Mapping Evapotranspiration in Idaho with Landsat

William J. Kramber, Idaho Dept. of Water Resources
Dr. Richard G. Allen and Dr. Ricardo Trezza
University of Idaho
Anthony Morse, Spatial Analysis Group (ret. IDWR)

Partners and Collaborators: Dr. M. Tasumi, Univ. Miyazaki, Japan; Dr. Jeppe Kjaersgaard, South Dakota State Univ.; Clarence Robison, Univ. Idaho; Carlos Kelly, Univ. Idaho; Dr. Magali Garcia, Univ. LaPaz, Bolivia; Dr. Wim Bastiaanssen, WaterWatch, Netherlands; Dr. J. Wright, USDA-ARS; Dr. Allan Wylie, IDWR.

Stanford Water in the West Uncommon Dialogue on Groundwater Technology, April 20, 2012

University of Idaho

INNOVATIONS IN AMERICAN GOVERNMENT AWARD WINNER

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
- Irrigation in the US
  - 50 million acres agriculture, 32 million acres recreational
  - Accounts for over 80% of the water consumed

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

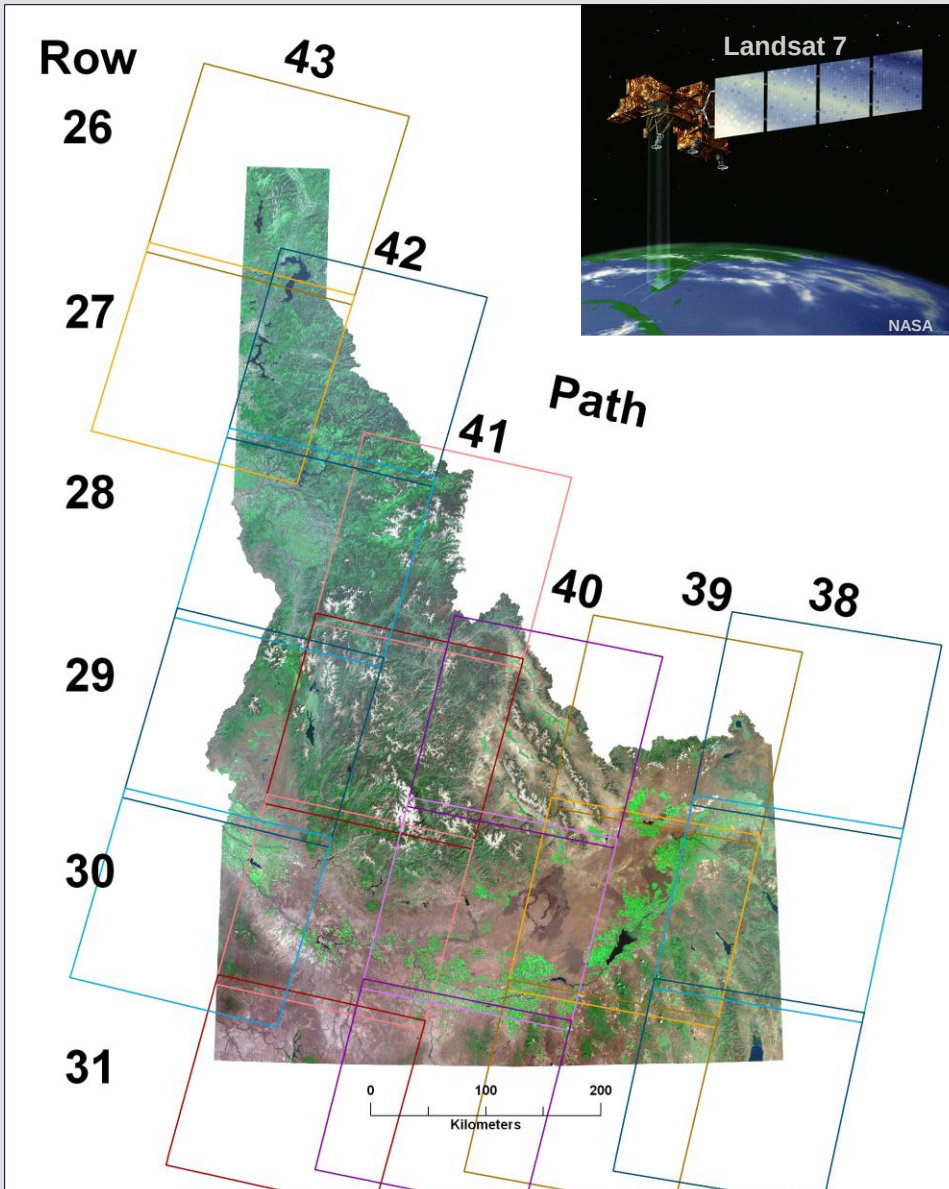
- Actual ET from Landsat using METRIC
  - No crop information required
  - ET per pixel can be summed by field

Landsat

- USGS/NASA mission
- L5 launched 1984
  (halted November 2011)
- L7 launched 1999
  (anomaly May 2003)

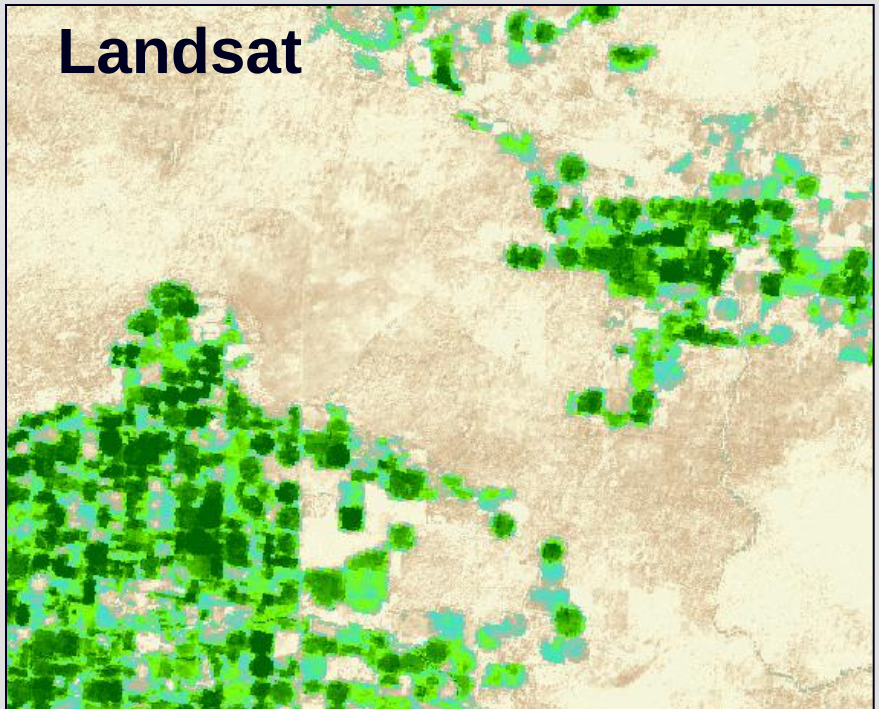
- 30 meter pixels
- 16 day cycle
- 100 by 100 miles
- *Free*

