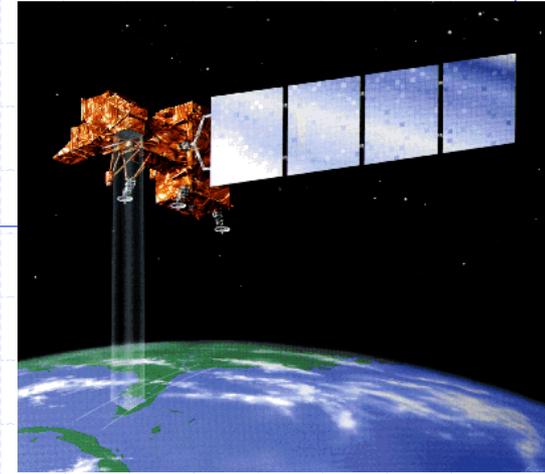


# Field-Scale ET Applications in Water Rights Management:

Why Thermal?

Why Field-Scale?

Why more 30 m Satellites?



**Rick Allen** – Prof. Water Resources Engineering, Univ. Idaho,  
Kimberly, Idaho

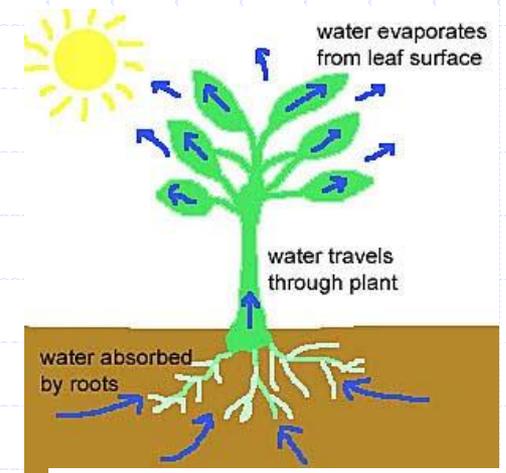
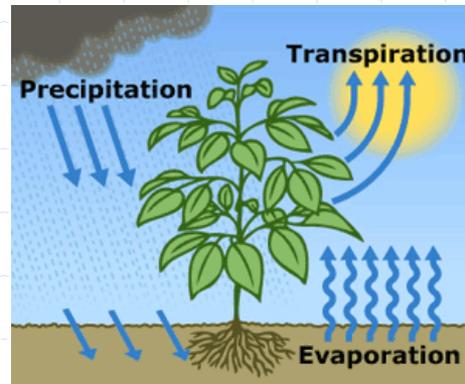
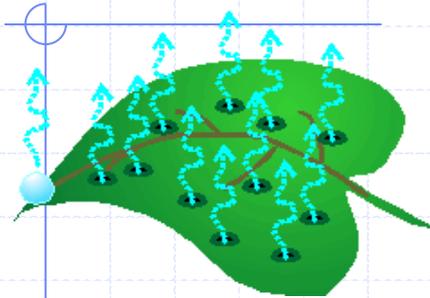
**Ayse Kilic** – Assoc. Prof. Civil Engineering/Natural Resources,  
Univ. Nebraska-Lincoln

**Tony Morse** – Principal, Spatial Analysis Group

**Development Partners and Collaborators:** R.Trezza, Univ. Idaho, Bill Kramber, Idaho Dept. Water Resources, M. Tasumi, Univ. Miyazaki, *Japan*; W. Bastiaanssen, WaterWatch, *Netherlands*; I. Lorite, Andalucia, *Spain*; J. Wright, USDA-ARS; Jeppe Kjaersgaard, Minn. Ag; Clarence Robison, Univ. Idaho; Jan Hendrickx, NMT; Justin Huntington, Desert Research Institute, *Reno, NV*



# What is Evapotranspiration (ET)?



Soil evaporation plus leaf transpiration  
ET converts liquid water to vapor



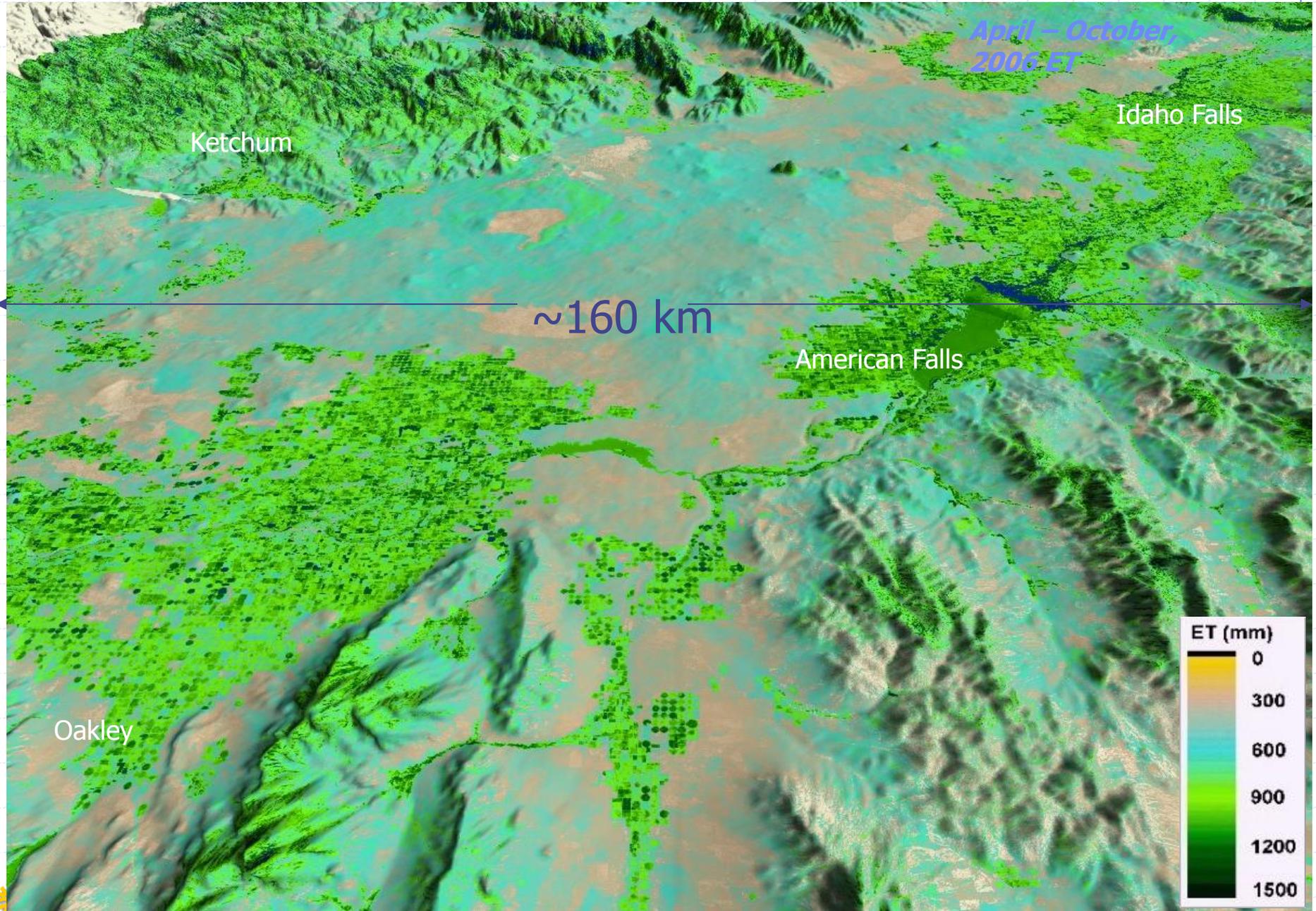
ET consumes water from soil that  
must be replaced by rainfall or  
irrigation

ET from irrigation water is 90% of  
world-wide water consumption



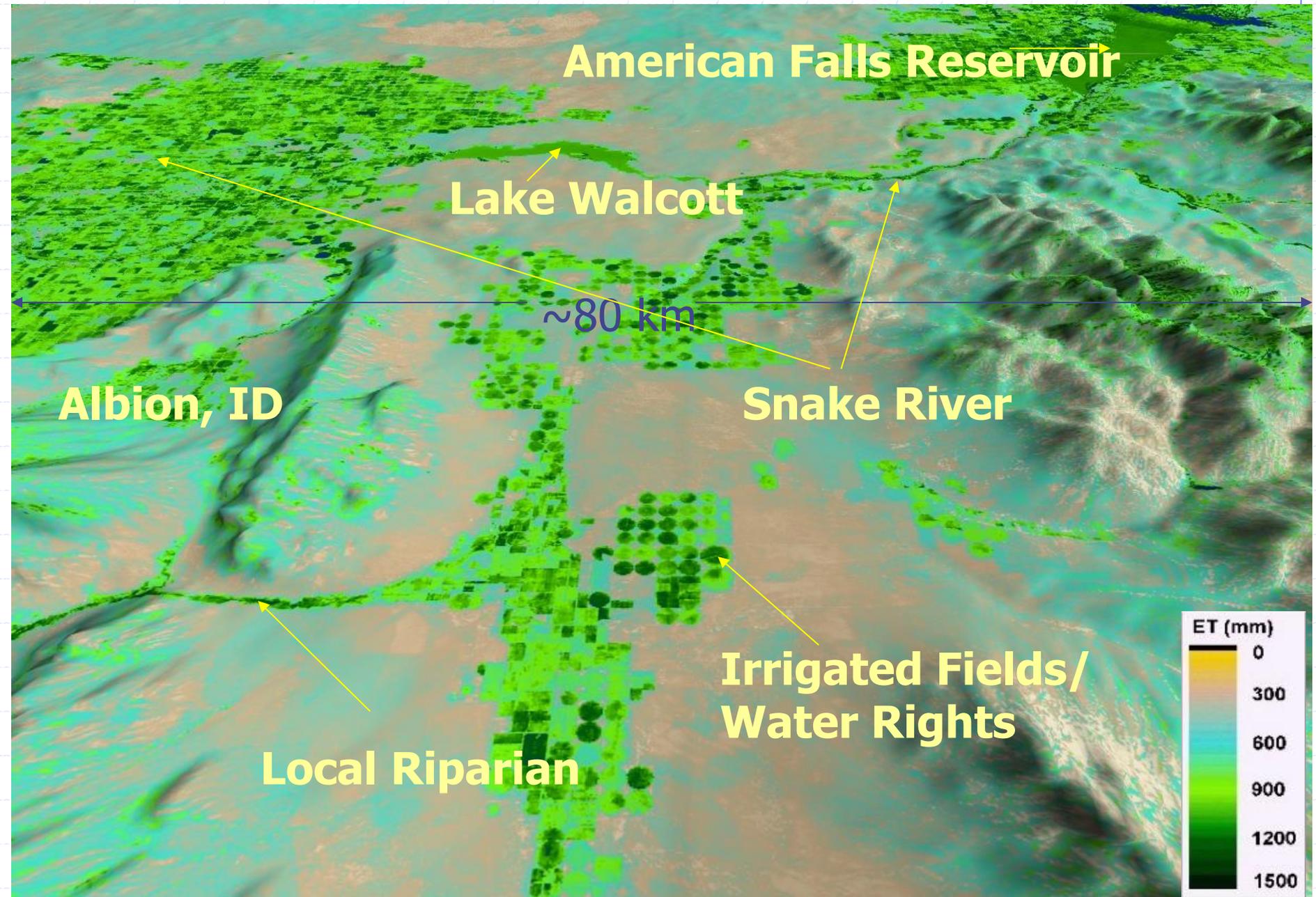
# Vegetation and ET vary in Space

-- Monthly and Seasonal ET at 30 m resolution for the Eastern Snake Plain of Idaho



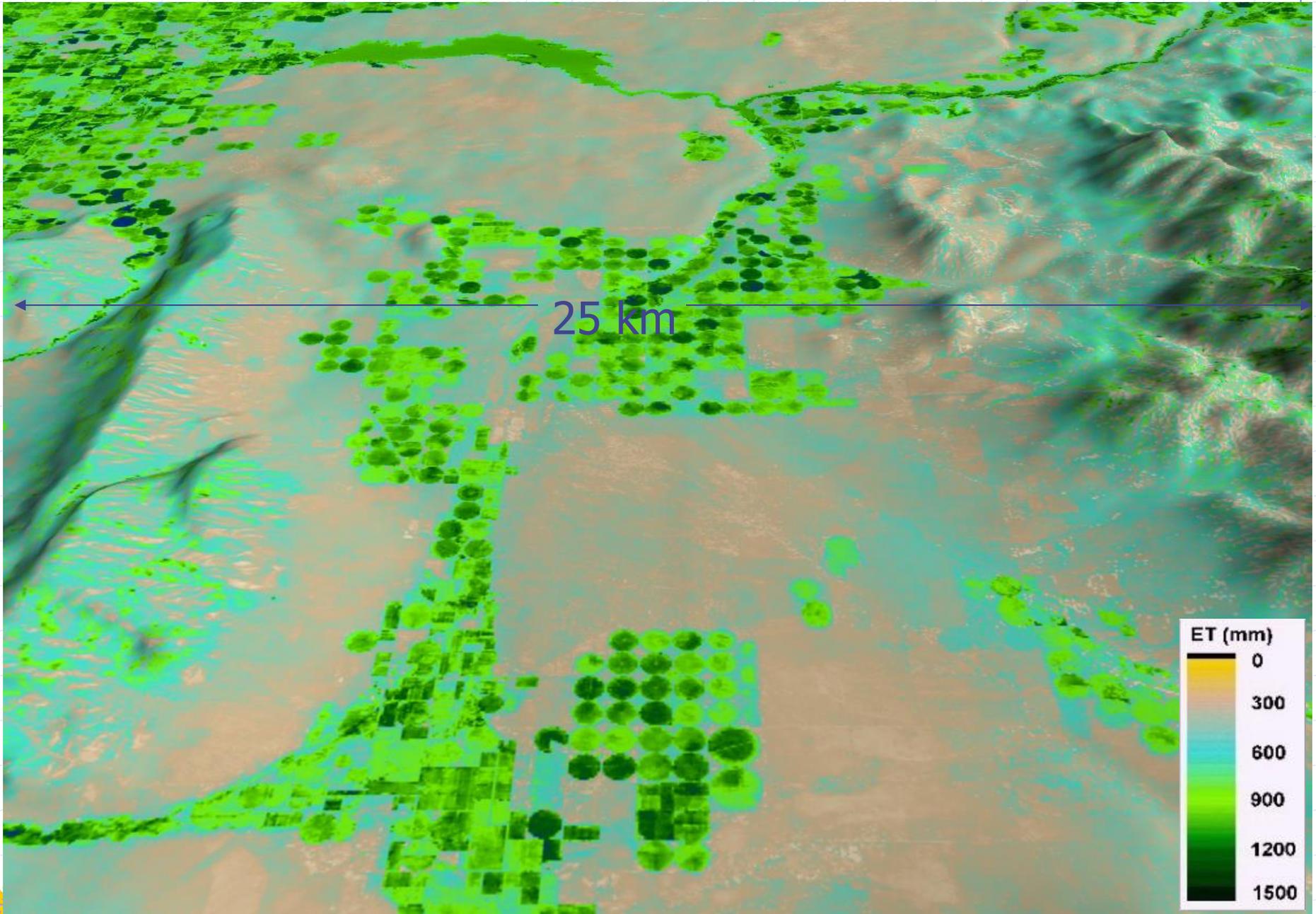
# ET features at 30 m resolution

April – October, 2006 ET from  
METRIC-Landsat

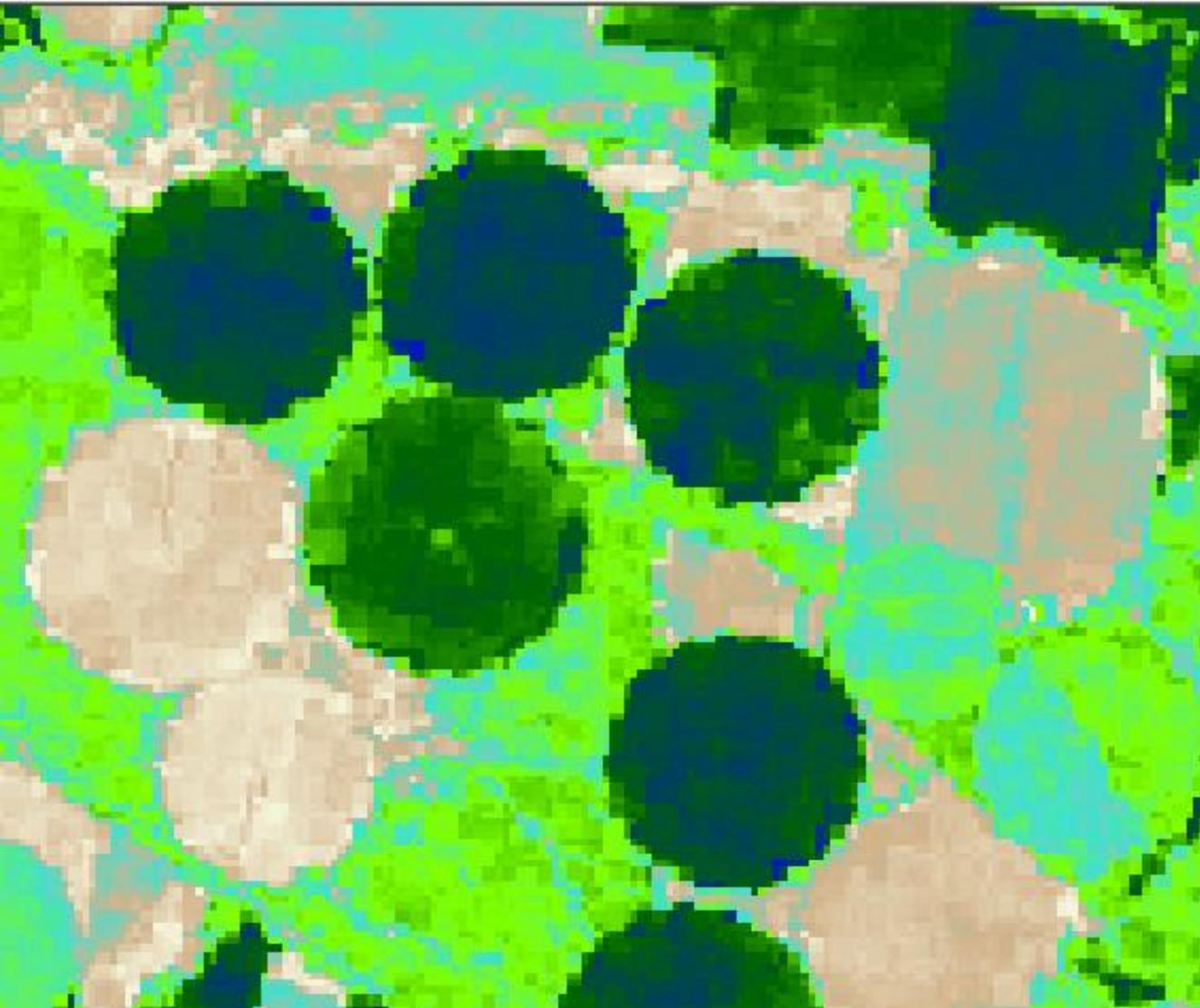


# ET features at 30 m resolution

April – October, 2006 ET from  
METRIC-Landsat

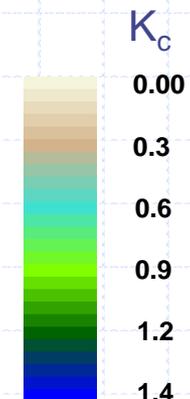


# Close up of ET from Irrigation



## Andalusia Region of Spain

- Ground-water depletion area
- New irrigation development
- Many traditionally rainfed olives are now irrigated



