods, Inc.



Seasonal 2006 METRIC ET with ESPA Model cells. Junior water rights affected by the curtailment order are highlighted in yellow.

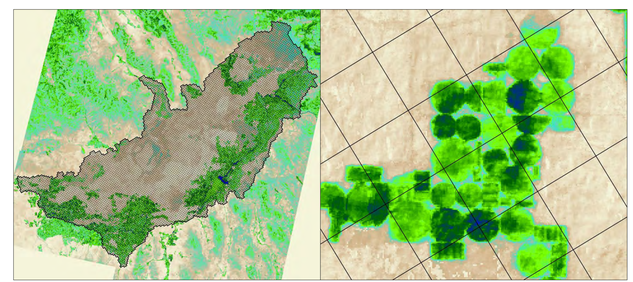
Compliance Assessment



The Bell Rapids Irrigation Project irrigated 25,000 acres of cropland using high-lift pumps to lift water 200 meters from the Snake River. The state purchased the water rights in 2005 for $24.3 million. The Bureau of Reclamation leases the water from the state to increase flows for salmon recovery and the state uses the lease payments to pay back state funds.

METRIC ET images for the irrigation seasons of 2000 and 2006 show the large change in consumptive water use (ET) before and after the water rights buyout in 2005.

Hydrologic Modeling



Seasonal 2000 METRIC ET with the ESPA model cells (close up on the right). Each model grid cell is one square mile.

			Mean ET (mm)		
Cell ID	Source	Acres	2000	2002	2006
SPO22011	Surface water	105	574	601	782
SPO22013	Surface water	59	593	568	552
SPO22111	Mixed	122	741	632	791
SPO22112	Mixed	388	727	736	704
SPO22113	Mixed	350	619	715	739
SPO22114	Mixed	73	646	814	738
SPO22163	Mixed	369	785	749	867
SPO22164	Ground water	12	755	765	840
SPO22165	Ground water	227	942	757	782
SPO22170	Mixed	81	529	671	879
SPO22171	Surface water	69	508	700	714
SPO22172	Surface water	45	560	657	771
SPO22196	Surface water	320	460	512	567
SPO22197	Mixed	51	309	538	465
SPO22197	Surface water	505	413	548	581
SPO22198	Surface water	546	515	637	654
SPO22199	Surface water	632	647	673	713
SPO22200	Surface water	428	465	555	592

Hydrologists used monthly and seasonal METRIC ET to calibrate MODFLOW ground water models of the Eastern Snake Plain Aquifer (ESPA) and the Boise Valley aquifer. This improves the accuracy of estimated distribution and quantities of depletions from the aquifers caused by pumping, as well as improving estimates of incidental recharge to the aquifers stemming from irrigation diversions. These more accurately calibrated ground water models are being used in litigation involving conjunctive use of ground water and surface water resources.

For the ESPA model, there is METRIC ET data processed for years: 1996, 2000, 2002, and 2006. Monthly and seasonal METRIC ET data are being developed for all years having sufficient cloud-free imagery from the mid 1980s to the present. This will allow analysis of long term trends in ET over the ESPA and the resulting impact on the aquifer.

The table shows trends in ET from irrigated land for years 2000, 2002, and 2006 by model cell and source. The sources are surface water, ground water, and mixed (both surface water and ground water).

University of Idaho

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ASPRS 2011 Annual Conference
Milwaukee WI, May 3, 2011

University of Idaho

Idaho Department of Water Resources

Why is measuring Evapotranspiration (ET) important

- ET is the water consumed by irrigated agriculture
- Important for administration, management and planning of water resources
- Irrigated agriculture in Idaho
  - 3.4 million acres
  - Accounts for over 90% of the water consumed
  - Worth $5 billion per year
- Irrigation in the US
  - 50 million acres agriculture, 32 million acres recreational
  - Accounts for over 80% of the water consumed
  - Crops worth $70 billion per year