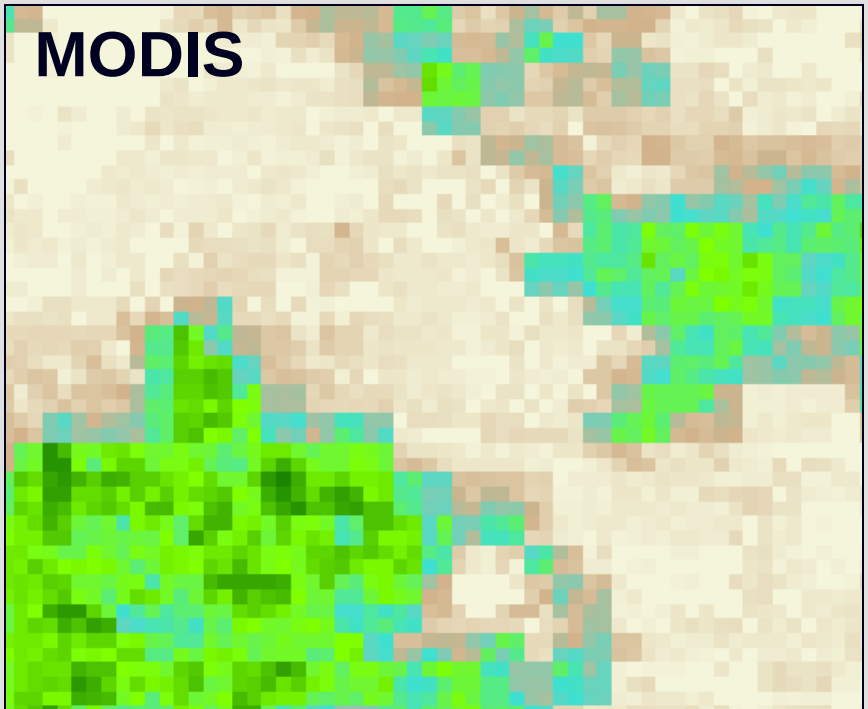
- Landsat 8 will launch in January 2013
- Landsat 9?



Why not use other satellites

- MODIS: 500 meter pixels
- AVHRR: 1000 meter pixels
- SPOT: no thermal band
- IRS AWiFS: no thermal band
- Aster: for research





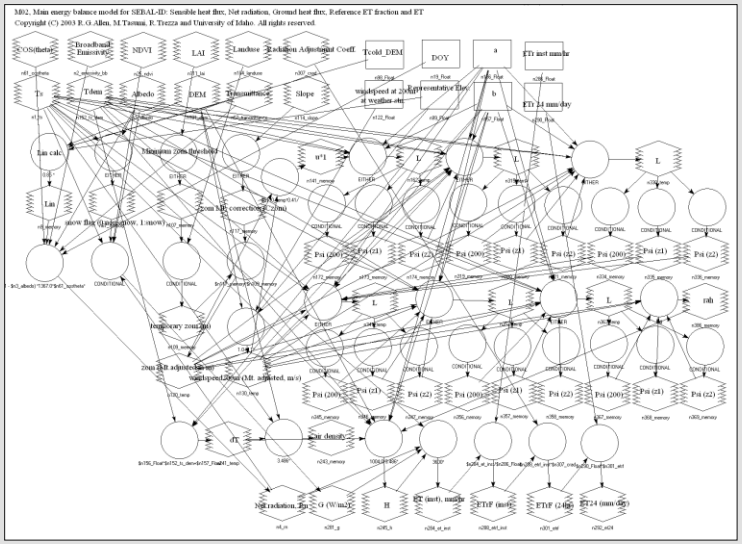
Landsat Thermal Band

- 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

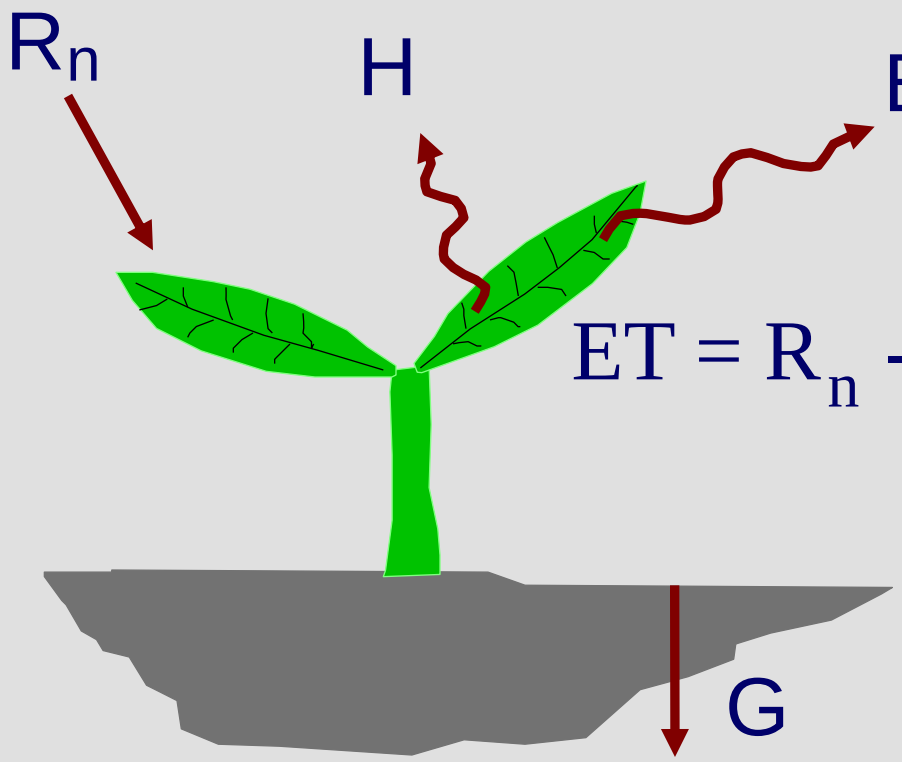
Mapping **E**vapo**T**ranspiration at high **R**esolution with **I**nternalized **C**alibration

- 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 ‘see’ impacts on ET caused by:

- water shortage
- disease
- crop variety
- planting density
- cropping dates
- salinity
- management
- wet soil

Weather Data

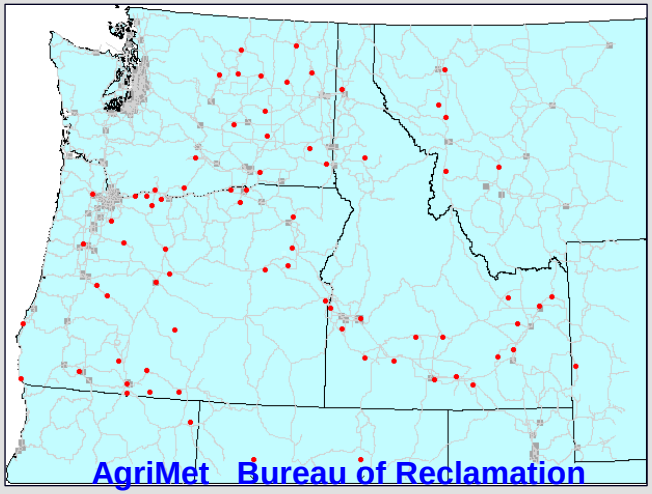
In METRIC, Weather Data are used for:

Wind speed for sensible heat flux calculation

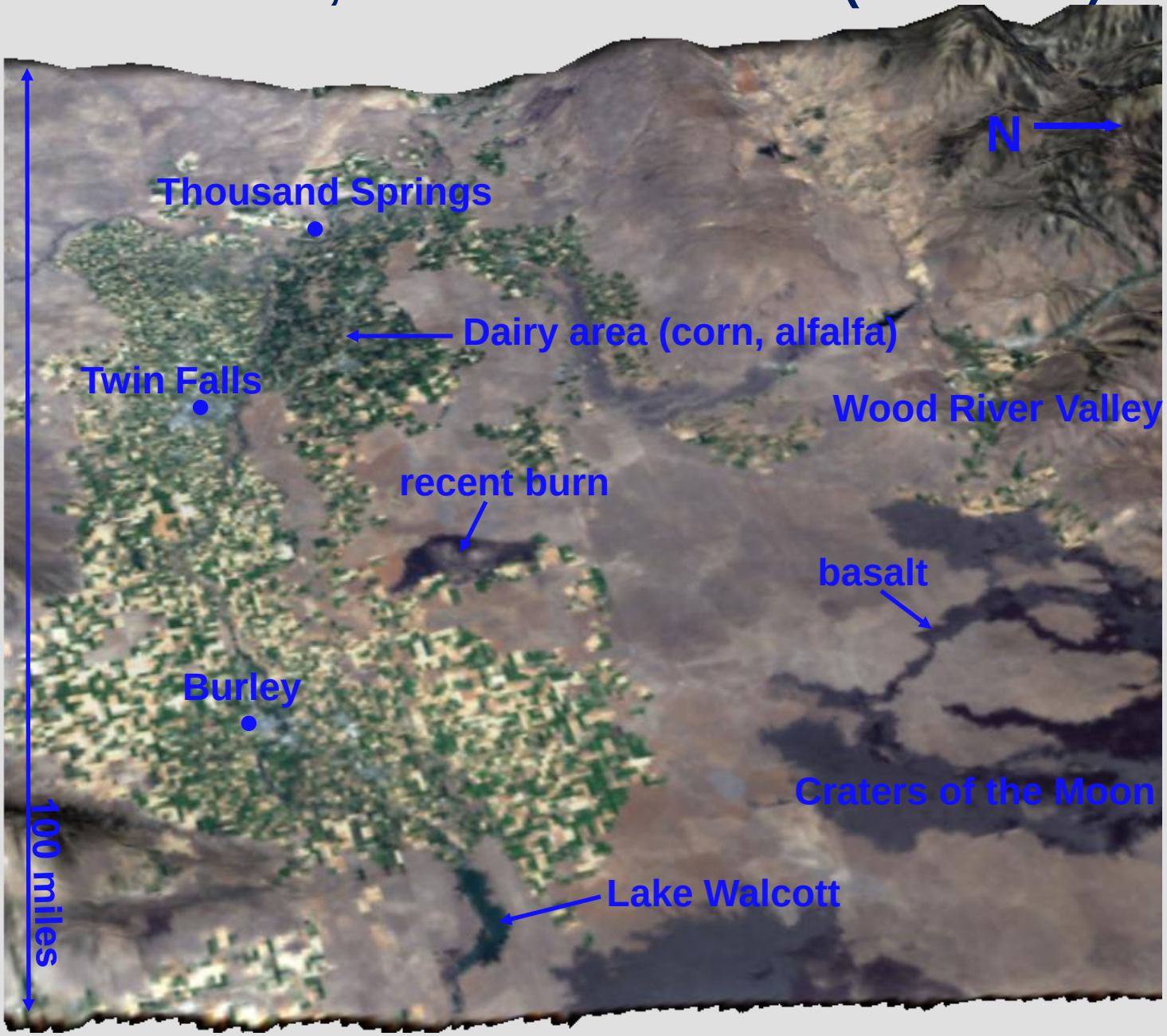
Reference ET for calibrating the Energy Balance