( $K_c$  based on  $ET_o$ )

*METRIC application in La Mancha, Spain, 2003*

# Recent Landsats

## ◆ Landsat 8

- Launched February 11, **2013**
- **30 m pixel size** for short-wave data
- **100 m pixel size** for thermal data
- Revisit each 16 days



## ◆ Landsat 7

- Launched February **1999**
- 30 m pixel size for short-wave data
- 60 m pixel size for thermal data
- Revisit each 16 days, 8 days after Landsat 8



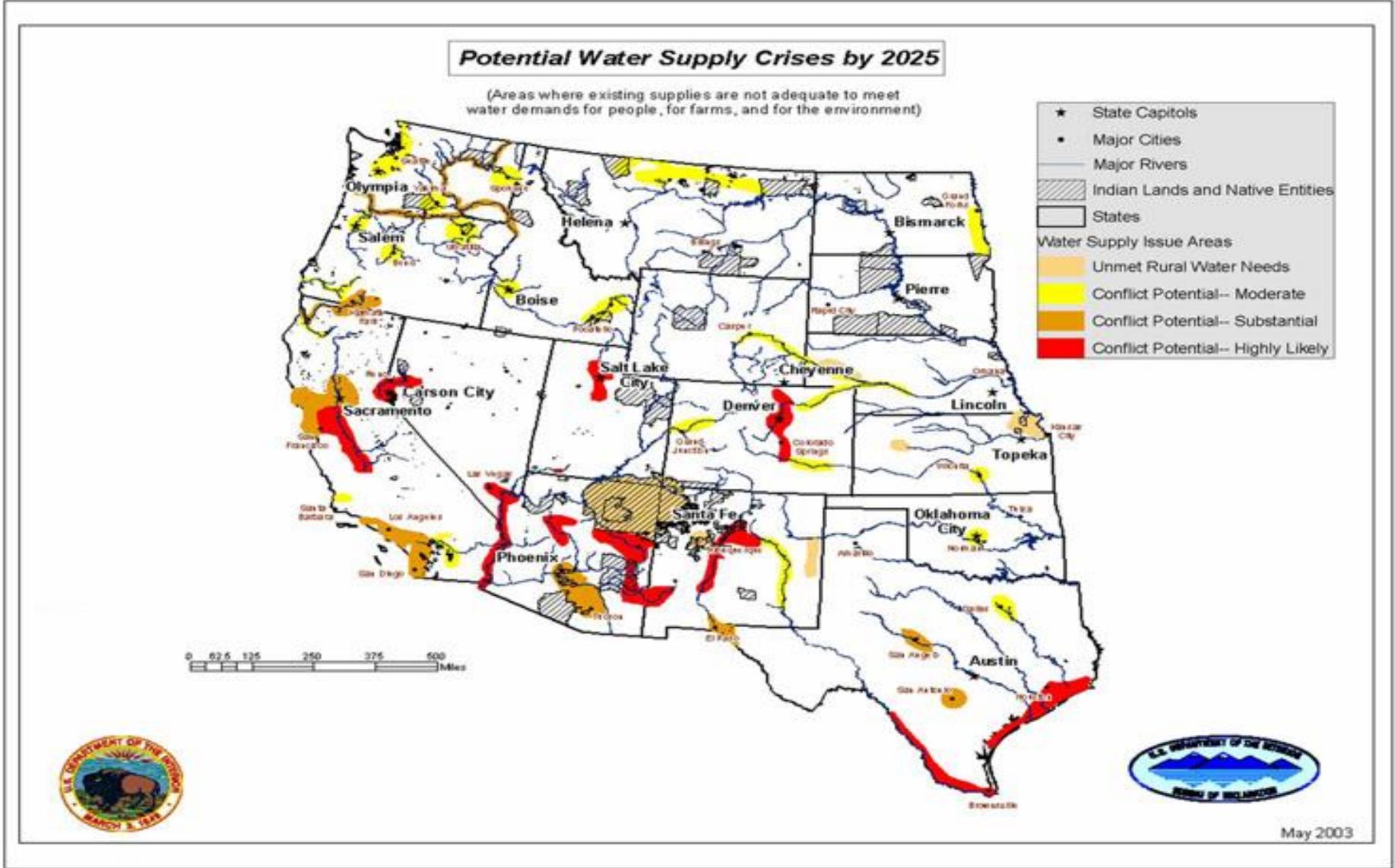
*Ayse Kilic,  
Landsat  
Science  
Team  
member, at  
the Launch*

## ◆ Landsat 5

- Launched **1984** ended 2012
- 30 m pixel size for short-wave data
- 120 m pixel size for thermal data
- Revisit each 16 days
- Landsat 5 retired in 2012 (worn out), replaced by L8

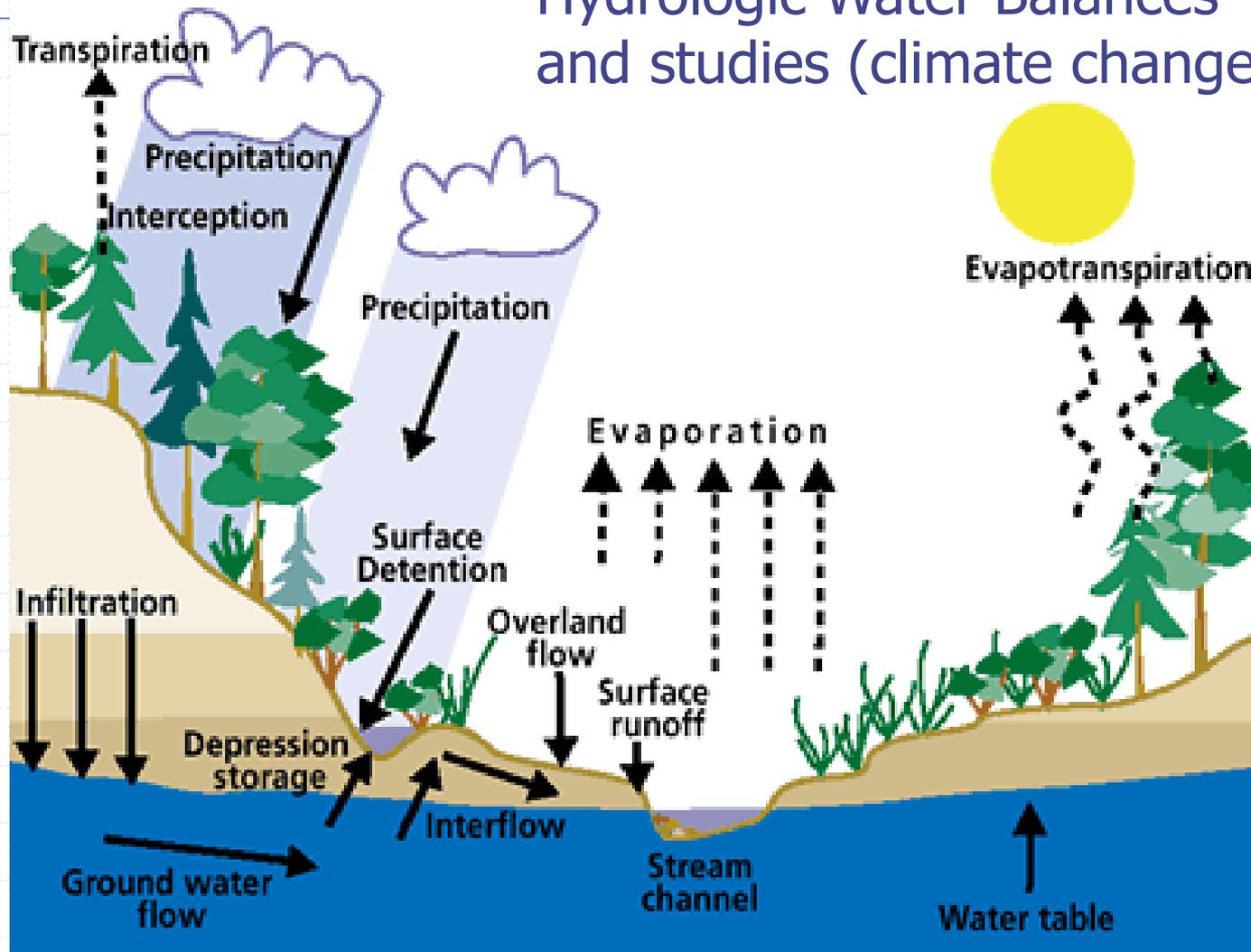


# Potential (and re-occurring) Water Conflicts



# Why Quantify ET?

Hydrologic Water Balances and studies (climate change)



slide courtesy MNR, Ontario, Canada

IWRRI Ground Water Connections Conference, Sept 24, 2008, Boise, ID

# Why use an “Energy balance”?

- ◆ ET is calculated as a “residual” of the energy balance – driven by THERMAL

$R_n$  (radiation from sun and sky)

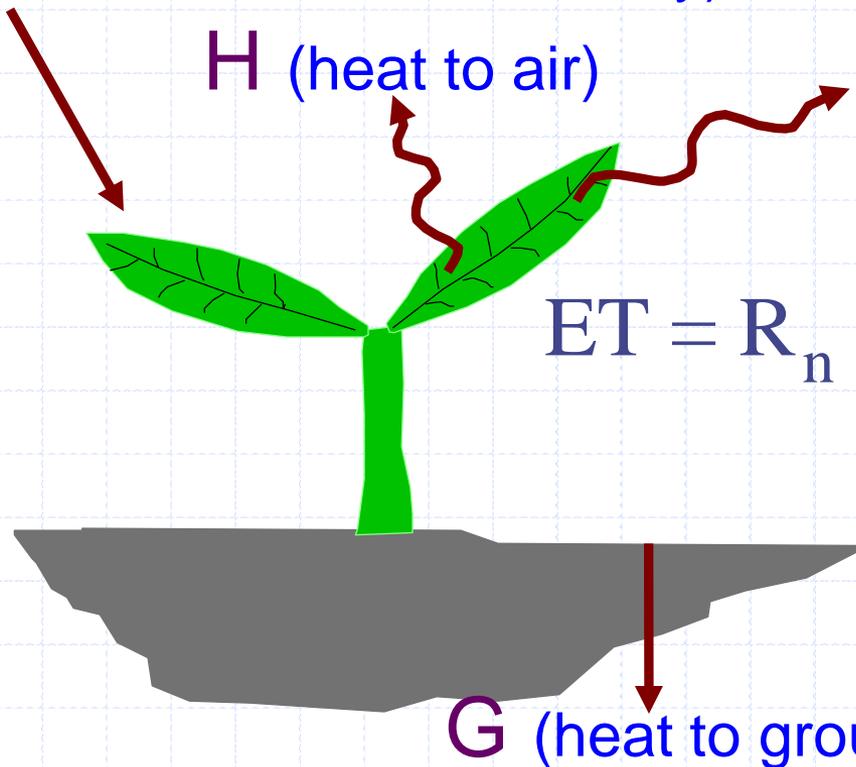
$H$  (heat to air)

ET

$$ET = R_n - G - H$$

## Basic Truth:

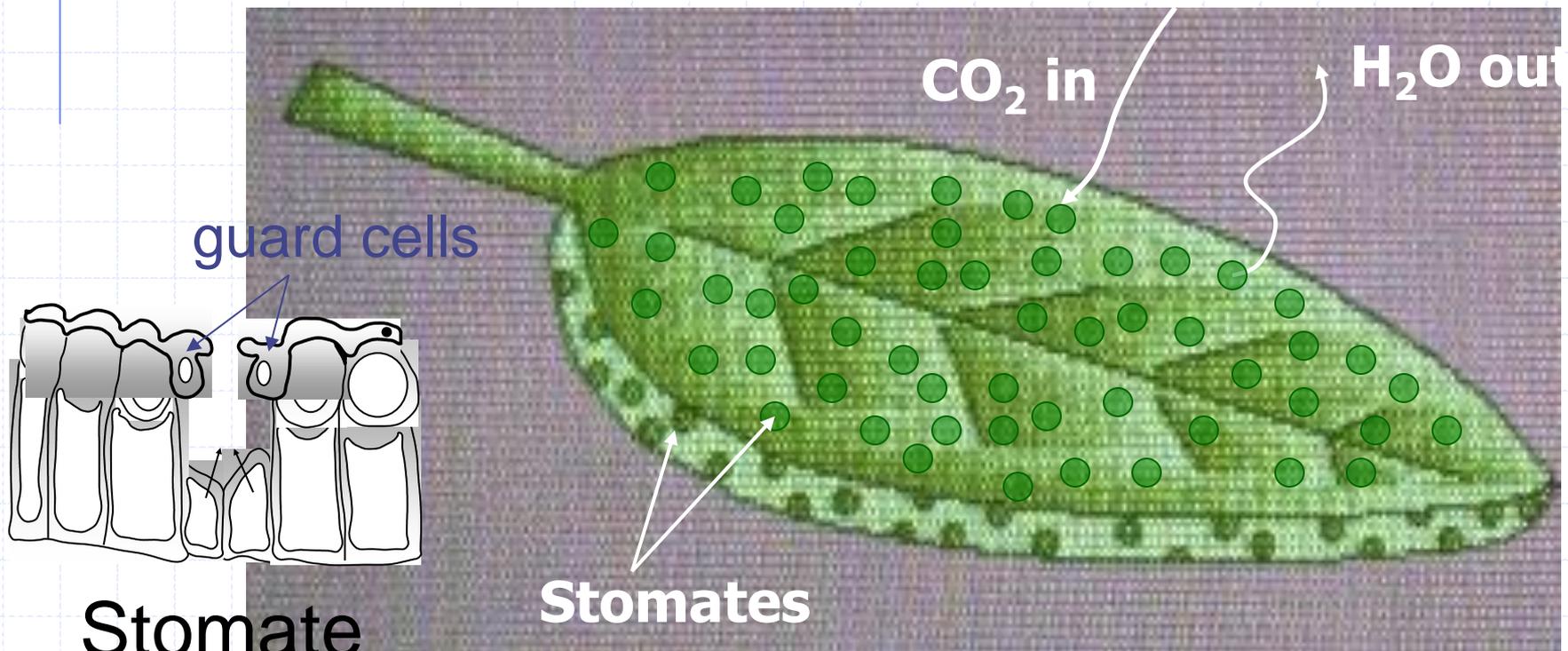
Evaporation  
consumes  
Energy



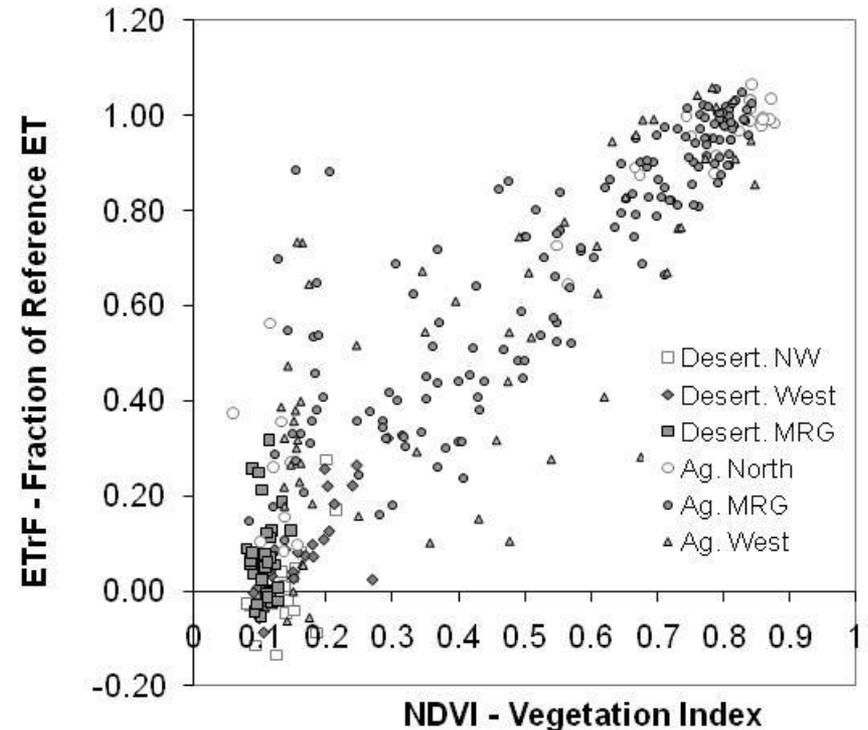
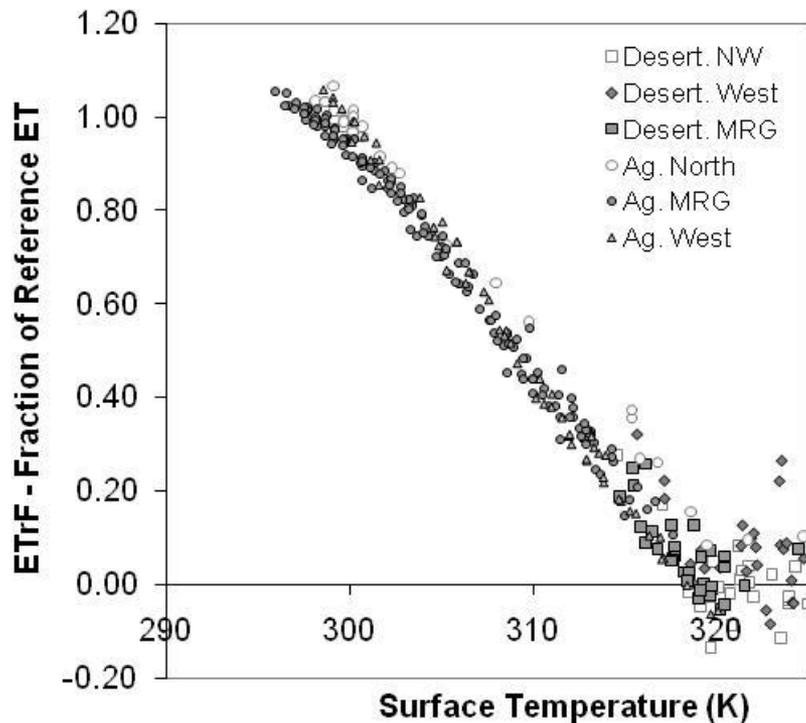
$G$  (heat to ground)

# ET may not be proportional to the amount of vegetation: *Stomatal Conductance can vary*

Water Vapor flow out of stomates  
CO<sub>2</sub> flows in for Photosynthesis.  
*Stomates close when plant is stressed and ET decreases*



# ET is Correlated more with Surface Temperature than with Vegetation Amount – due to wetness



Middle Rio Grande, New Mexico, 2002

# Energy balance gives us “actual” ET

We can ‘see’ impacts on ET caused by:

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



# METRIC Applications in Idaho

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Water Planning

Aquifer Depletion

Hydrologic Modeling

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Endangered Species

Agricultural Water Use

Legal Finding-of-Fact

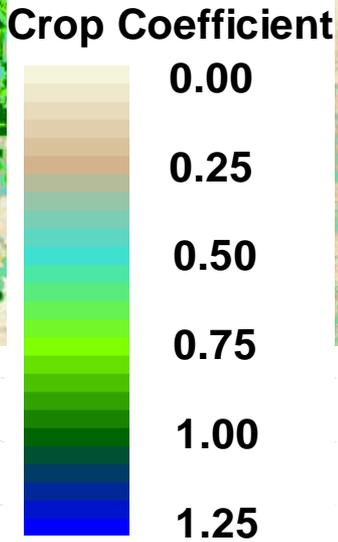
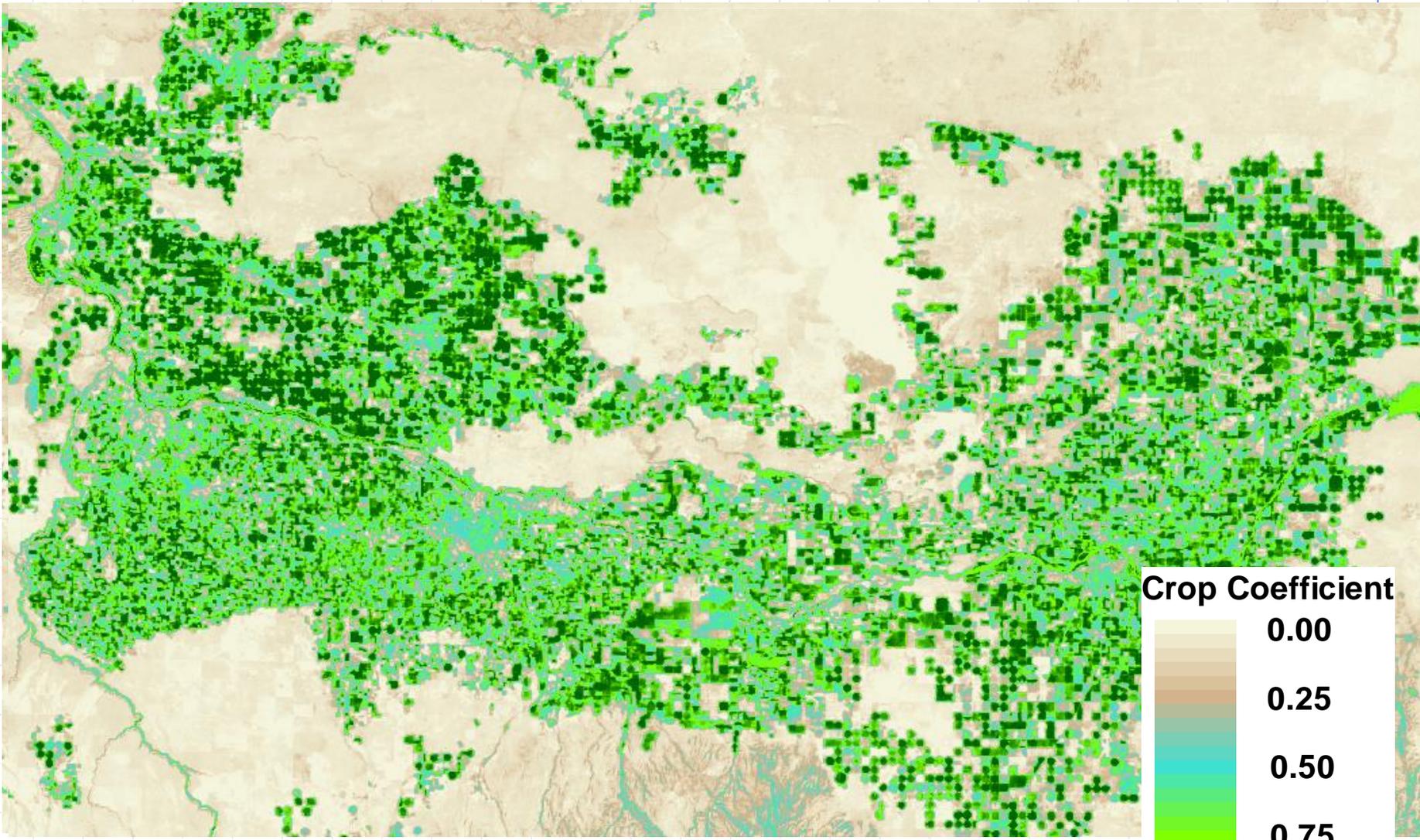
Water Rights Buy-Back

Water Rights Compliance

In-Season Water Demand

Tribal Water Rights Negotiations

# Time Series of ET near Twin Falls, ID



8/22/2000

9/28/2015

Snake River Plain and Aquifer  
Yellow "dots" are ground-water wells  
( > 4000 )

"Junior" Irrigators from Aquifer ~1960

Senior Aquiculture  
from Springs ~1950

Junior consumption from Aquifer  
"Injures" Senior River and Spring Rights

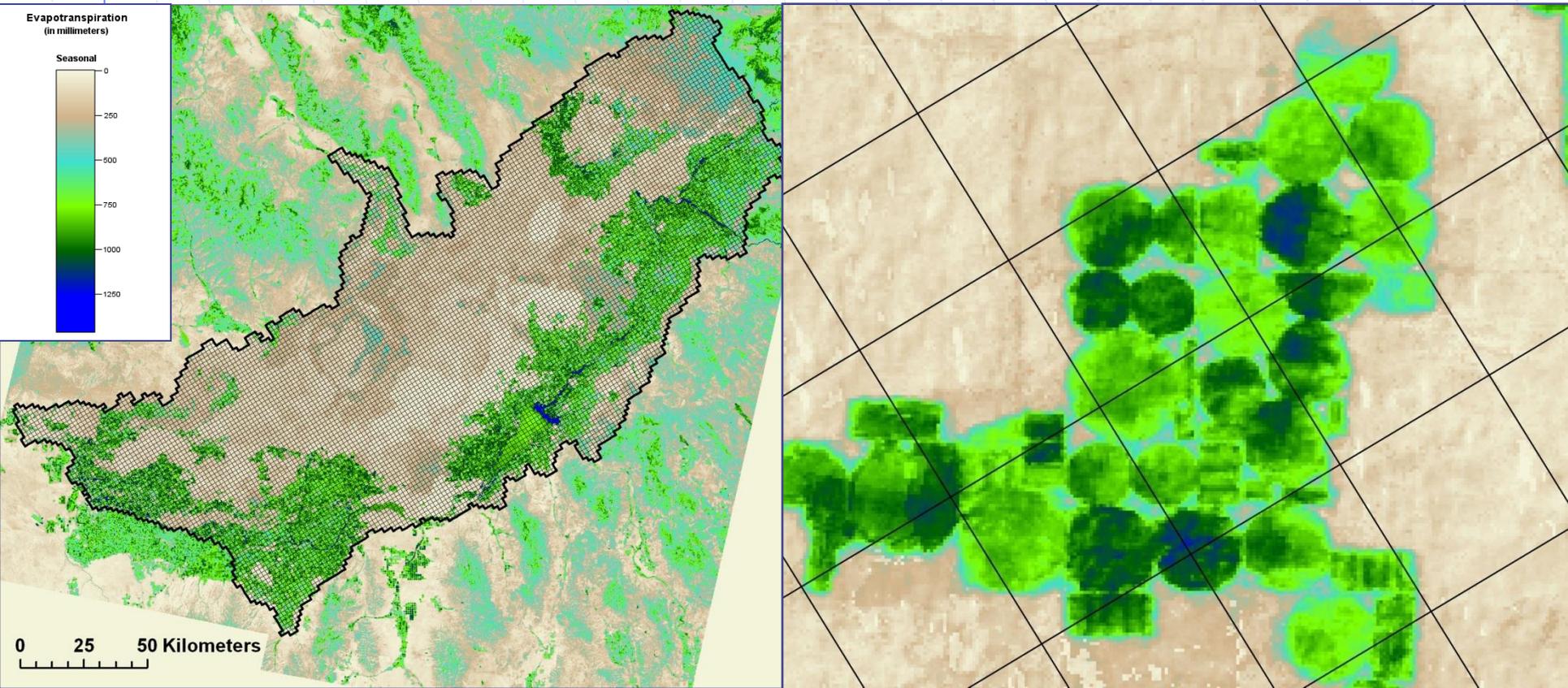
"Senior" Irrigators from River ~1900

# Idaho

## Hydrologic Modeling

### Eastern Snake Plain Aquifer Model

Developing METRIC ET data from 1986 to present.  
ET is used to calculate a water balance for each model grid cell.



# Idaho

## Eastern Snake Plain Aquifer Model

### METRIC ET data:

- ◆ More accurately calibrate the groundwater model
- ◆ Improve accuracy of depletions and recharge estimates
- ◆ More confidence in using groundwater model for curtailment
- ◆ Shows long term trends and annual variation in ET

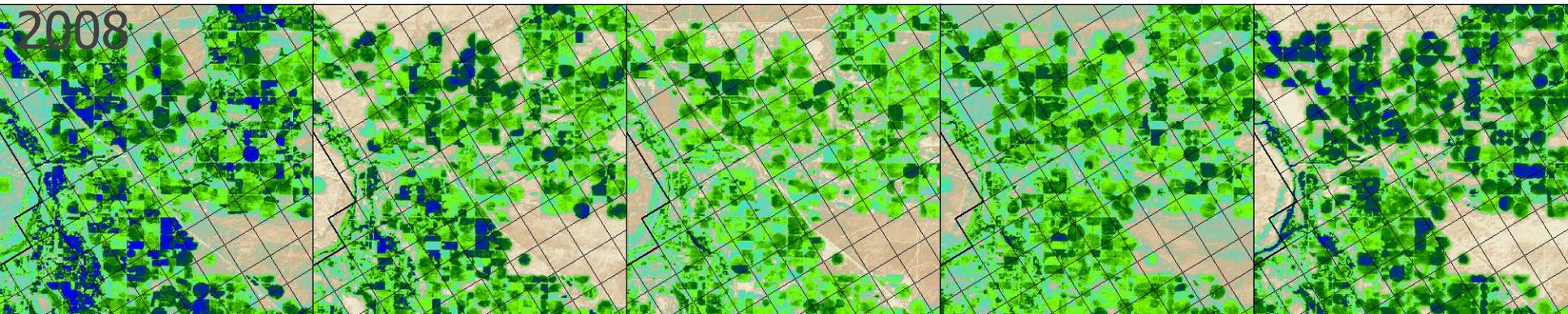
1996

2000

2002

2006

2008



# Snake River Canyon, southern Idaho



← Upgradient GW irrigators →

# Example 1: Senior Surface/Spring users vs. Upgradient GW Pumpers –

Example: Clear Springs Foods, Inc. (Trout Production)



## Water watch begins

8/1/2009

### Unprecedented well shut-off goes into effect in valley

By Nate Poppino and Jared Hopkins

WENDELL - Employees of Idaho's state water agency quietly fanned out across the Magic Valley Friday morning, to see if nearly 250 water-right holders have complied with an order to stop using some groundwater rights.

It was the first time that the Idaho Department of Water Resources actually enforced widespread well closures to provide water to another entity.

### Talks fail to find well shutoff solutions

#### State continues curtailment enforcement

By Nate Poppino  
Times-News writer

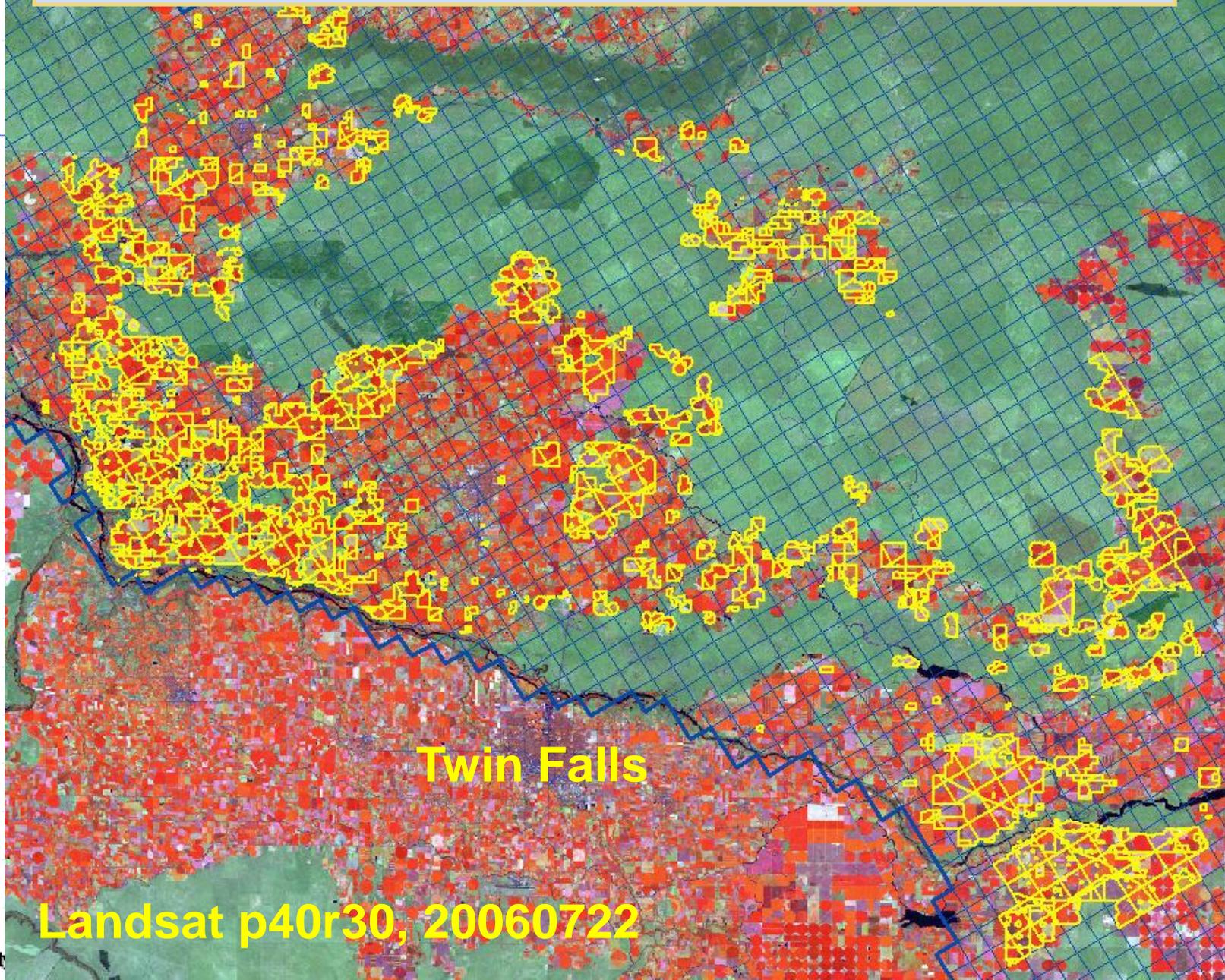
8/11/2009

Officials with two Magic Valley groundwater districts have not been able to reach an arrangement with a Buhl-area fish company, a setback in efforts to lift wide-scale well closures in the region.

Representatives of the North Snake and Magic Valley groundwater districts were attempting to reach an agreement to end curtailment of about 150 water rights affecting businesses, towns and about 4,150 acres of irrigated land. But Lynn Carlquist, chairman of the North Snake Ground Water District, said Monday afternoon that the districts will not be able to agree to requirements Clear Springs Foods listed as necessary for the company to consider a plan submitted last week acceptable.

The water rights were ordered shut down on July 31 by Idaho Department of Water Resources Interim Director Gary Spackman after he concluded the districts were not following through on a portion of an agreement aimed at providing more water for the springs Clear Springs relies on. Spackman's predecessor, Dave Tuthill, ruled last year that groundwater pumpers were depriving the company of part of its water.

# GW Model Cells and Junior Water Rights



Twin Falls

Landsat p40r30, 20060722

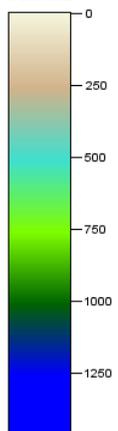
# METRIC ET 2006 April to October

Outcome:

1. Junior users brought to the mitigation table
2. When provision of 'replacement water' failed: Junior GW users "bought" the Trout Farm

Evapotranspiration  
(in millimeters)

Seasonal



Annual Water Consumption = 4 million acre-feet/year (3 Trillion gallons; 5 Trillion liters)

# Example 2: Legal Finding of Fact

Water 'Call' 12/2007 by A&B Irrigation District (senior ground-water users vs. junior ground-water users)

## Water Call

Claim of injury due to water shortage in 2006

- caused by lowering of aquifer by junior pumpers

Demand for curtailment order to junior GW irrigators

## A Curtailment Order

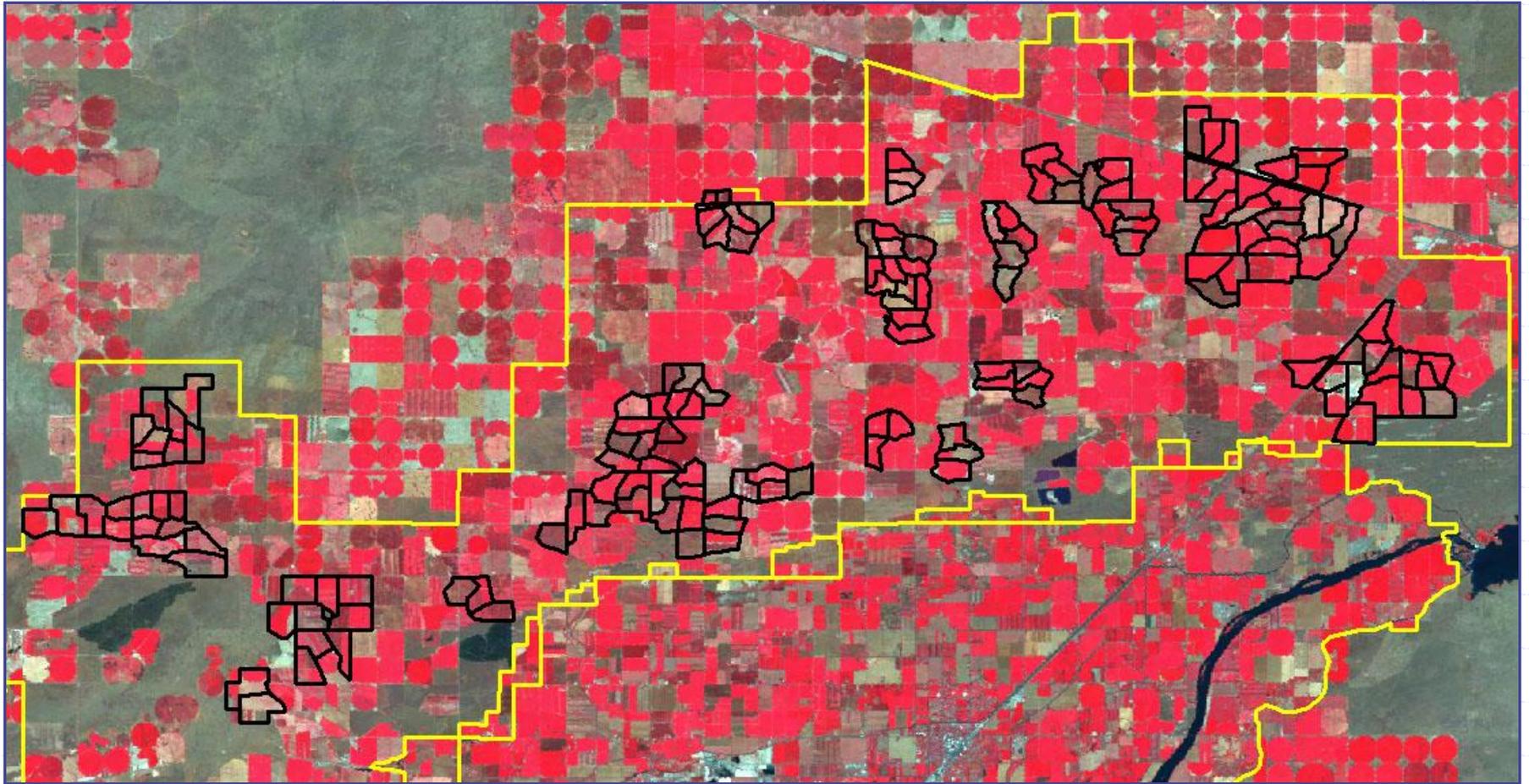
Issued by Idaho Dept. Water Resources

Has the force of law

Built on Finding of Fact

At stake: >1,000 farmers' livelihoods.