Ground-based ET

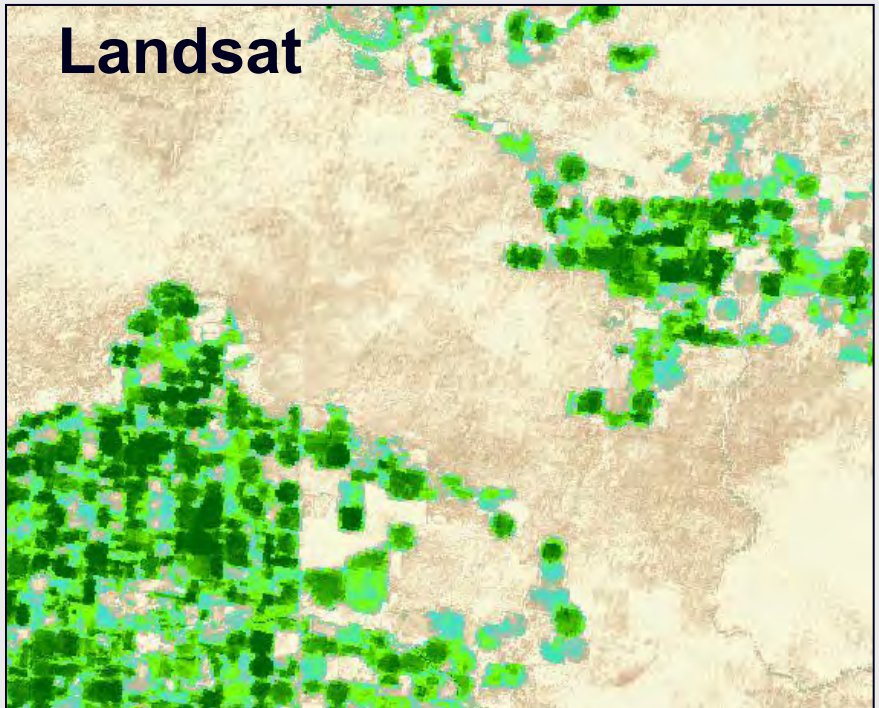
- Potential ET using crop coefficients
  - Needs crop type acres and stage of growth
  - Produces one ET value per county

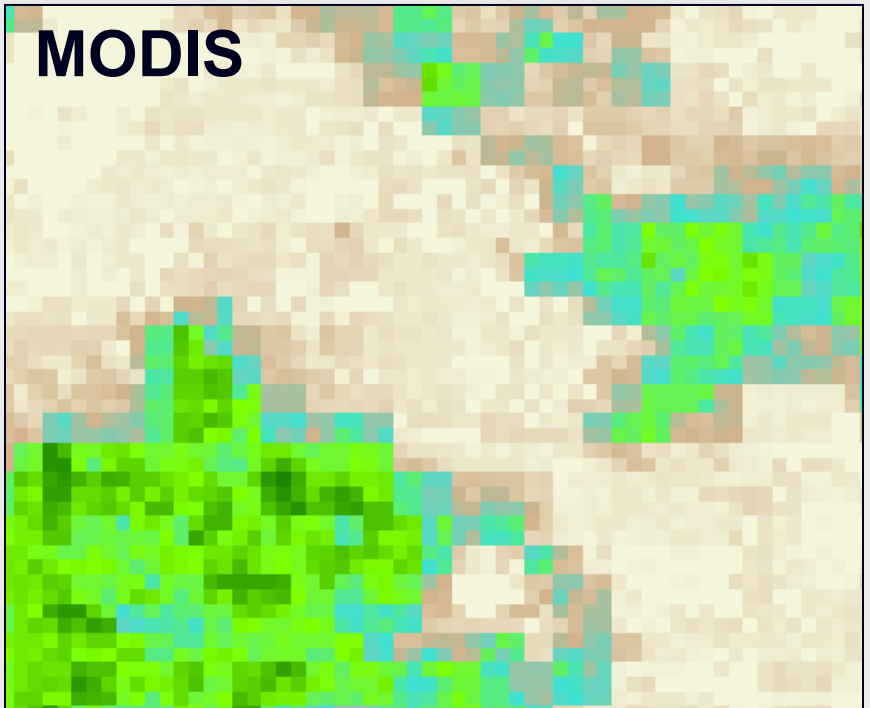
Satellite-based ET

- Actual ET from Landsat using METRIC
  - No crop information required
  - ET per pixel can be summed by field

Landsat Thermal Band

- Required for surface temperature
- Landsat is the only operational satellite with a "thermal band" and a pixel size small enough to map ET for individual fields!