Reference ET to extrapolate ET

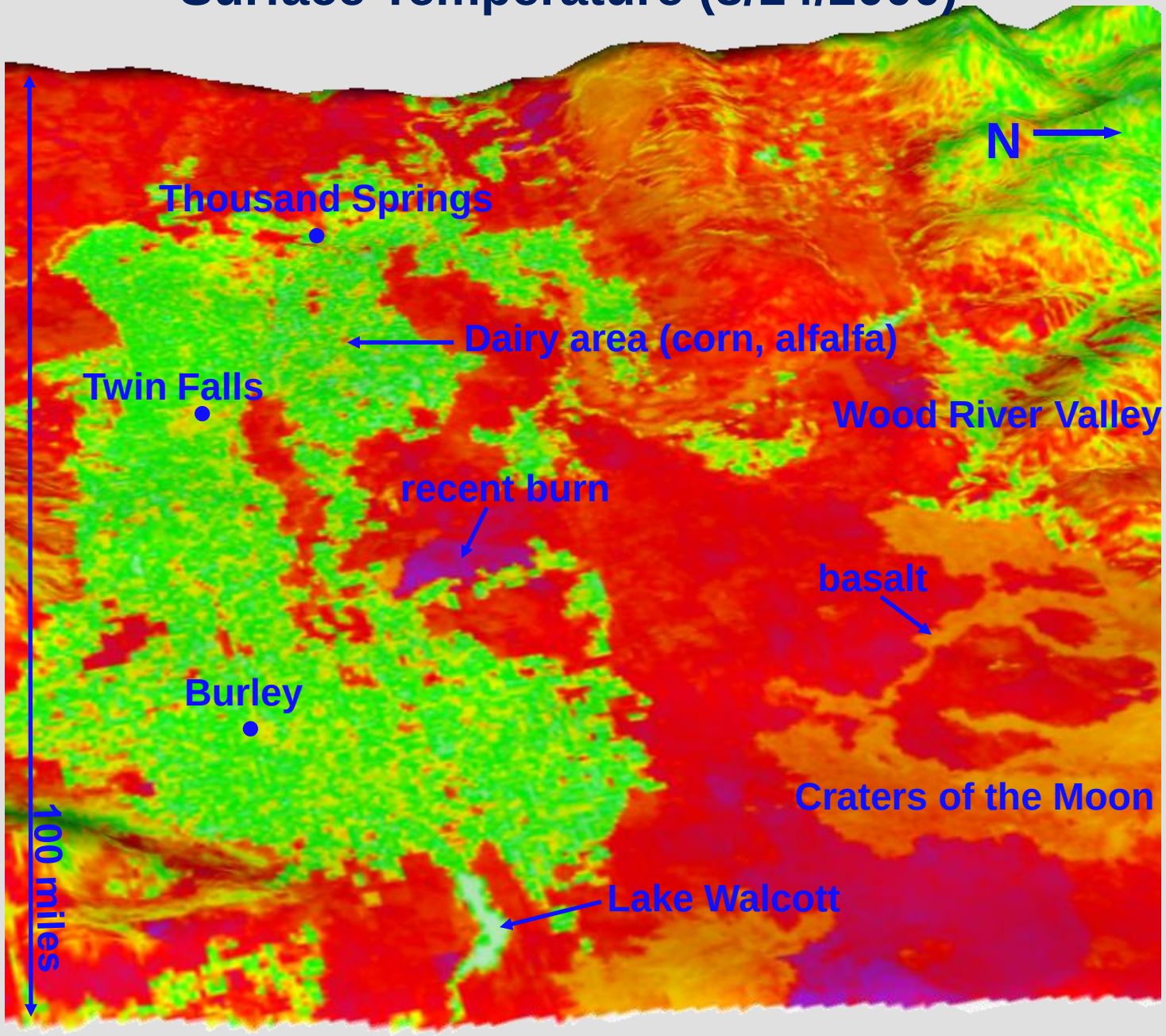
- 24-hour period
- Days between images



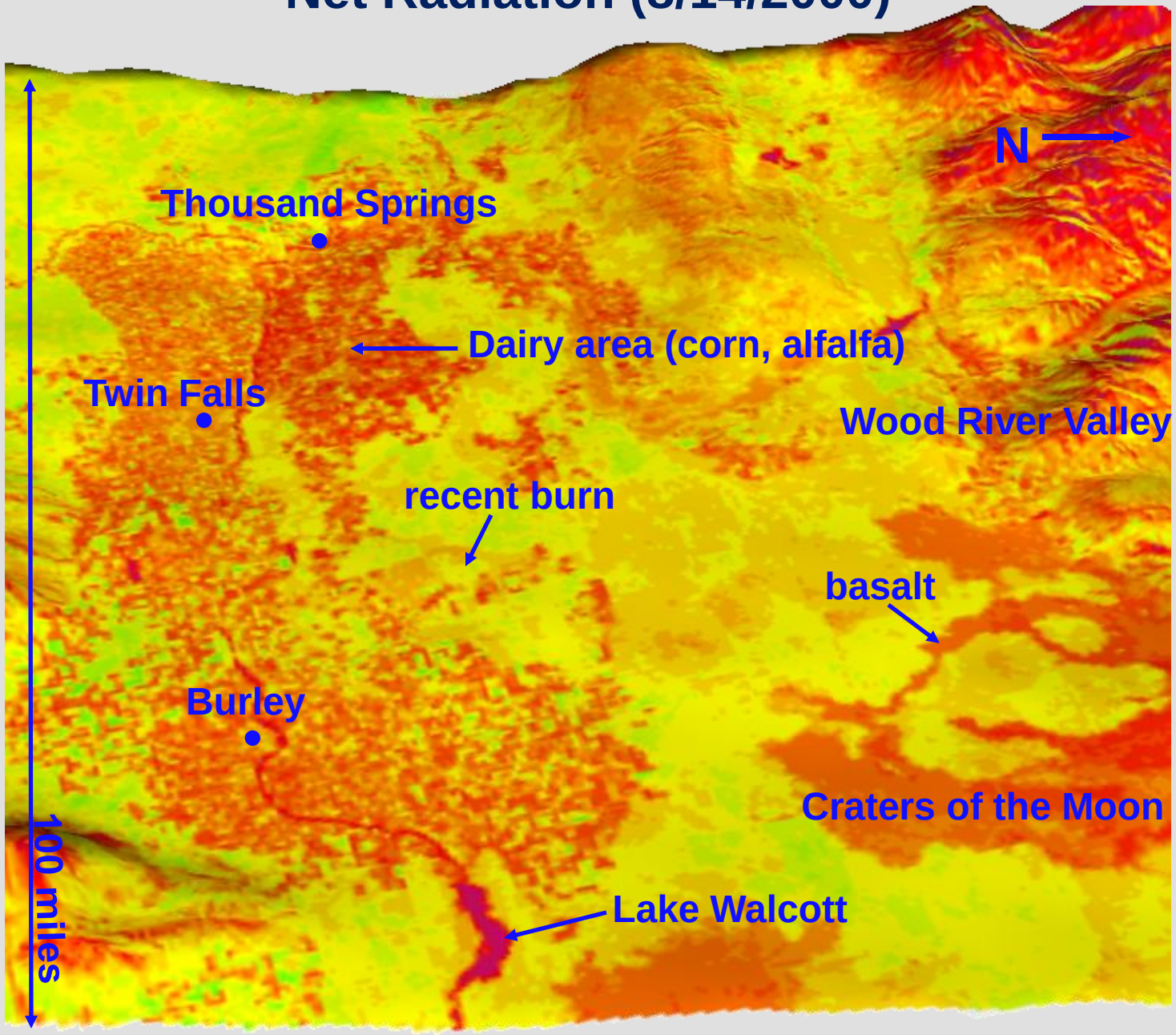
Landsat, south-central Idaho (8/14/2000)

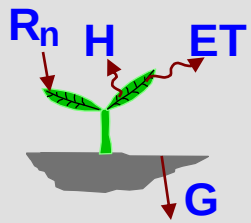


Surface Temperature (8/14/2000)



Net Radiation (8/14/2000)





Net Radiation (W/m^2)