# Legal Finding of Fact



Polygons of fields claimed to be water-short in 2006.

# The Crux of the Issue

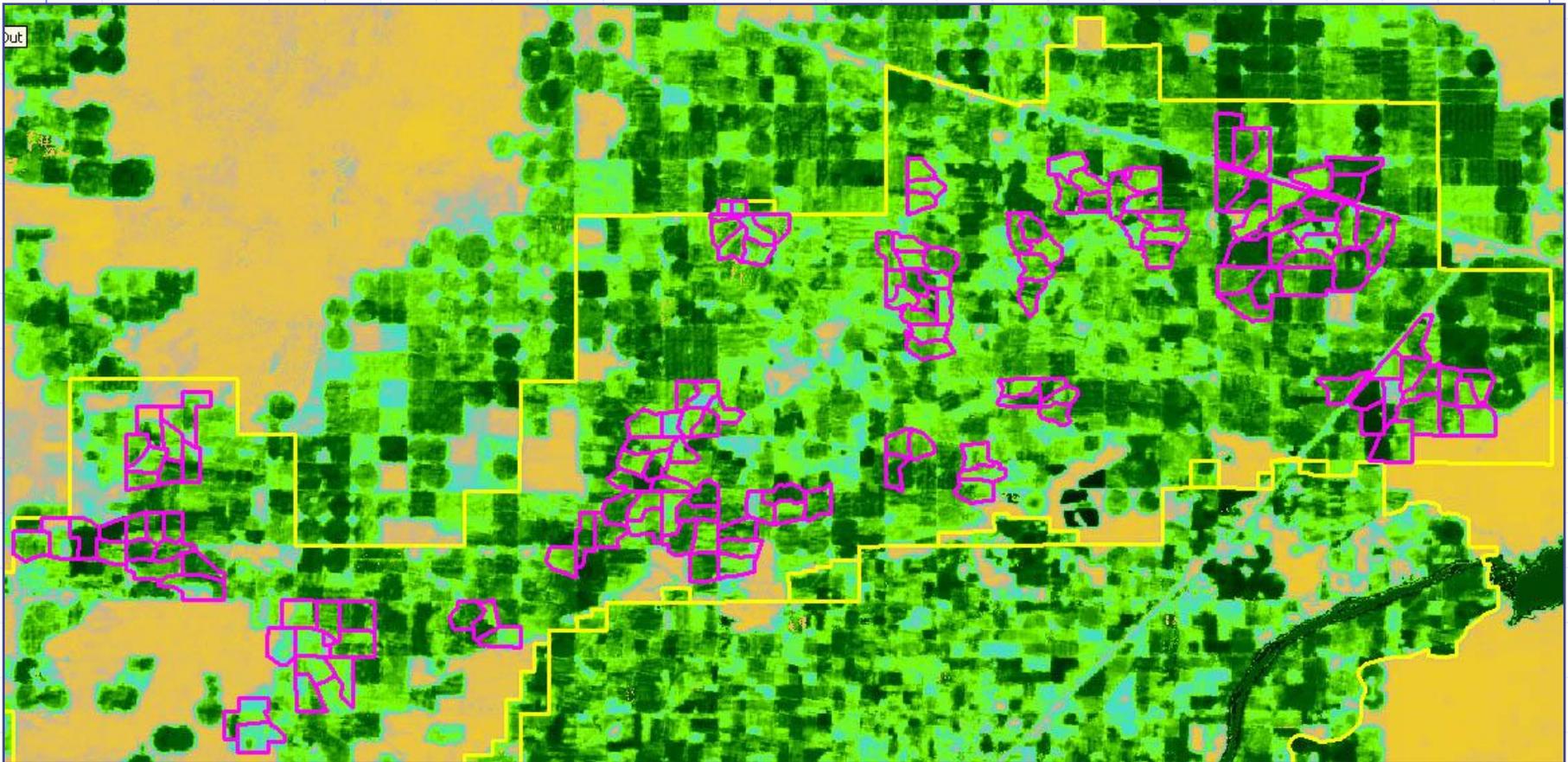
Was there enough water in 2006?

How do you assess that 2 years later?

How do you evaluate individual fields?

# The Answer

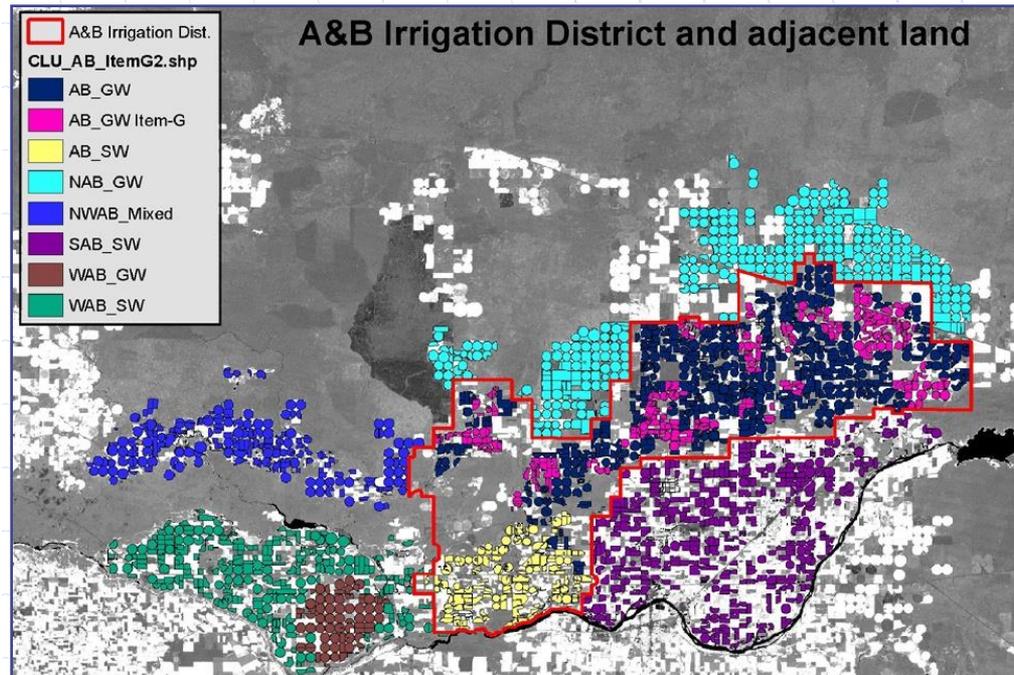
Use Landsat to map 2006 evapotranspiration



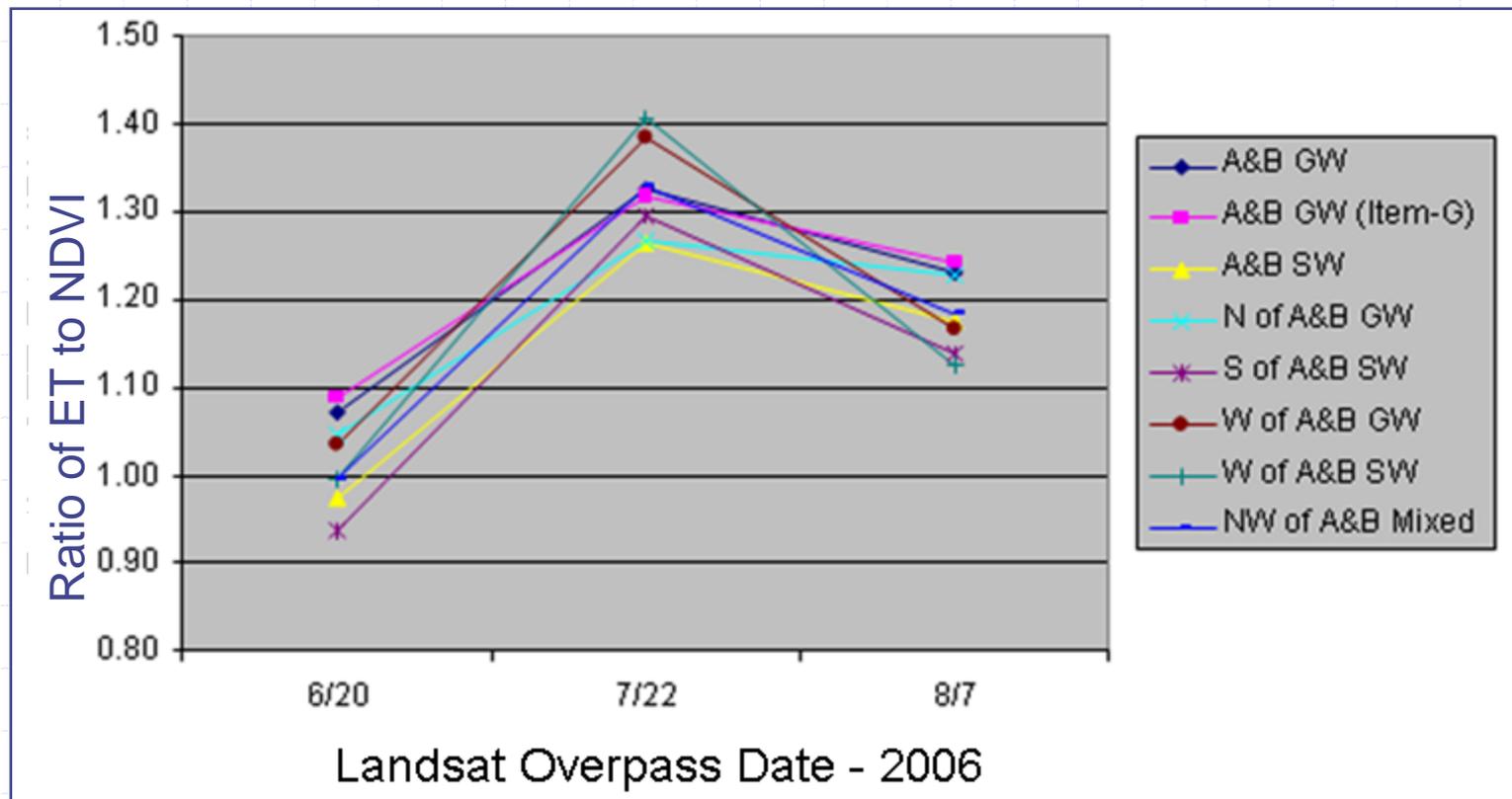
Purple polygons are fields claimed to be water-short in 2006

# The Analysis

METRIC ET Images for 6/20, 7/22, 8/7  
Compared mean 24-hour ET  
Compared mean Vegetation indices (NDVI)  
Compared mean ratio ET / NDVI.



# ET / NDVI



How much evapotranspiration per amount of vegetation?

*(A&B did not appear to suffer)*

# Result

IDWR denied the call

A&B appealed (**and lost**)

Analysis based on

Unbiased data sets

Single data source

Field-level data

Archive data

Landsat resolution (30 m)  
enabled the analysis

## BEFORE THE DEPARTMENT OF WATER RESOURCES

### OF THE STATE OF IDAHO

IN THE MATTER OF THE PETITION FOR )  
DELIVERY CALL OF A&B IRRIGATION )  
DISTRICT FOR THE DELIVERY OF GROUND ) **ORDER**  
WATER AND FOR THE CREATION OF A )  
GROUND WATER MANAGEMENT AREA )

This matter originally came before the Director of the Department of Water Resources ("Director" or "Department") on July 26, 1994 when the A&B Irrigation District ("A&B" or "District") filed a petition for delivery call, which sought administration of junior priority ground water rights diverting from the Eastern Snake Plain Aquifer ("ESPA"), as well as the designation of the ESPA as a ground water management area.

On May 1, 1995, A&B, the Department, and other participants entered into an agreement that stayed the petition for delivery call until such time as a motion to proceed was filed with the Director. On March 16, 2007, A&B filed a motion to proceed seeking the administration of junior priority ground water rights, as well as the designation of the ESPA as a ground water management area.

Based upon the Director's consideration of the available information and documents filed herein, the Director enters the following Findings of Fact, Conclusions of Law, and Order.

### FINDINGS OF FACT

#### Procedural History

1. On July 26, 1994, A&B filed a Petition for Delivery Call ("Petition") with the Department. The boundary of the A&B Irrigation District is depicted in Attachment A. According to the Petition, A&B "is the beneficial owner of Water License No. 20736, now known as A-36-02080, which entitles the Irrigation District to divert eleven hundred (1100) cfs from one hundred seventy-seven (177) wells for the irrigation of sixty-two thousand six hundred four and three tenths (62,604.3) acres within the irrigation district, with a priority of September 9, 1948." *Petition* at 1, ¶ 2. "That said water right is held in trust by the United States, for the benefit of the owners of said 62,604.3 acres, all of whom are landowners within and are included within A&B Irrigation District." *Id.* at 1, ¶ 3. Additionally, the Petition stated that due to diversions from the ESPA by junior priority ground water users, A&B "is suffering material injury as a result of the lowering of the ground water pumping level within the E[SPA] by an