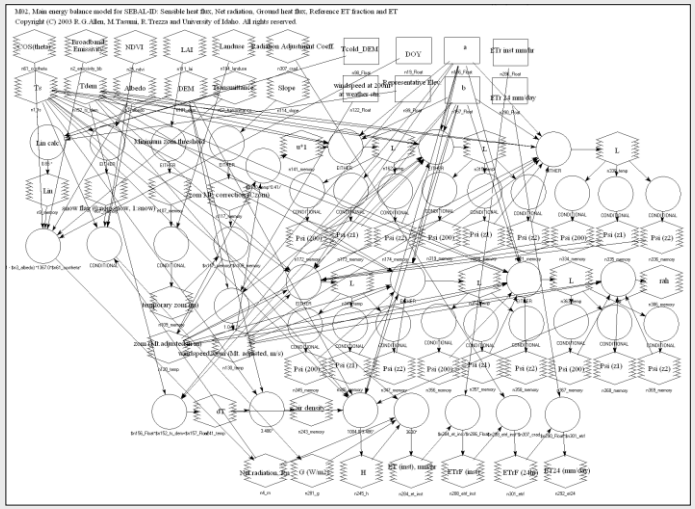




METRIC

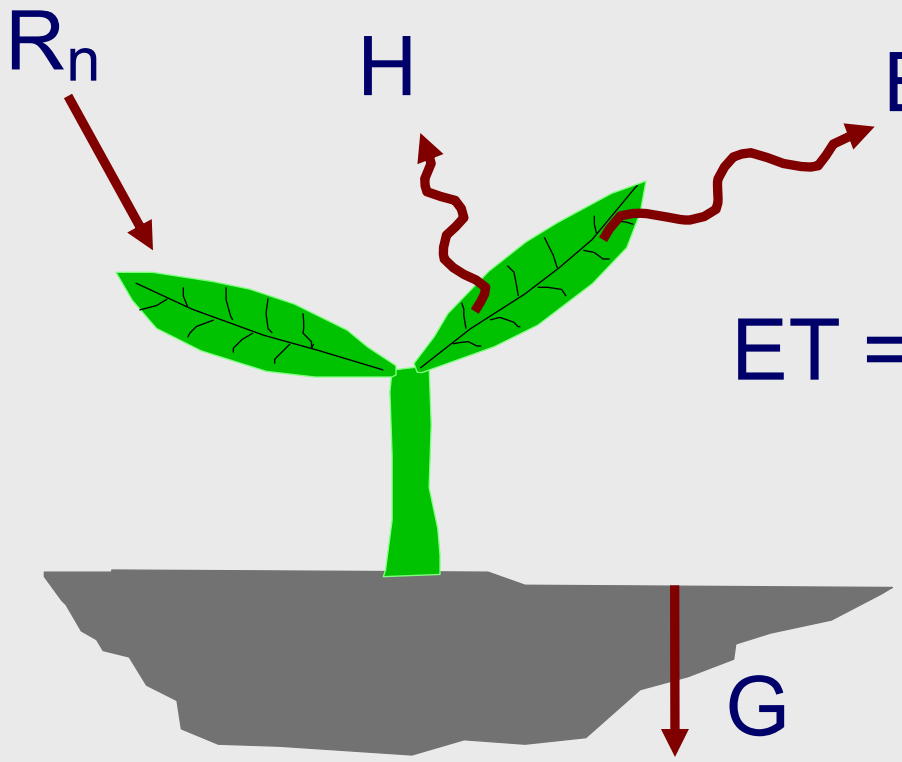
Mapping **E**vapo**T**ranspiration at high **R**esolution with **I**nternalized **C**alibration

- Satellite-based energy balance model that computes and maps actual ET
- Internalized Calibration ties down ET to weather data
- Over 90% accuracy compared to precision weighing lysimeter



Energy Balance for ET

ET is calculated as a “residual” of the energy balance



$$ET = R_n - G - H$$

The energy balance includes all major sources (R_n) and consumers (ET, G, H) of energy

Energy balance computes “actual” ET

Can „sæ’ impacts on ET caused by:

- water shortage
- disease
- crop variety
- planting density
- cropping dates
- salinity
- management
- evaporation from bare soil

Idaho and other western states now use METRIC ET data operationally to help manage water resources