0

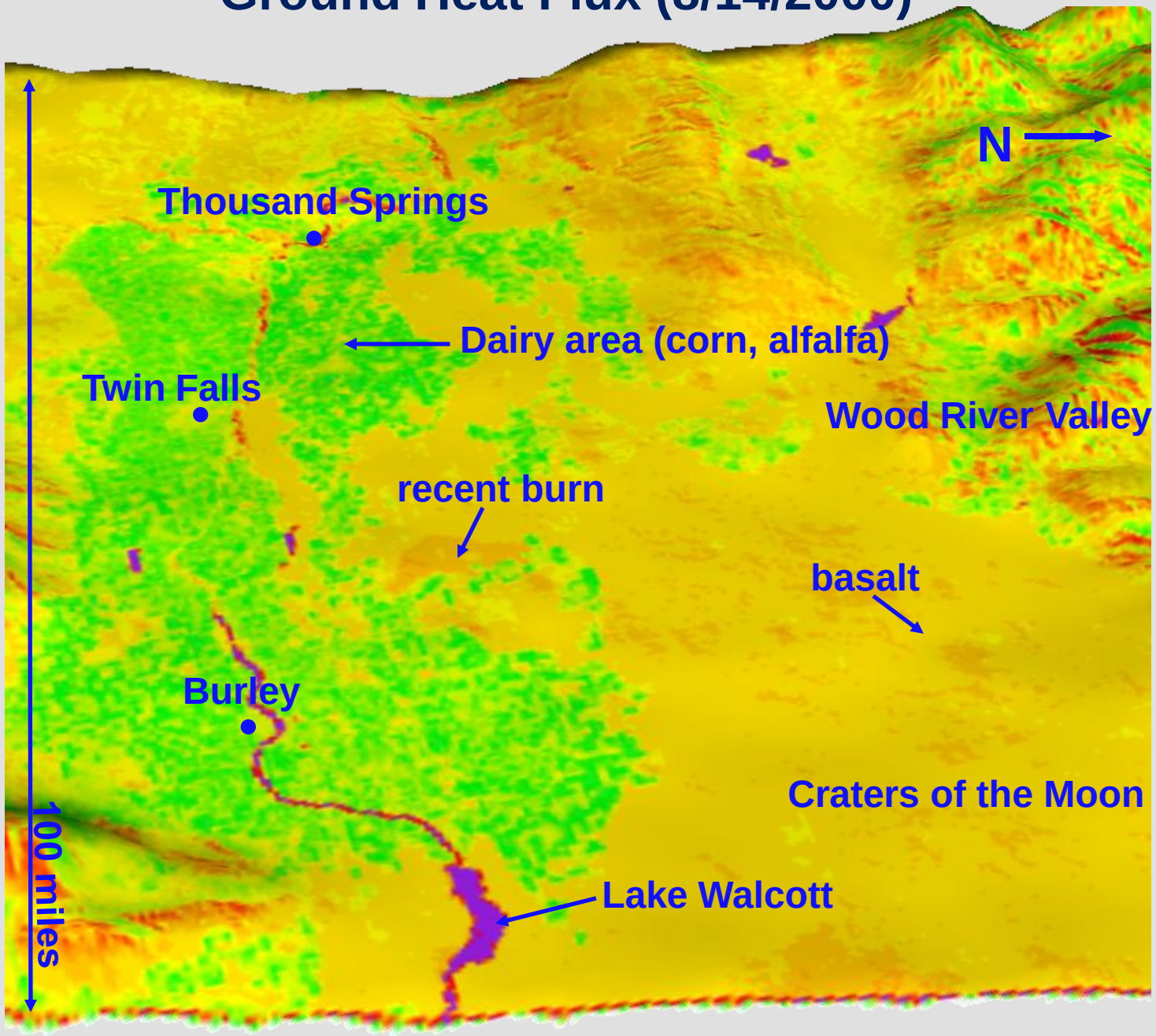
200

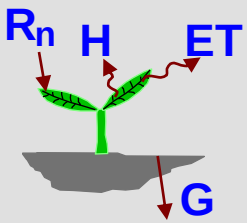
400

600

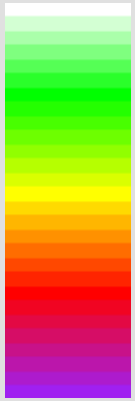
800+

Ground Heat Flux (8/14/2000)

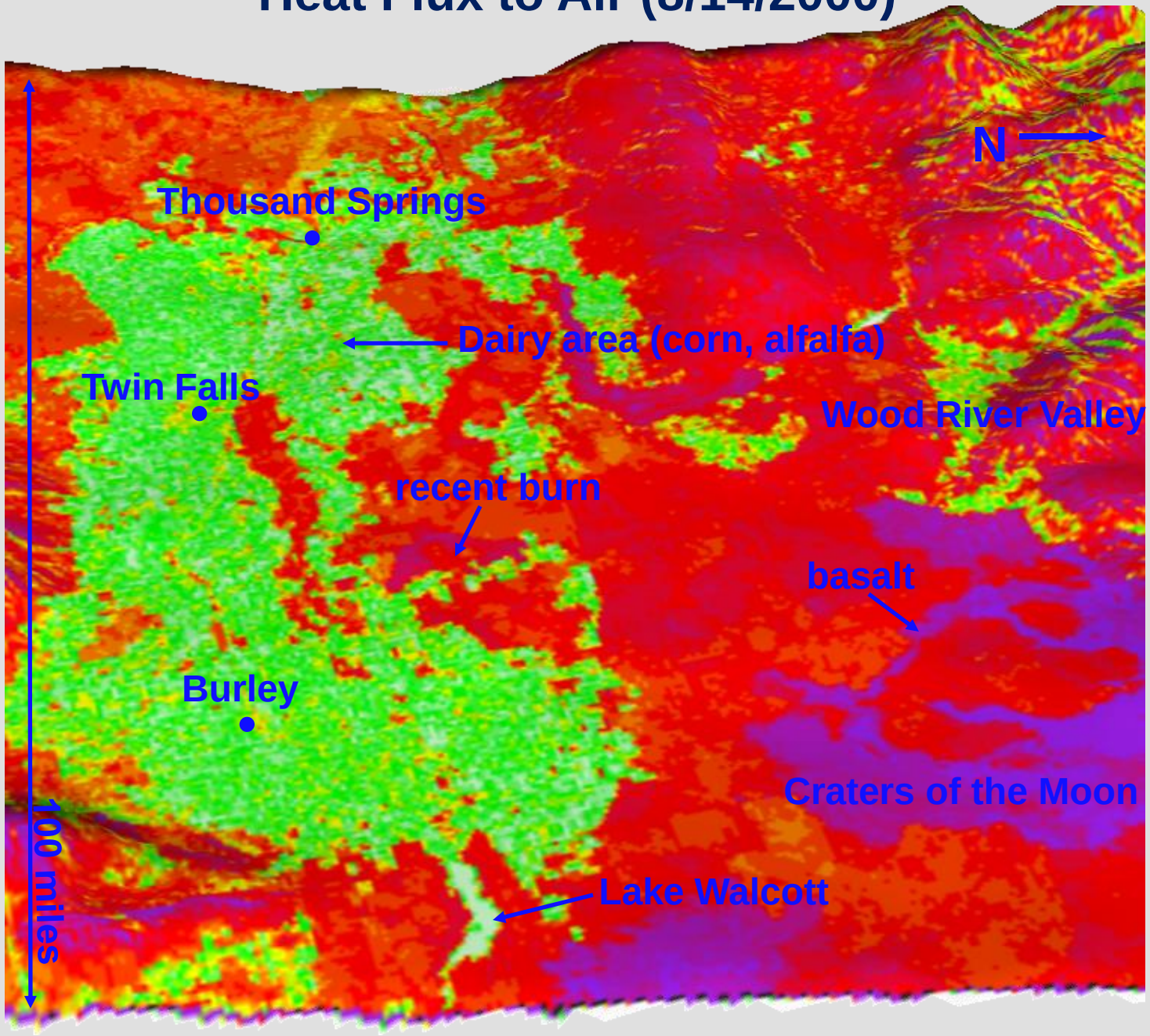


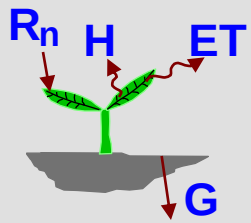


Soil Heat Flux (W/m^2)

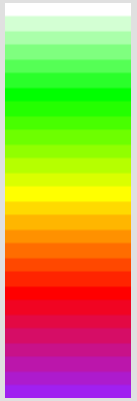


Heat Flux to Air (8/14/2000)