# Example 3: Water Rights Buy-Back

## Issue:

Maintain minimum Snake River Flows

Endangered species

Hydro power rights

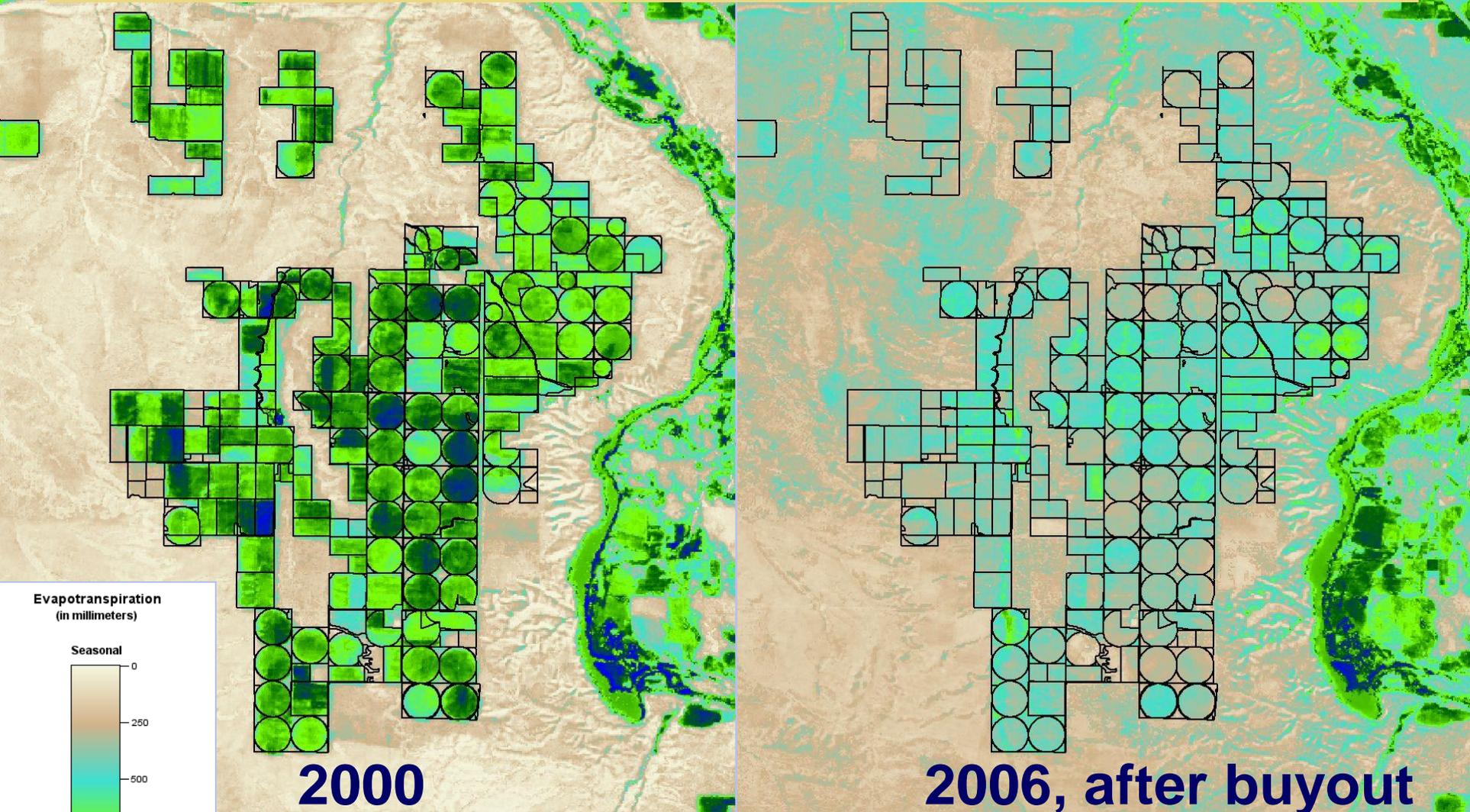
Method: Buy out marginal water rights

Negotiation

Farmer's position: buy full water right

IDWR's position: **buy wet water.**

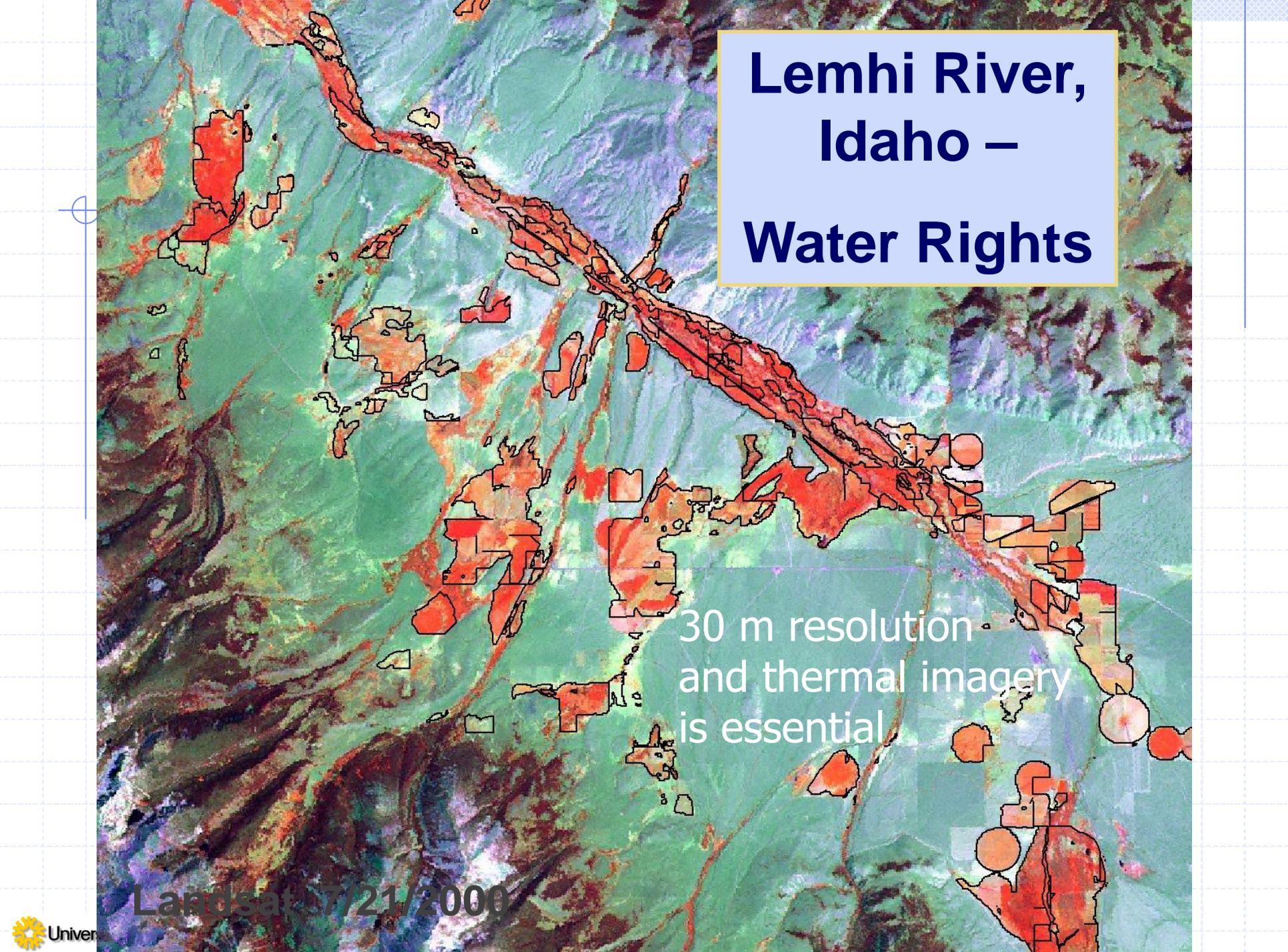
# Bell Rapids Irrigation Project, Idaho: Seasonal ET



- High lift pumps irrigated 25,000 acres
- State purchased water rights in 2005 for \$24 million
- Supports endangered salmon

# Example 4: Water Planning for Endangered Species

- Landsat-based ET estimates
- Consumptive portion compared to diversions to help producers reduce diversions and sustain streamflows during summer for Salmon

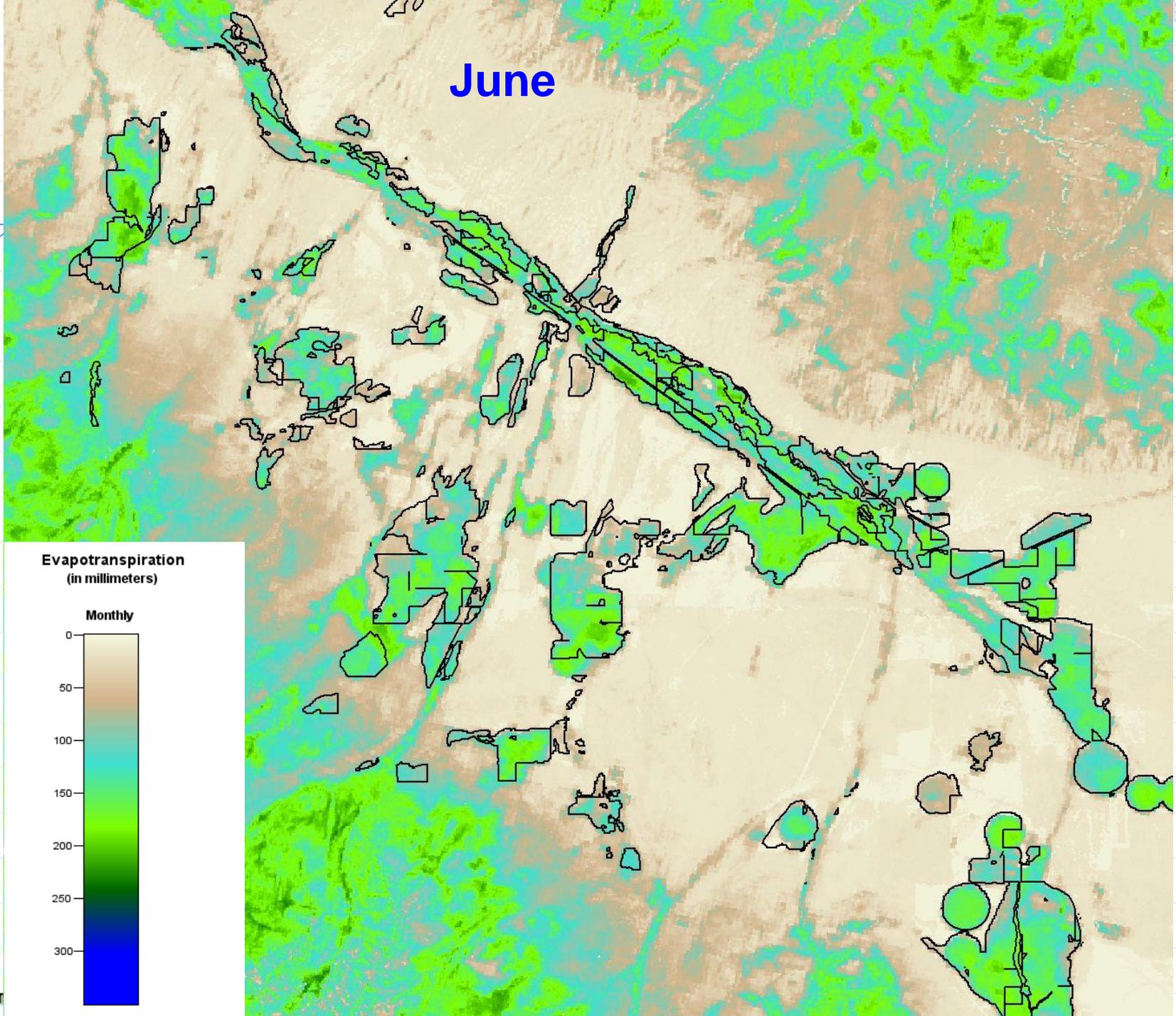


# Lemhi River, Idaho – Water Rights

30 m resolution  
and thermal imagery  
is essential

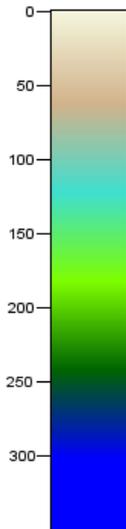
Landsat 7/21/2000

June

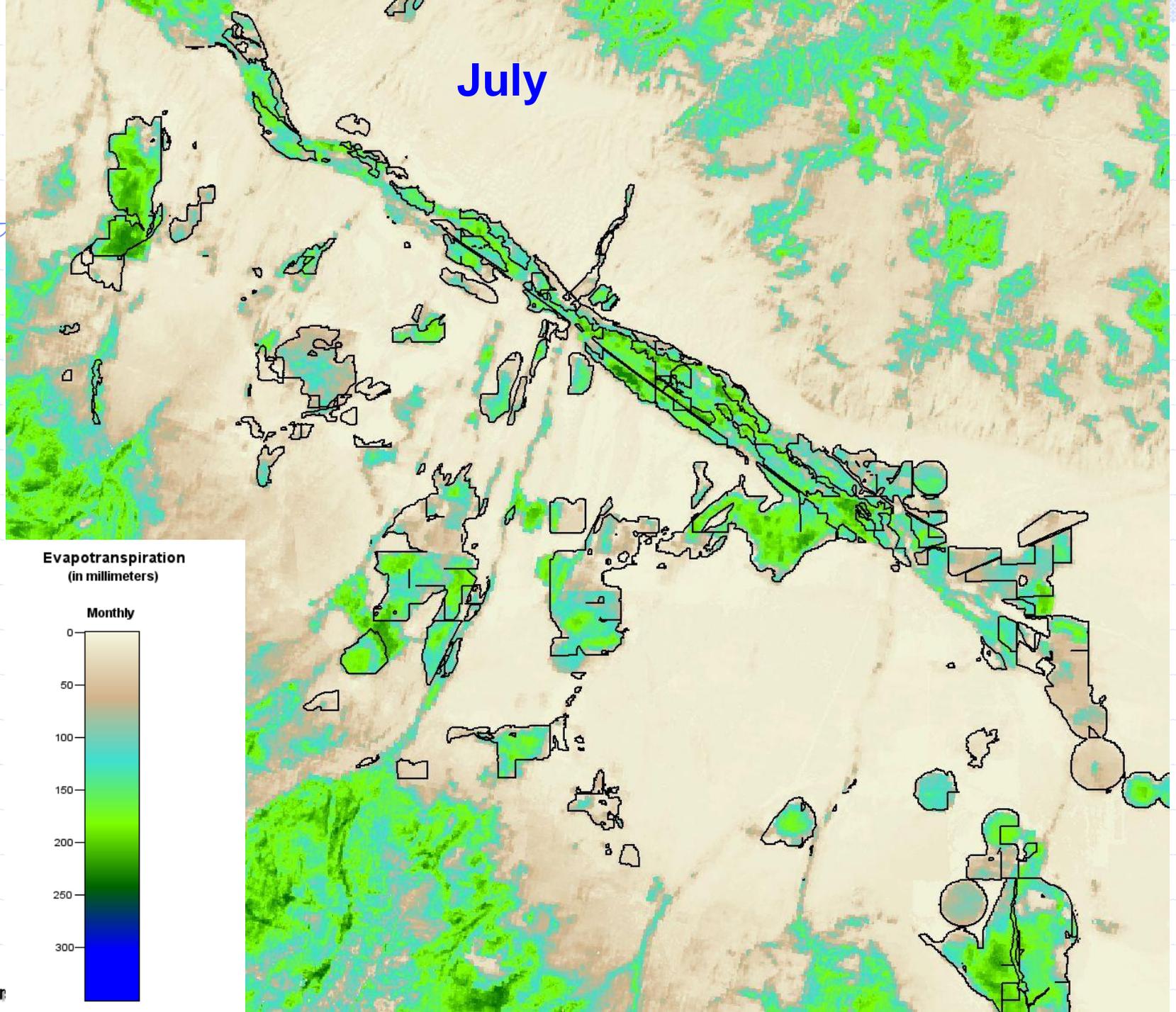


Evapotranspiration  
(in millimeters)

Monthly

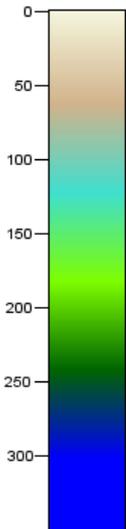


July

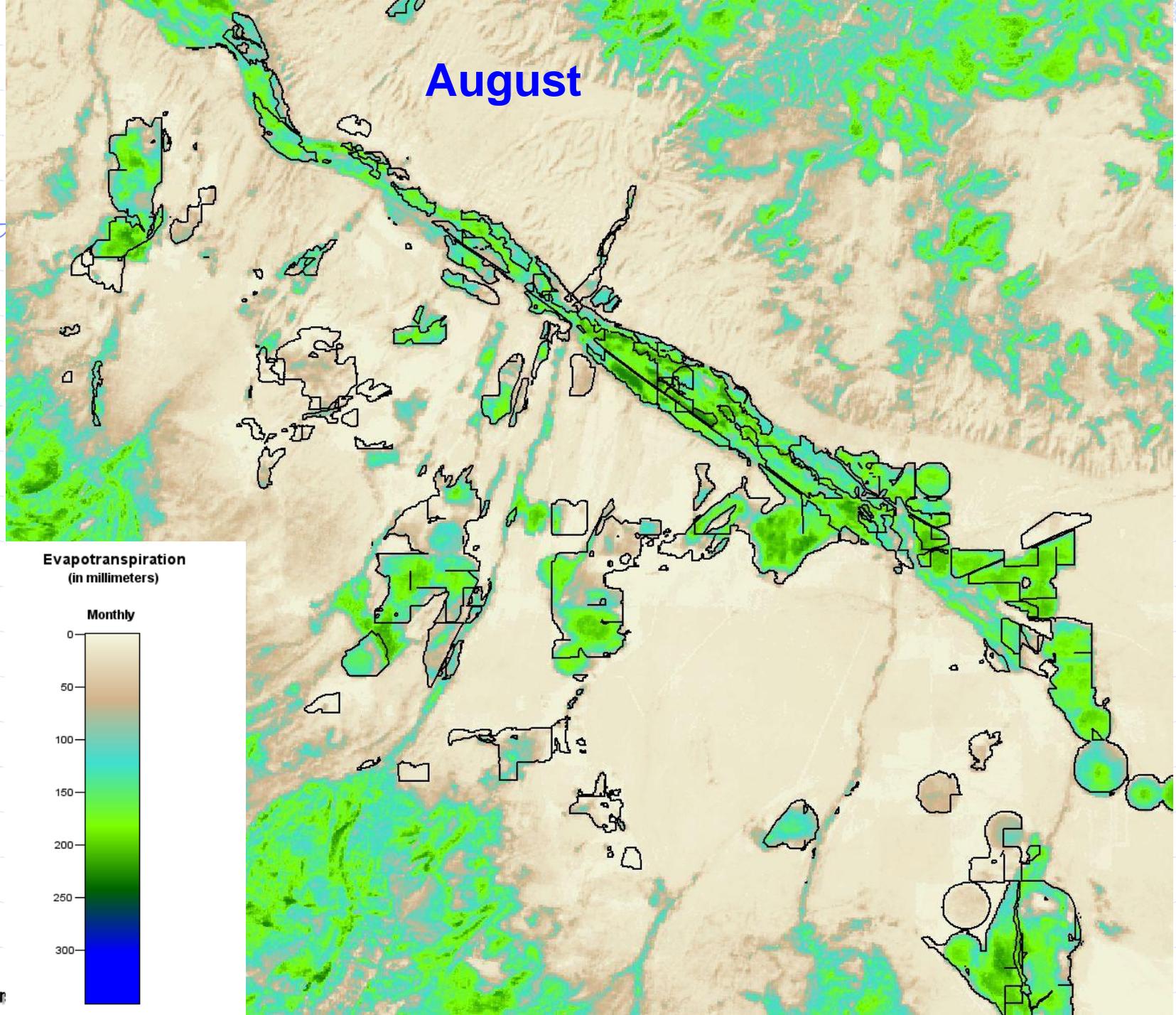


Evapotranspiration  
(in millimeters)

Monthly

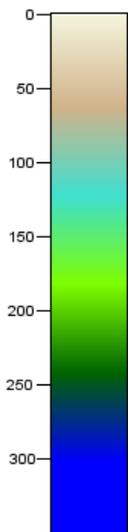


# August

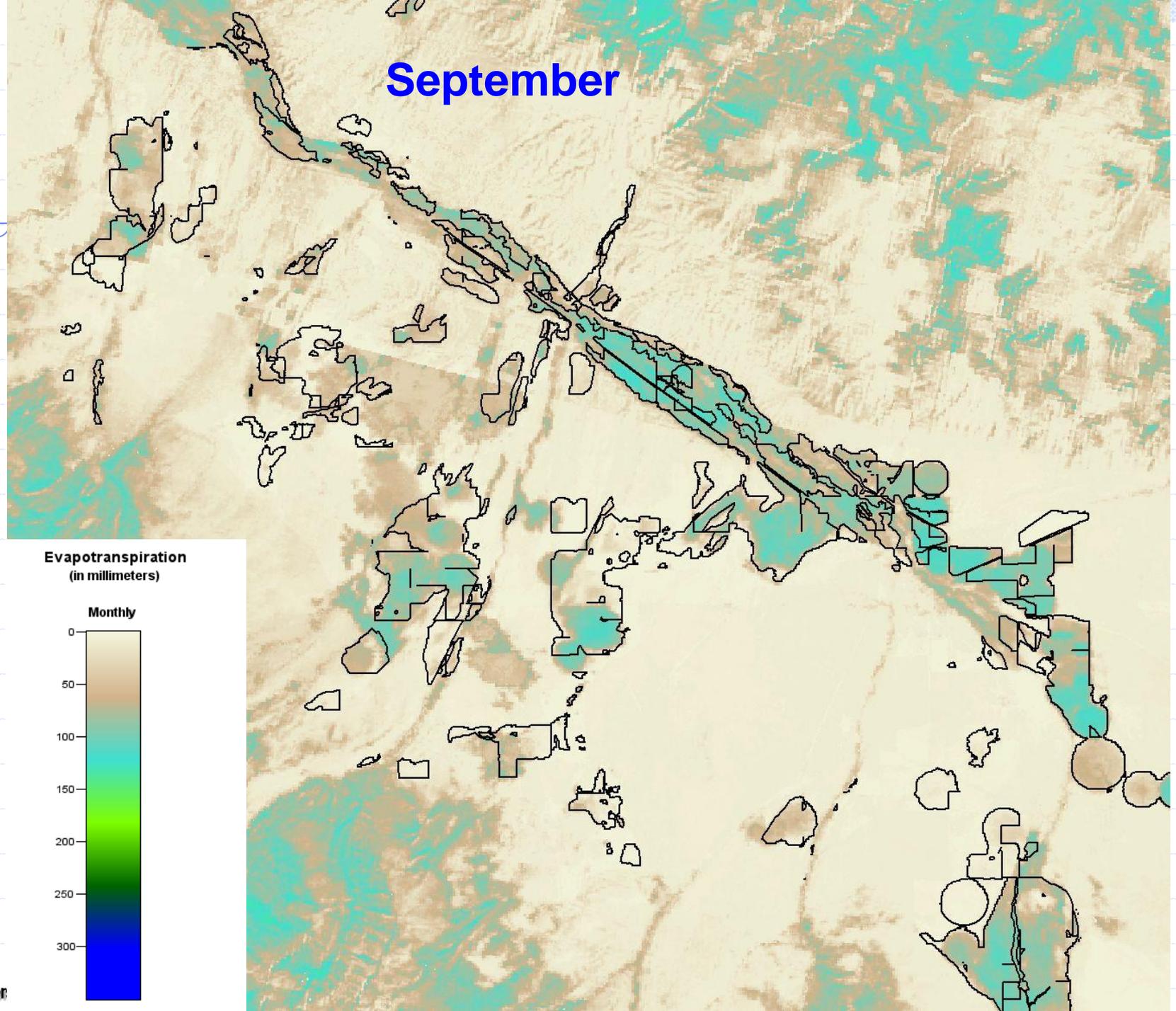


Evapotranspiration  
(in millimeters)