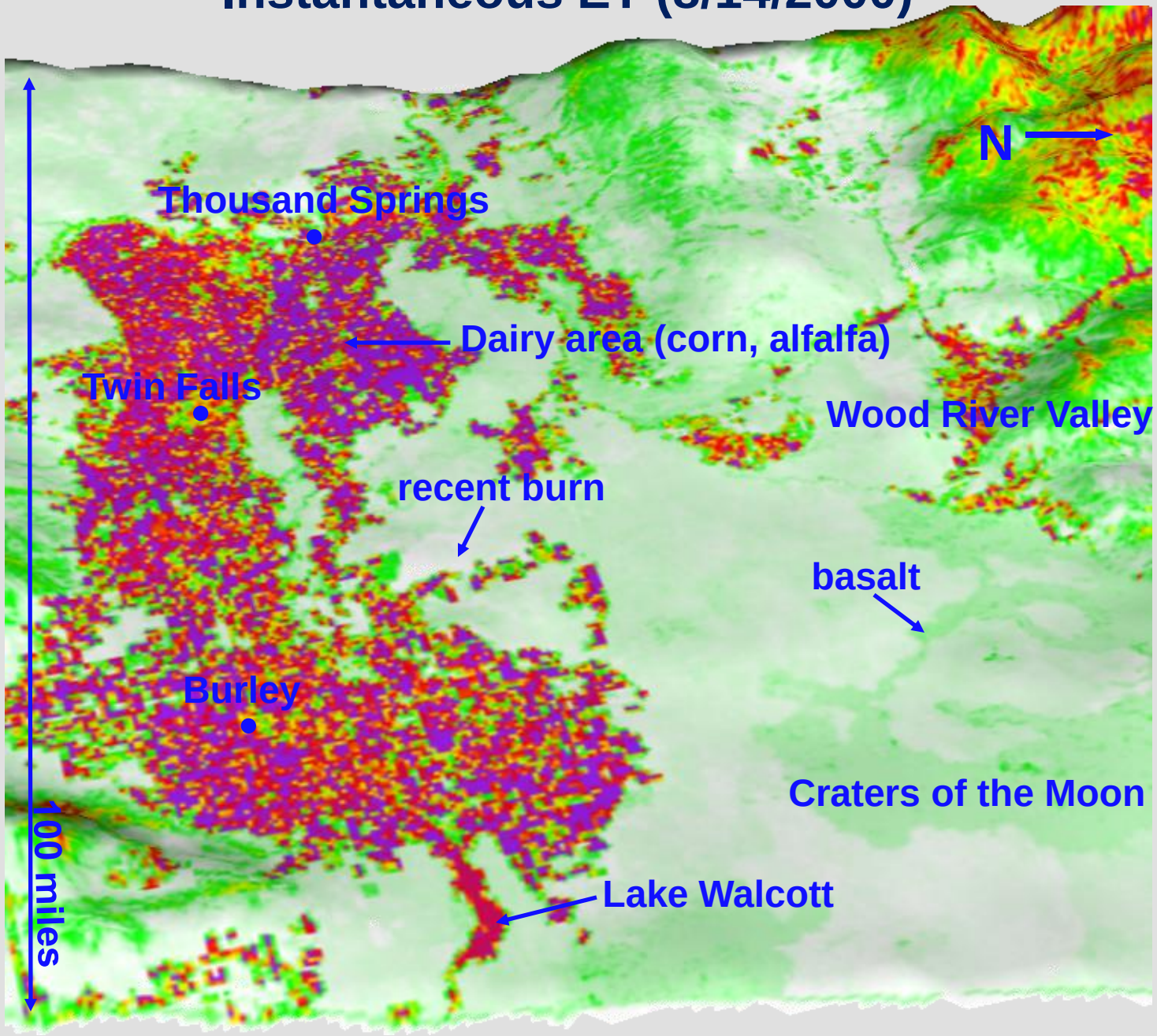


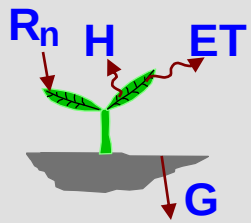


Sensible Heat (W/m^2)



Instantaneous ET (8/14/2000)





Latent Heat (W/m^2)

0

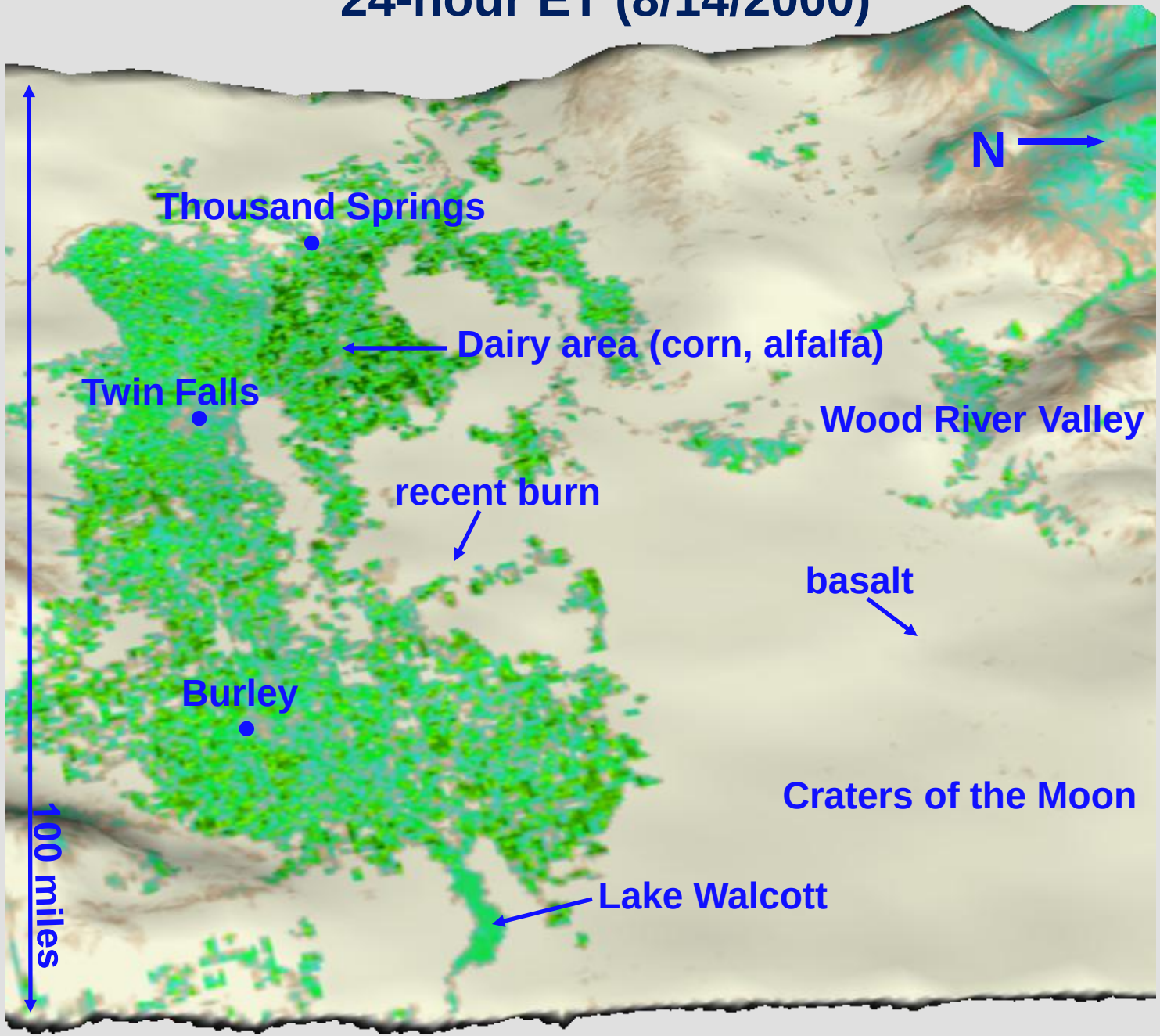
100

200

300

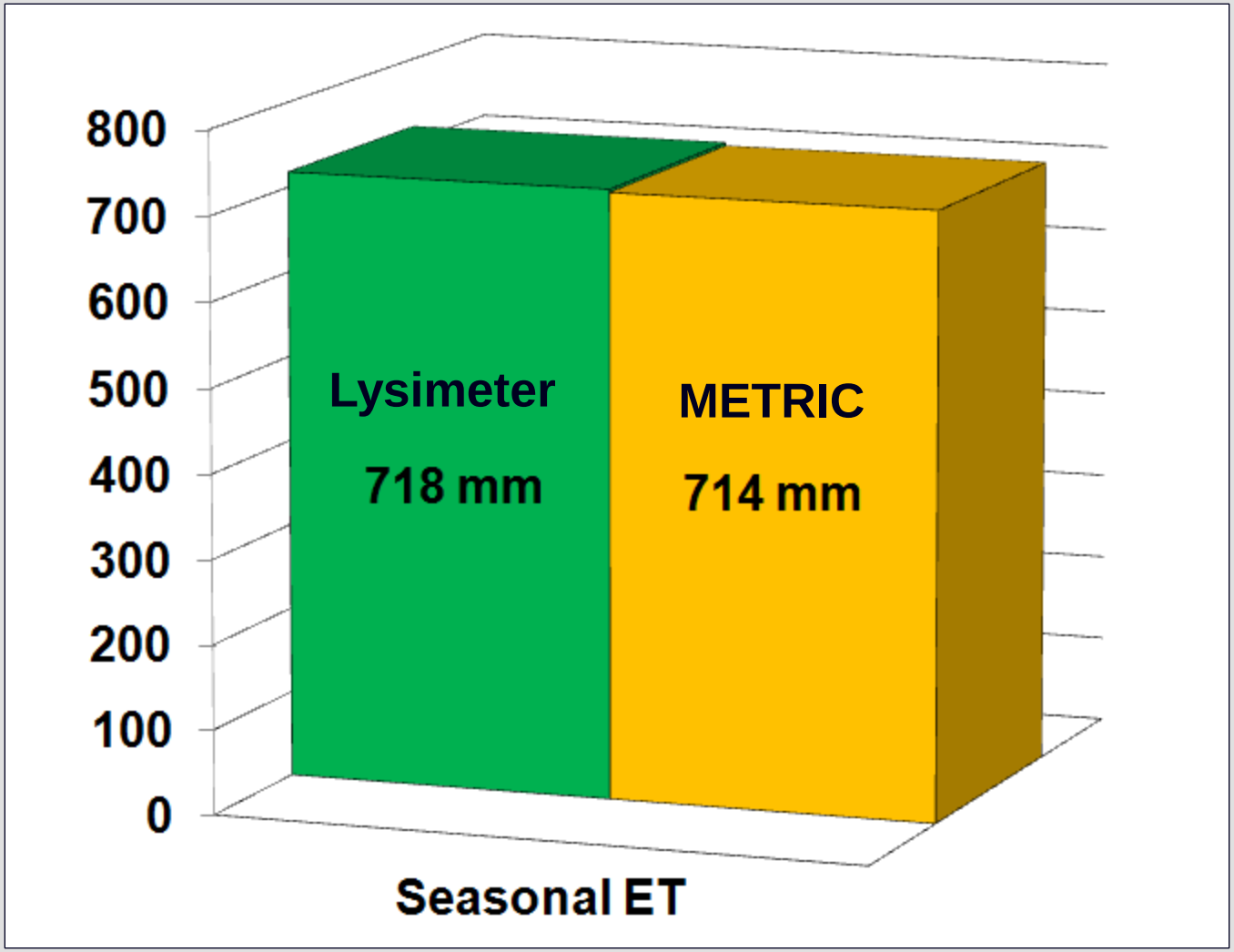
400+

24-hour ET (8/14/2000)



Comparison with Lysimeter Measurements

1968-1991



Seasonal ET for sugar beets at the Kimberly Research Station, April to September, 1989.

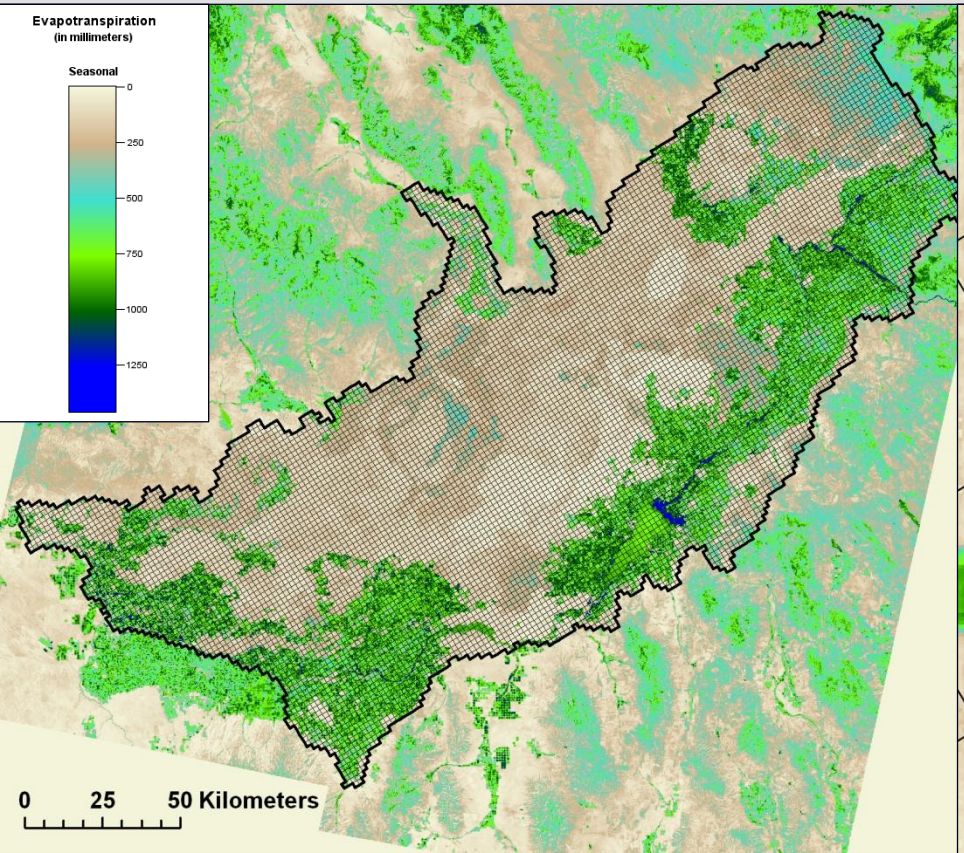
Applications in Idaho

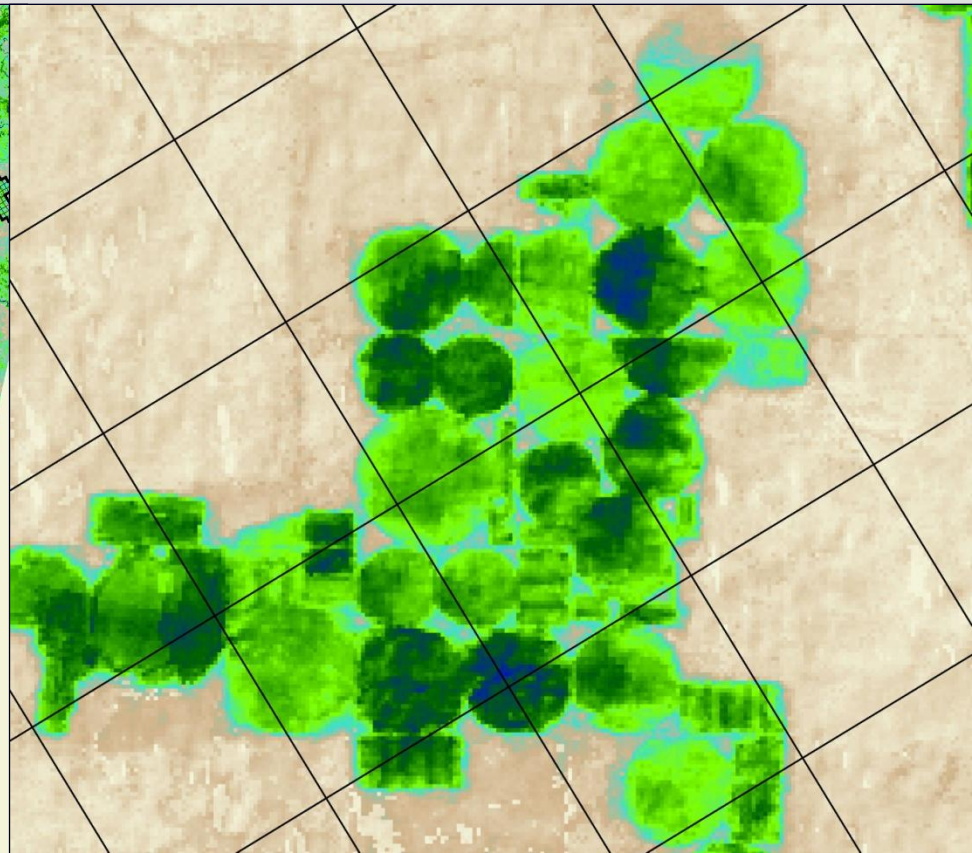
- Hydrologic modeling
- Water planning
- Water administration