Monthly

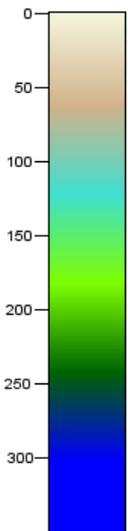


# September

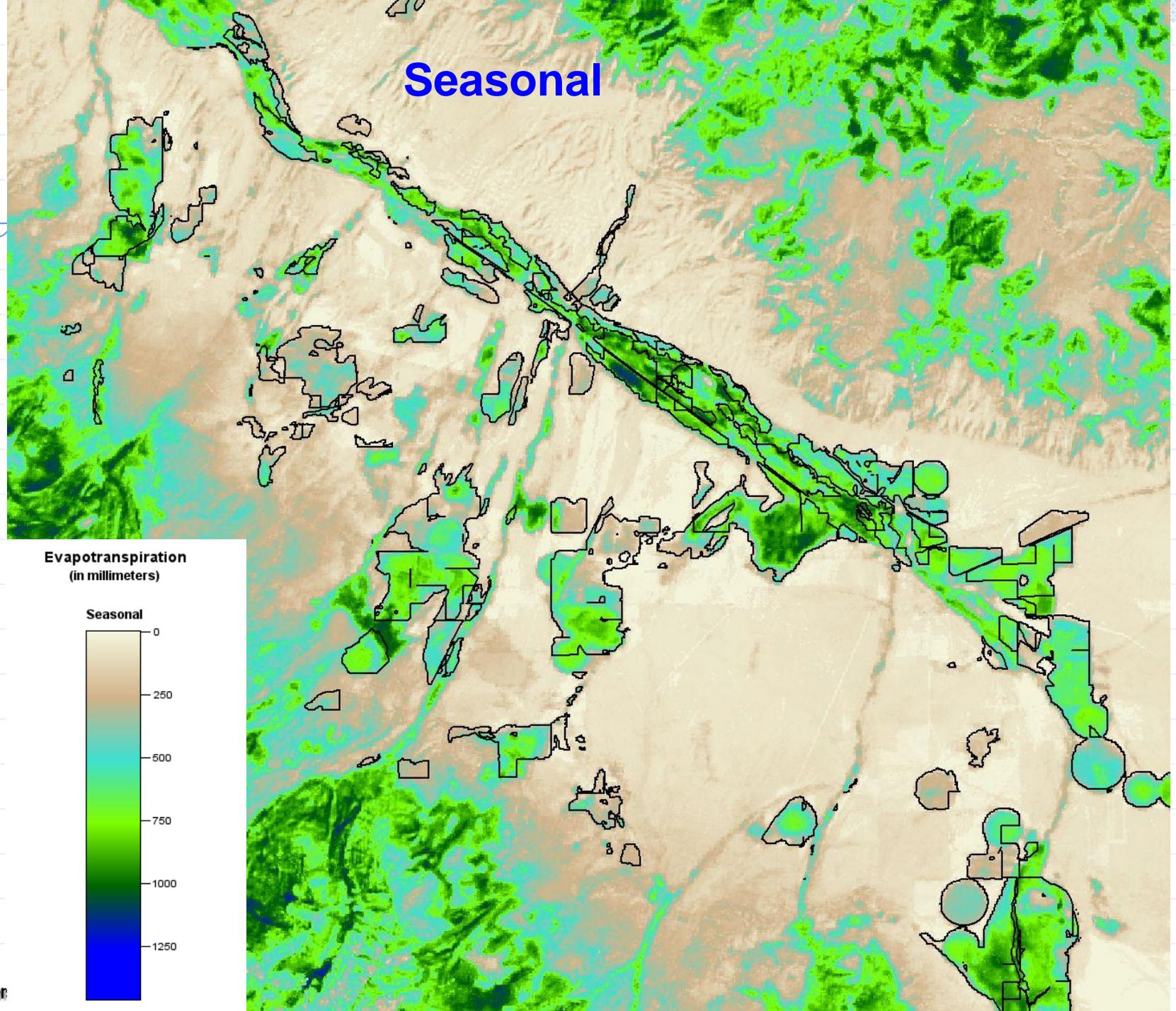


Evapotranspiration  
(in millimeters)

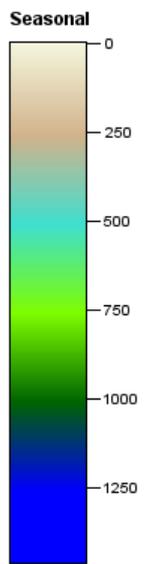
Monthly



# Seasonal



Evapotranspiration  
(in millimeters)

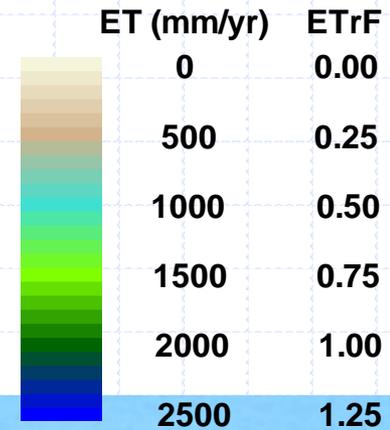




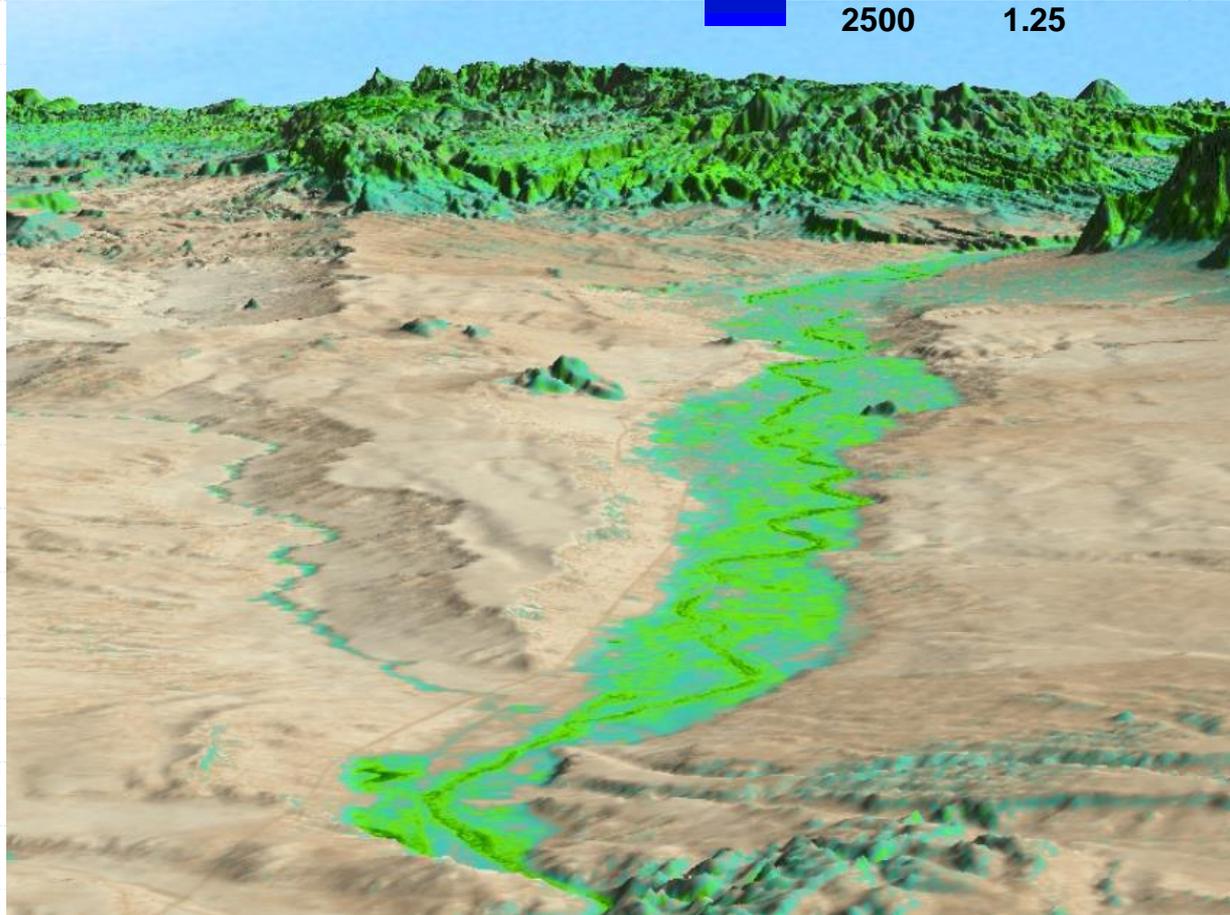
# Other METRIC Applications in Western Water Management

# New Mexico

## Rio Grande of New Mexico



- Pueblo (*native American*) water rights dating to Coronado in 1500's
- Invasion of salt cedar (*tamerisk*) vegetation
- Increased pecan production increases ET (*Texas may sue NM*)

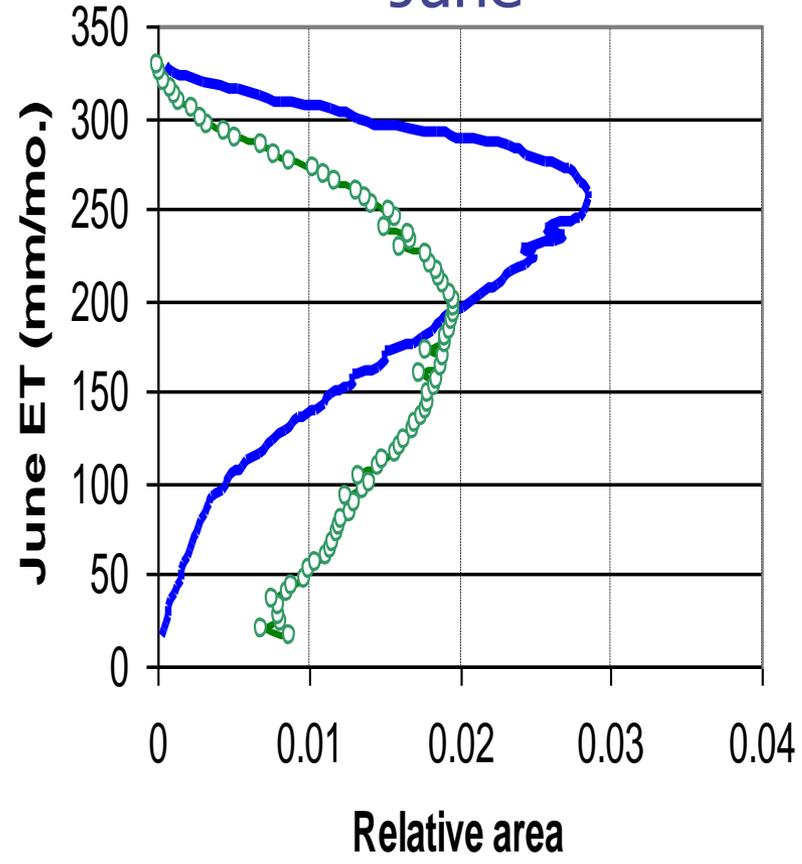


# New Mexico

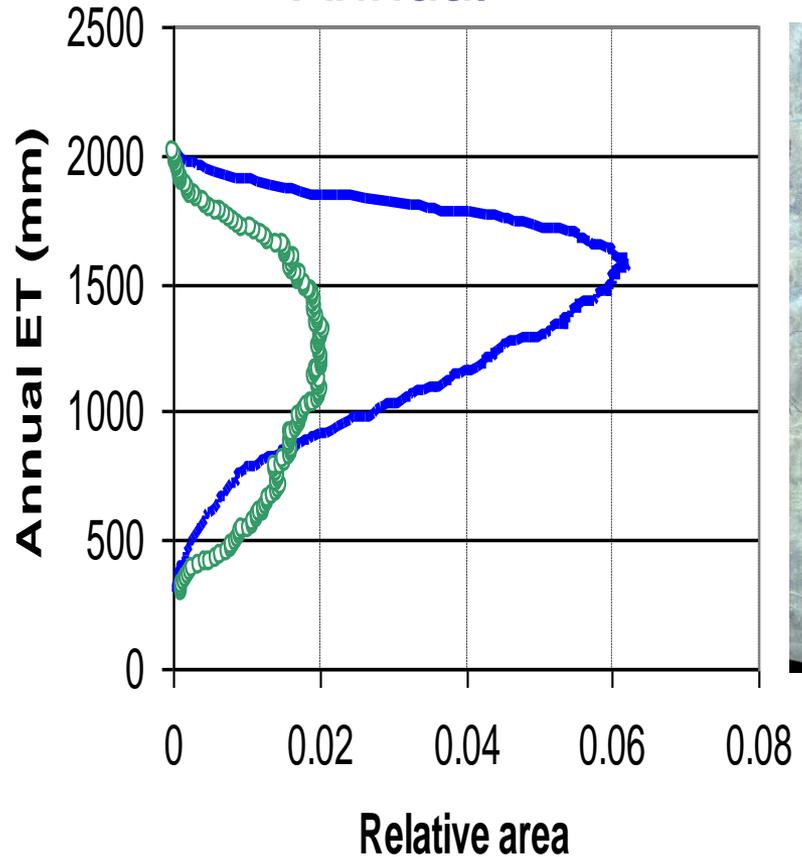
## Frequency Distribution of ET

15,000 acres of cottonwood and salt cedar

### June



### Annual



*Tasumi and Allen, 2006*

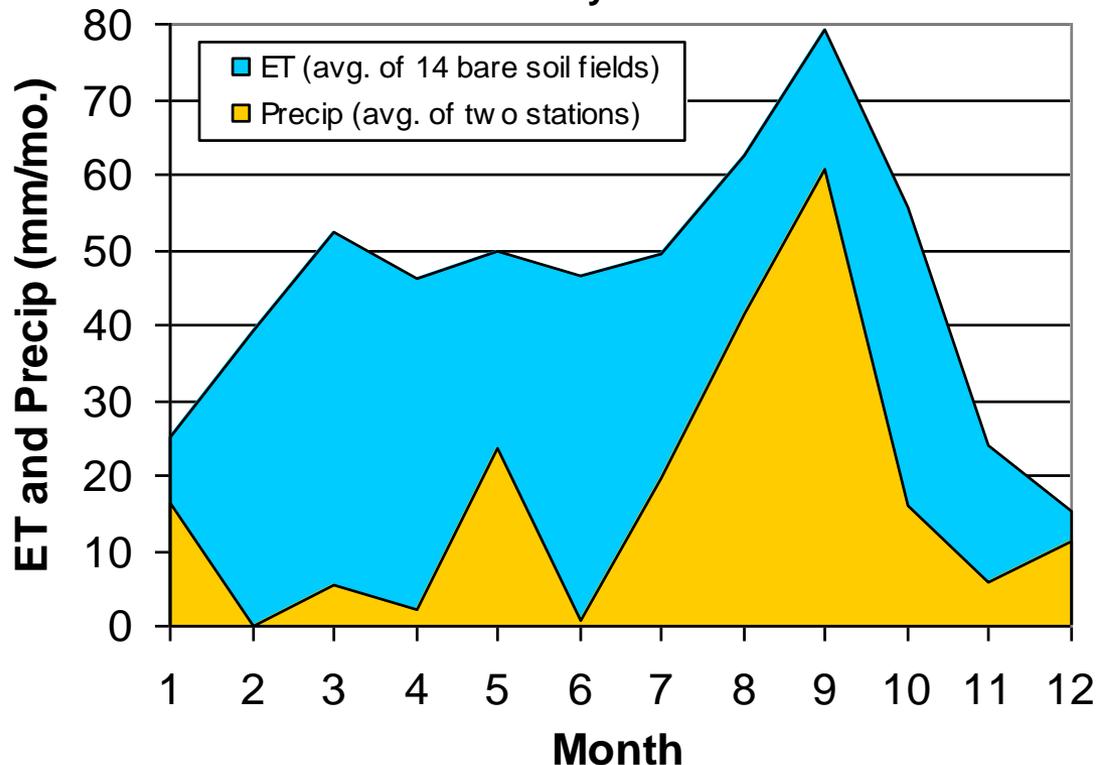
— Cottonwoods    —○ Saltcedar

— Cottonwoods    —○ Saltcedar

# New Mexico

With Thermal Imaging, we can see important evaporation from wet soil – for example from high water tables

Monthly bare soil ET and precipitation in MRG valley



*Evaporation during 2002 from continuously bare areas along the **Middle Rio Grande** of NM contrasted with precipitation*

# California

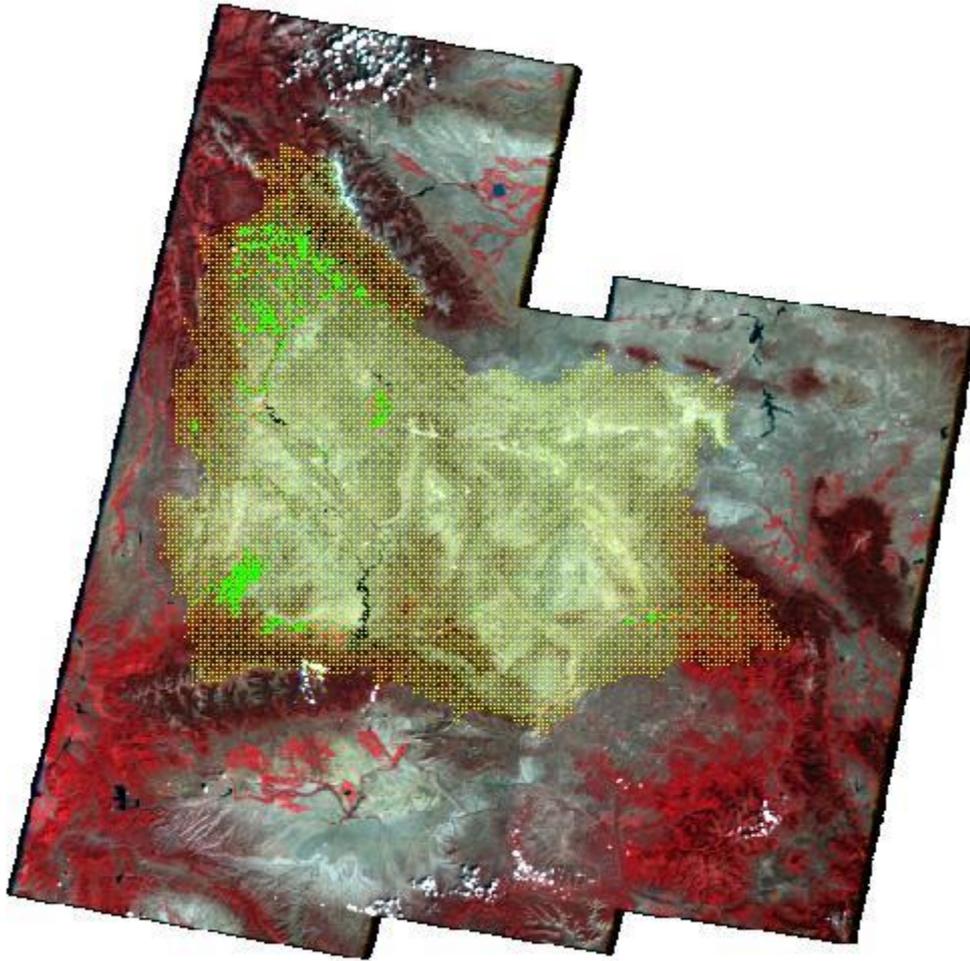
## Imperial Valley

Imperial Valley, CA  
via Landsat 7



- ~15% of traditional water supply to agriculture will now flow to San Diego/ Los Angeles
- What is the impact on ag. and on the Salton Sea?

# Wyoming



## Green River Basin

Wyoming must self-monitor depletion of the Green River due to irrigation as part of the Colorado River Basin Compact.

California, Arizona, Nevada have entitlements that must be filled.

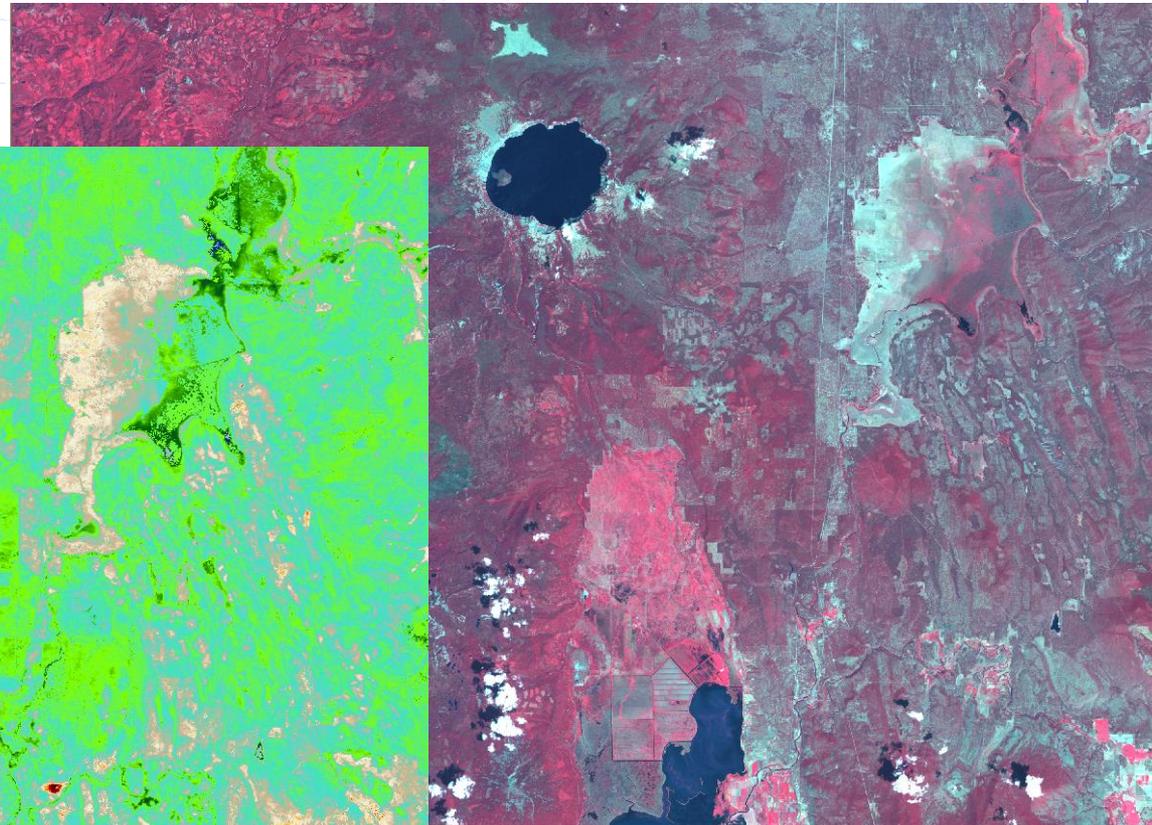
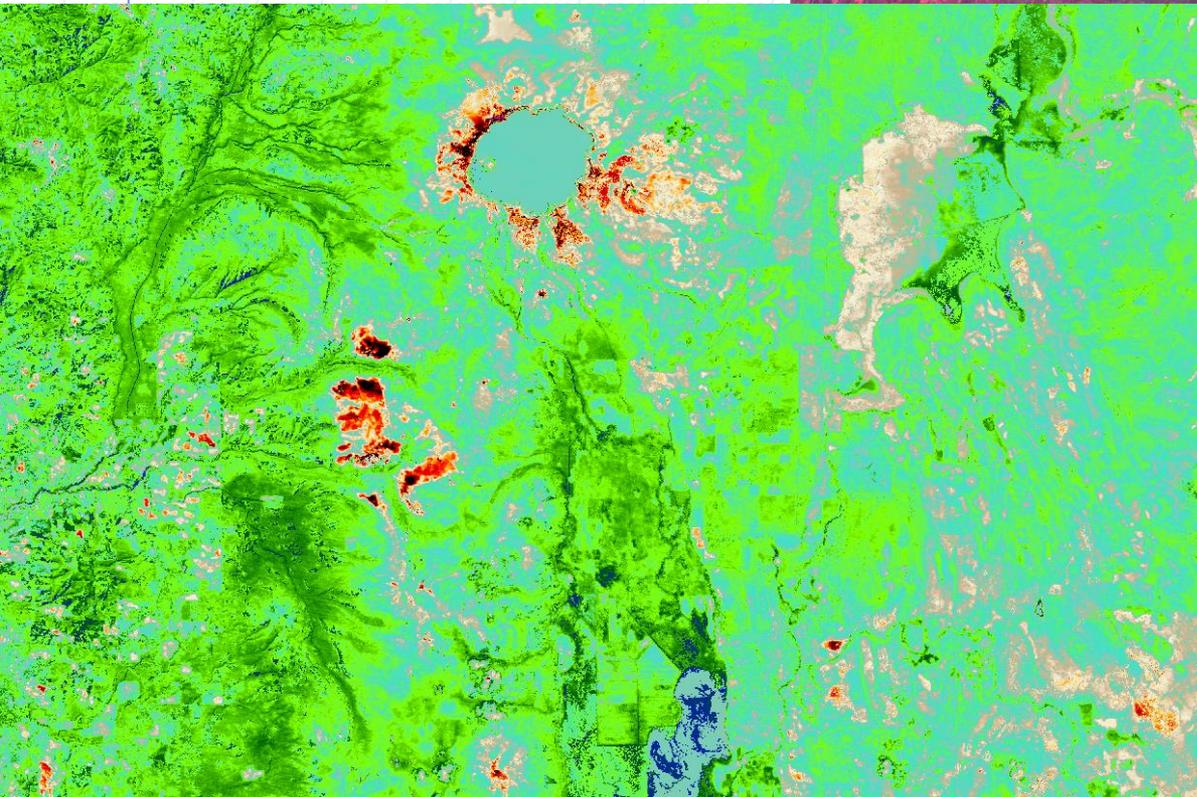
High resolution monitoring is needed due to narrow irrigation corridors along streams

*Allen and Hendrickx, 2013*

# Oregon

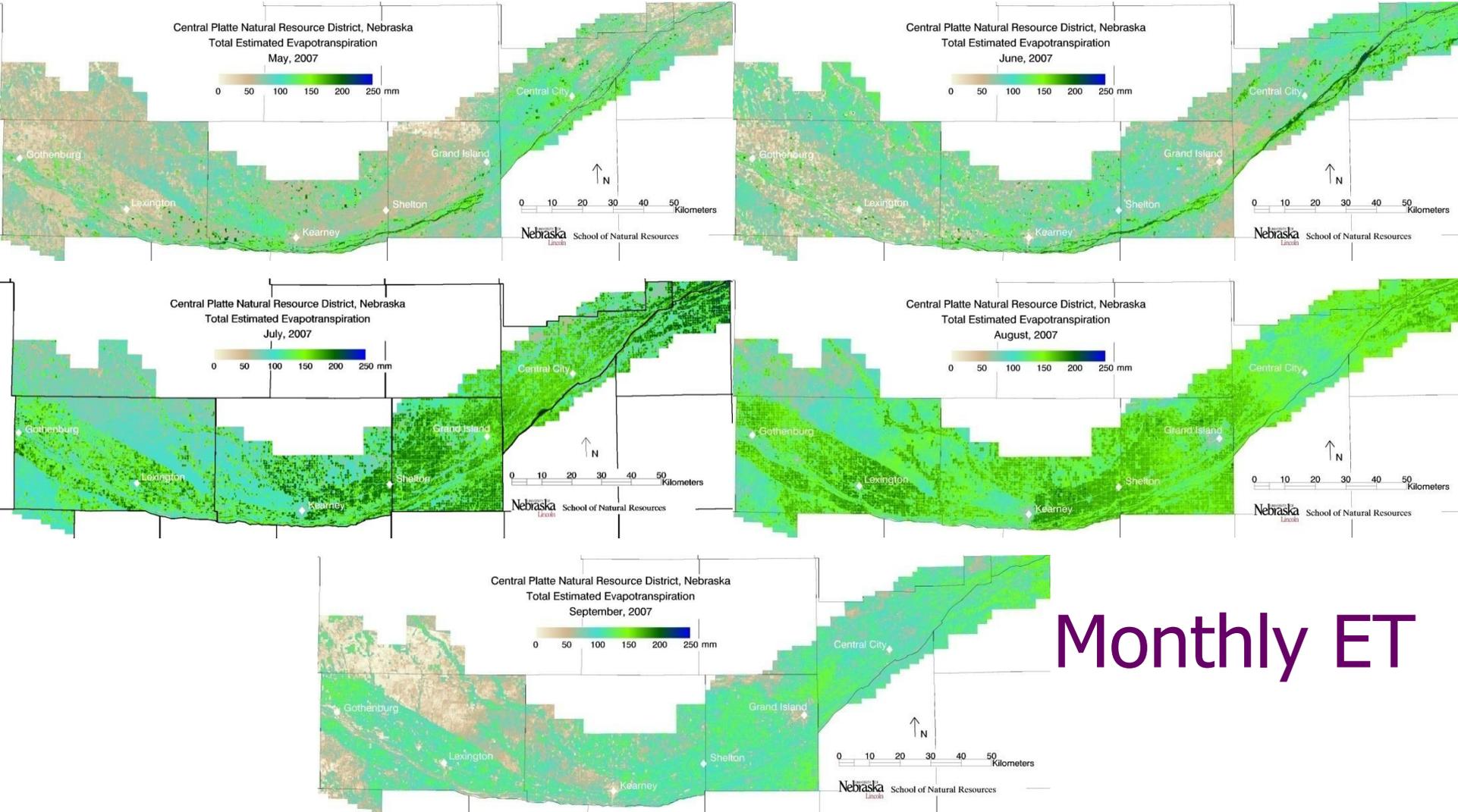
- ◆ Retirement of Irrigated areas in Klamath basin for Endangered Species (*USBR, USGS, State of Oregon, local irrigators, Klamath Tribes*)
- ◆ Retirement is on a field-by-field basis – *therefore 30 m ET is required*

*Near real-time monitoring with METRIC during 2013 and 2014*



# Nebraska

## Central Platte Natural Resource District --- Management of the Ogallala Aquifer

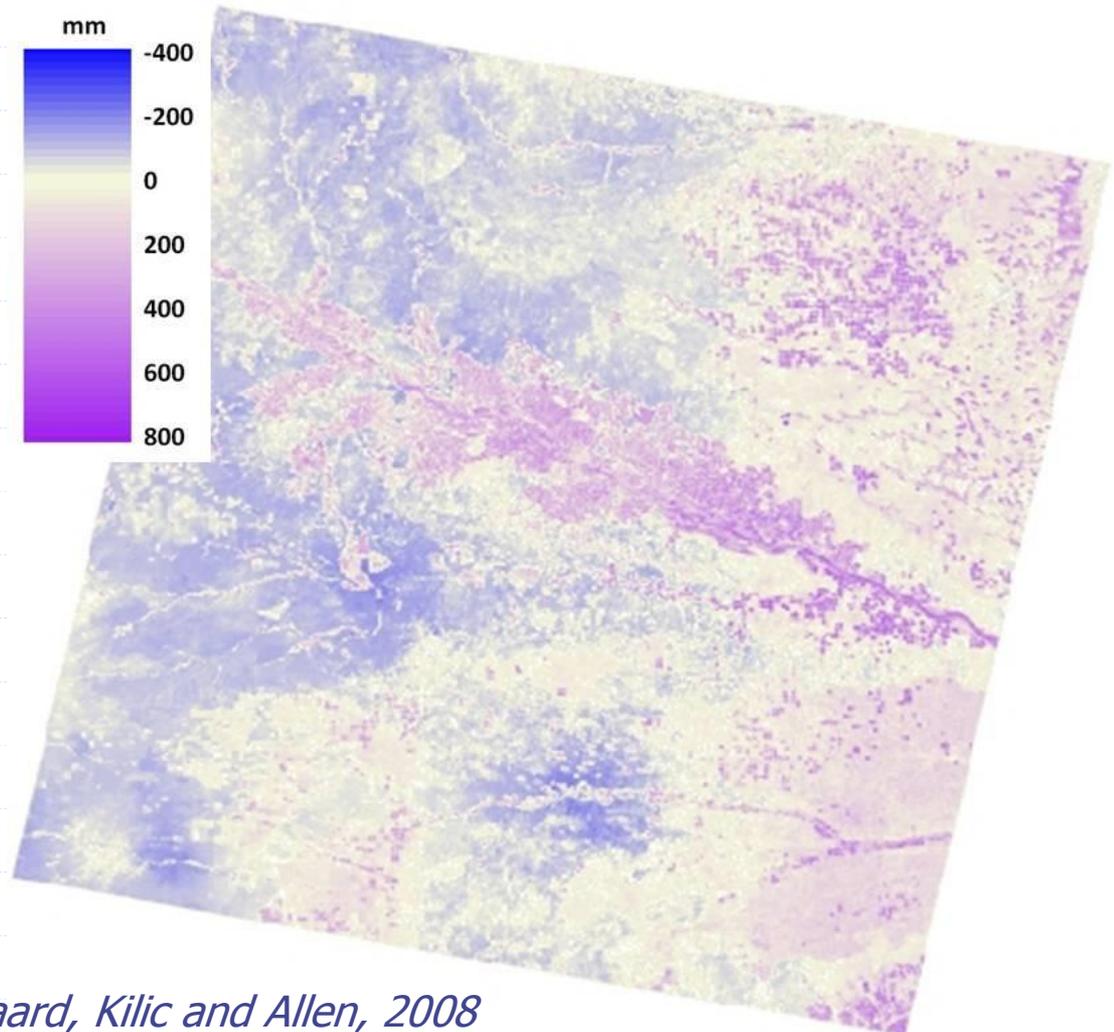


Monthly ET

# Nebraska

*Use ET maps to estimate Recharge  
--- Management of the Ogallala Aquifer*

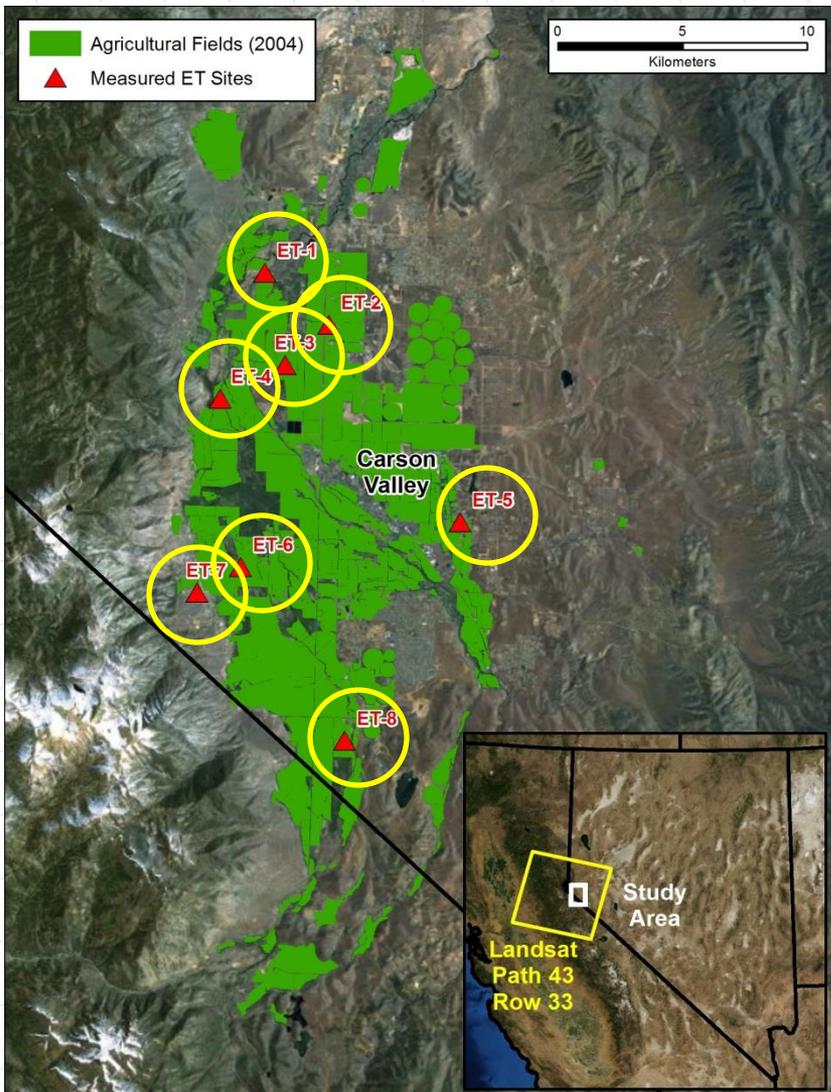
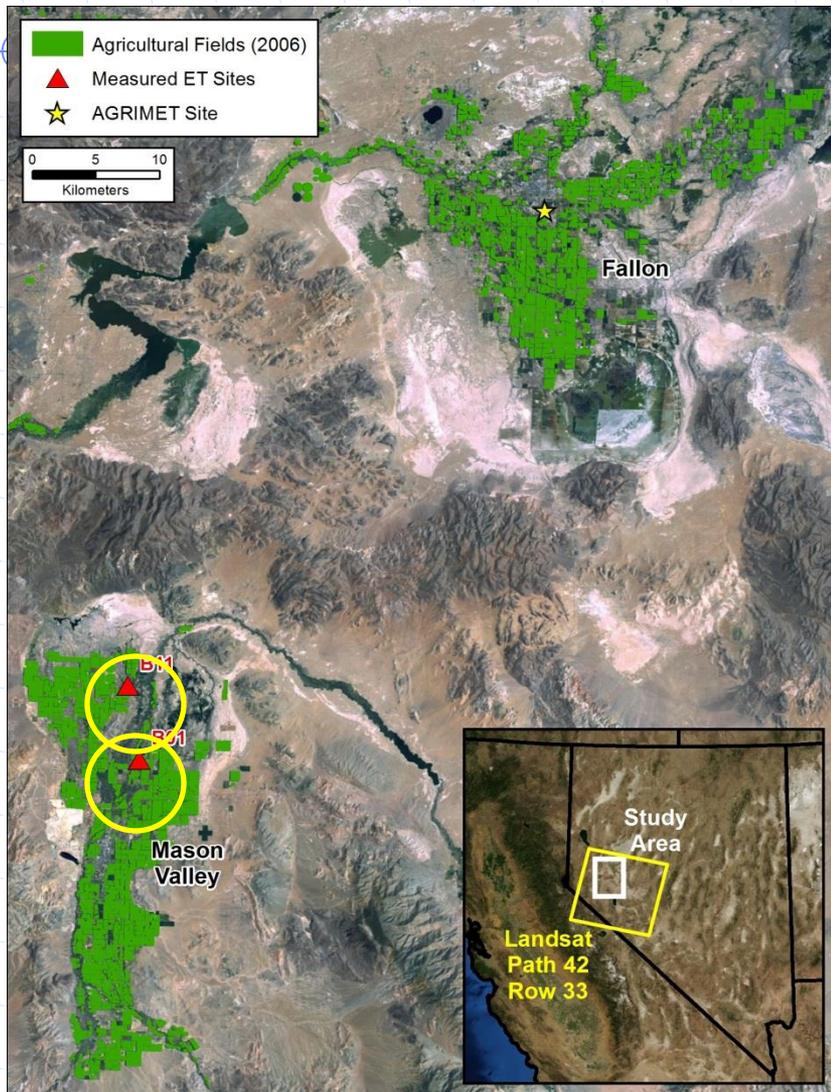
Evapotranspiration  
minus Precipitation  
for April 1 – October  
31, 1997 for Path 33,  
Row 31  
(Nebraska Panhandle)



*Kjaersgaard, Kilic and Allen, 2008*

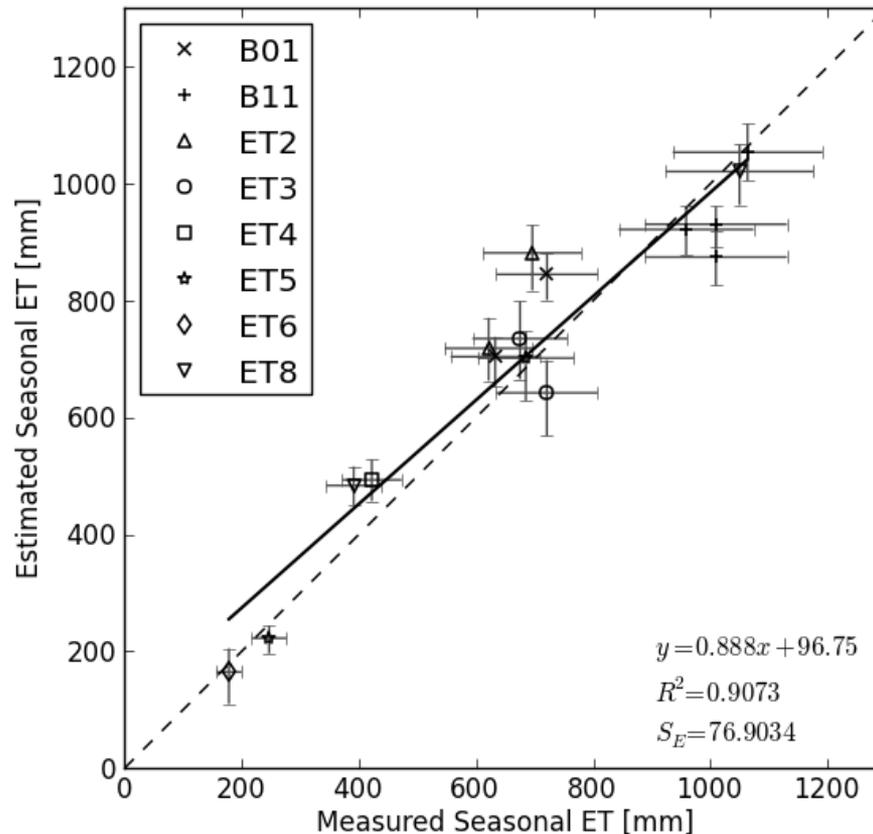
# Nevada

## Blind Comparison of METRIC Seasonal ET to Measured ET – Desert Research Institute



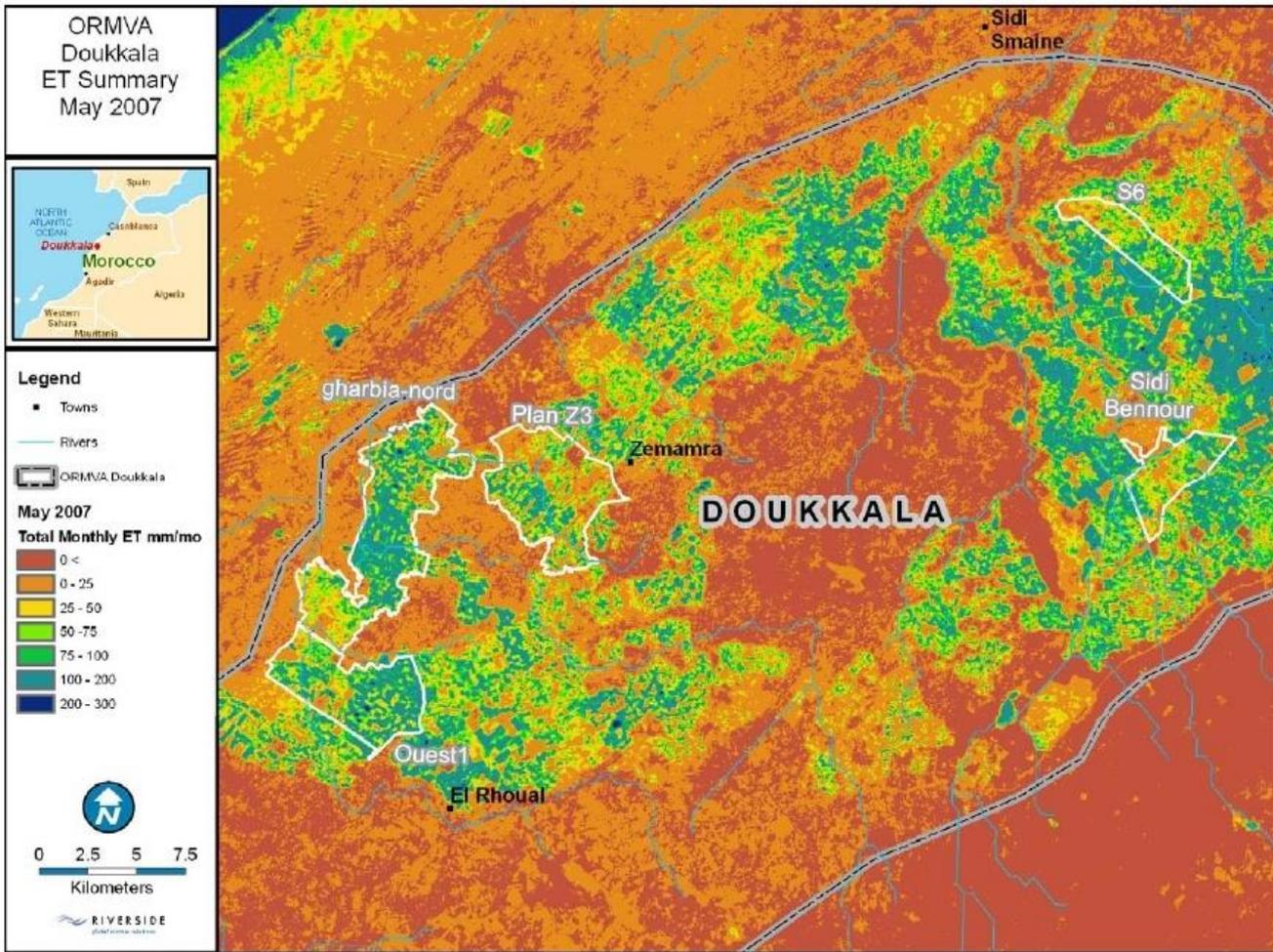
# Nevada

## Blind Comparison of METRIC Seasonal ET to Measured ET



- ◆ Whiskers on X = +/- 12% USGS estimated uncertainty in measured Bowen ratio/eddy ET
- ◆ Whiskers on Y = +/- 95% confidence interval of 100 Monte Carlo METRIC ET estimates

# Morocco

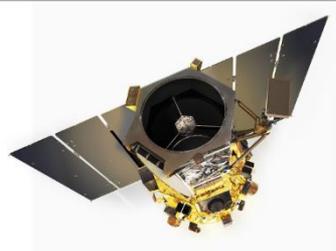


- Poverty reduction program of the World Bank
- Ground-water is overexploited
- ET from satellite can indicate how out-of-balance water use might be
- Better infrastructure may encourage more cash crops
- We can show that conversion to 'drip' isn't going to do it

*Riverside Technology, Inc. and ETPlus*

# Matching Imaging with Impact Scale

High resolution (< 10 m) imaging is highly valuable, but not necessary for high frequency mapping of evolutionary processes like vegetation growth and water consumption on 1) a parcel scale and 2) nationally or globally



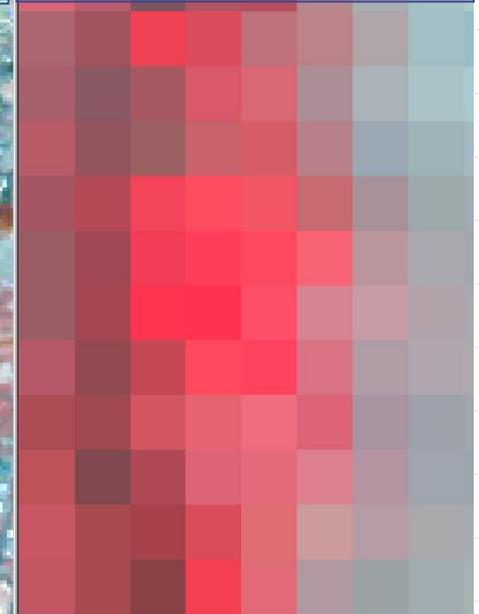
High Resolution intra-human impact scales



Landsat specific human impact scale



MODIS/VIIRS subregional / local scale



# Google Earth Engine

## Evapotranspiration Flux --- EEFlux



2015-08-17 / LC80150332015229LGN00

### Products

BASE MAP

TRUE COLOR

FALSE COLOR (4, 3, 2)

FALSE COLOR (7, 5, 3)

ALBEDO

NDVI

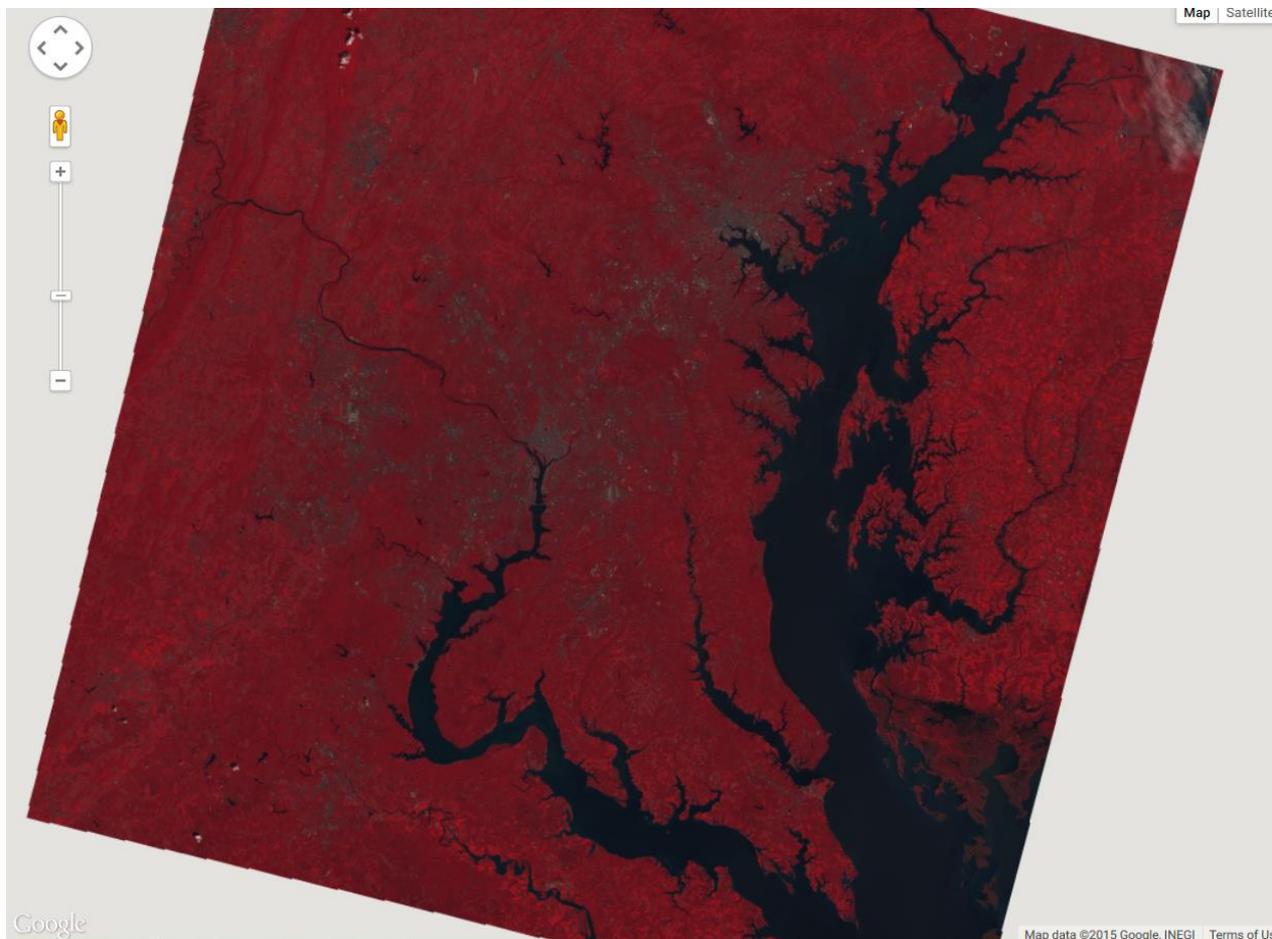
DEM

LAND COVER

SURFACE TEMPERATURE

ETRF

DOWNLOAD ETRF



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# Google Earth Engine

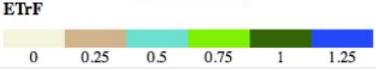
## Evapotranspiration Flux --- EEFlux



2015-08-17 / LC80150332015229LGN00

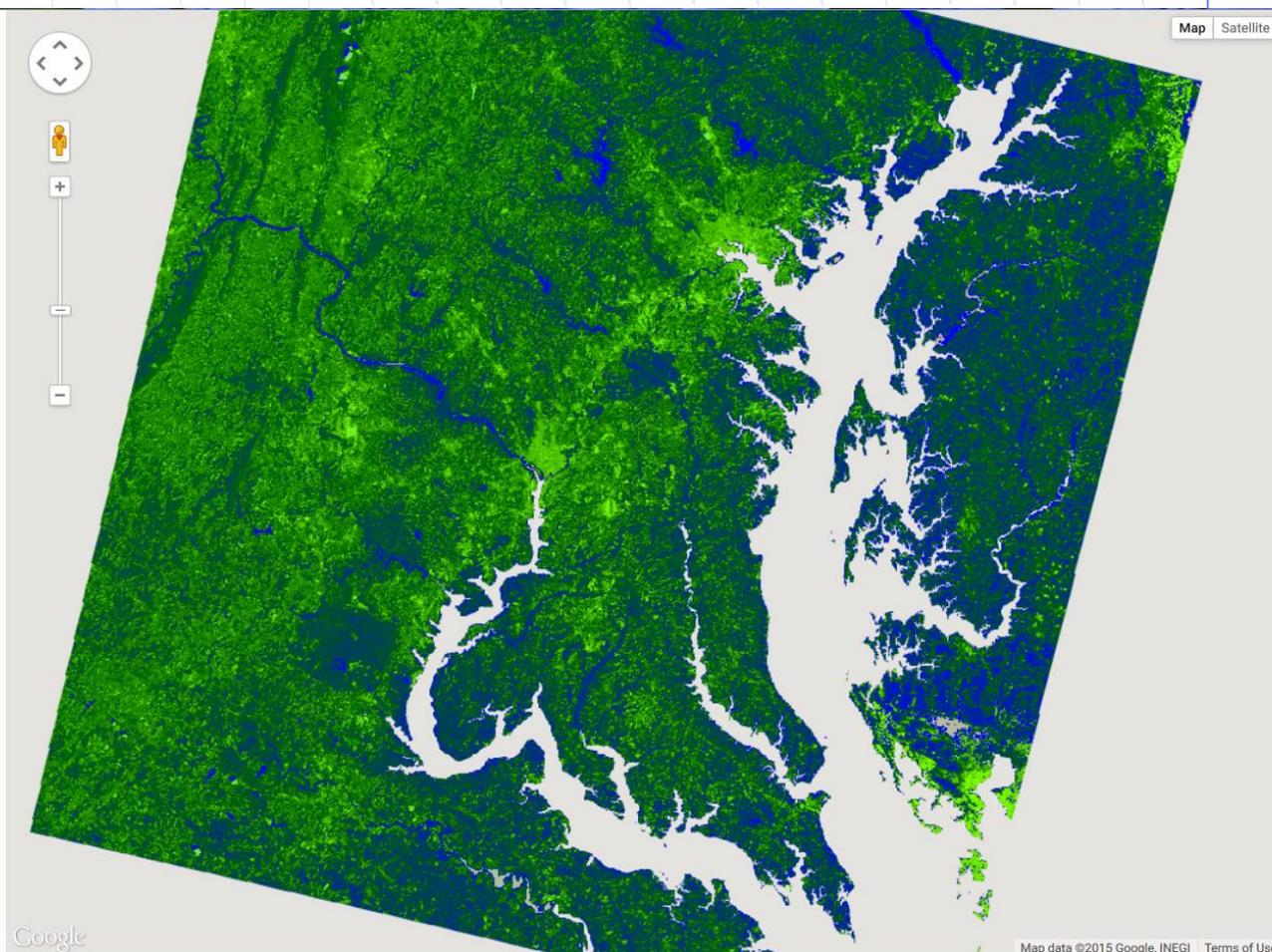
Products

- BASE MAP
- TRUE COLOR
- FALSE COLOR (4, 3, 2)
- FALSE COLOR (7, 5, 3)
- ALBEDO
- NDVI
- DEM
- LAND COVER
- SURFACE TEMPERATURE
- ETRF



ETRF

0 0.25 0.5 0.75 1 1.25



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# Conclusions

- ◆ 30 meter Satellite imagery helps us estimate water consumption over large, diverse areas at the field scale.
- ◆ The Process for ET estimation has matured
- ◆ State and federal water management entities are beginning to utilize, but are frustrated by lack of revisit frequency
- ◆ We need more Landsat satellite types
  - ~ 30 m resolution
  - thermal band(s)
  - potential image each 2-4 days (therefore 4-8 Sats.)