Hydrologic Modeling

Eastern Snake Plain Aquifer Model

Developing METRIC ET data from 1986 to present

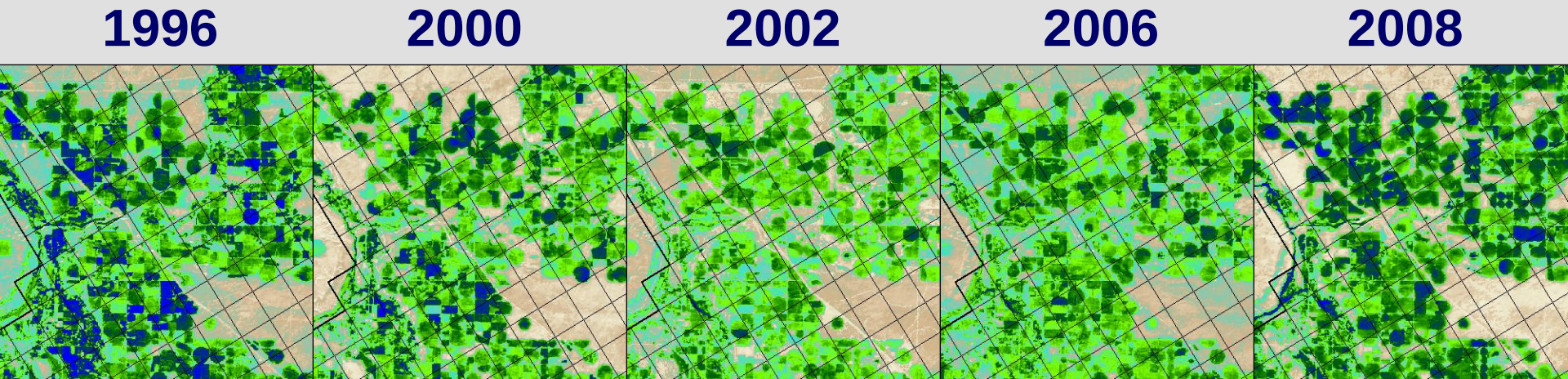




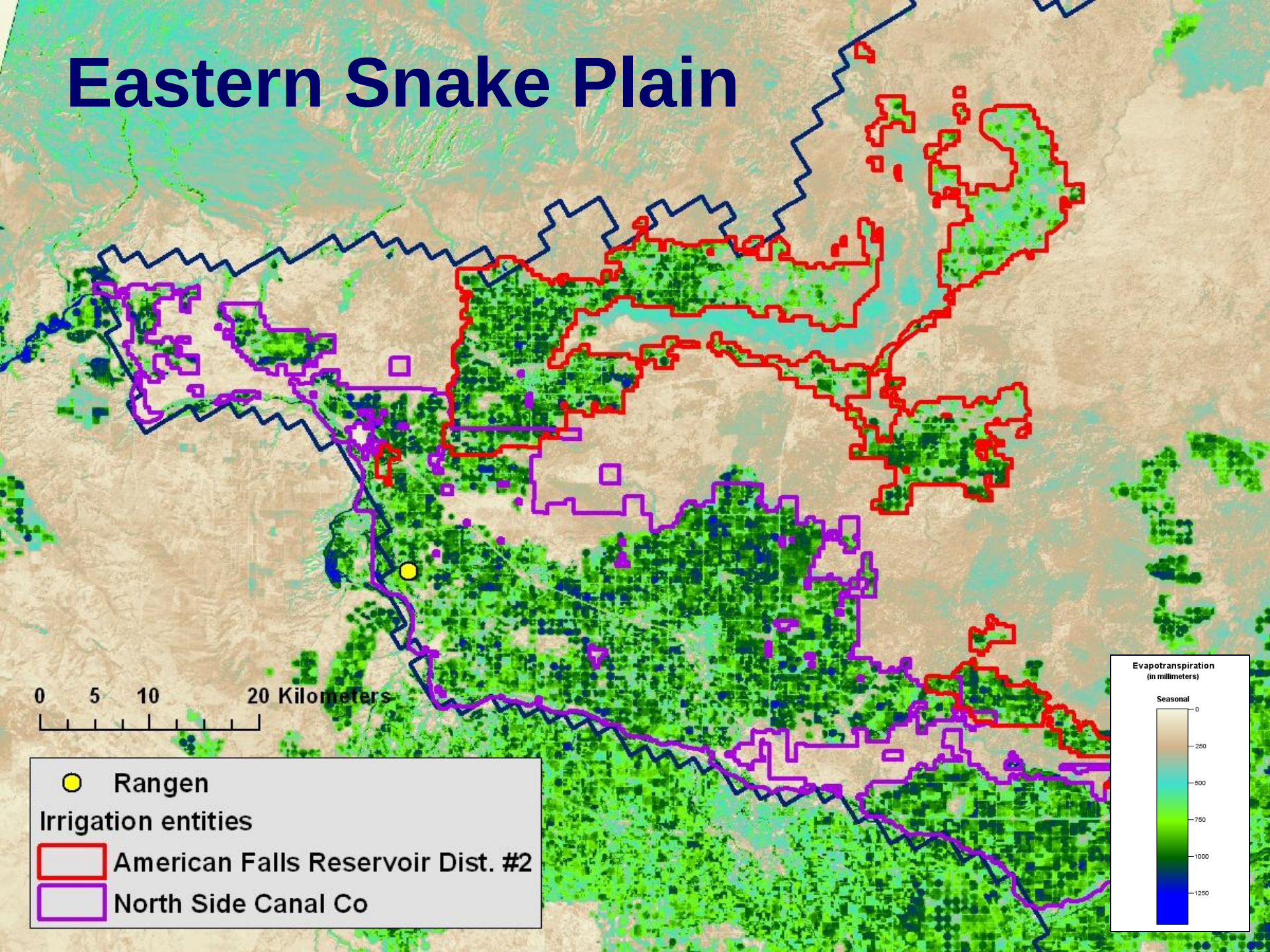
Eastern Snake Plain Aquifer Model

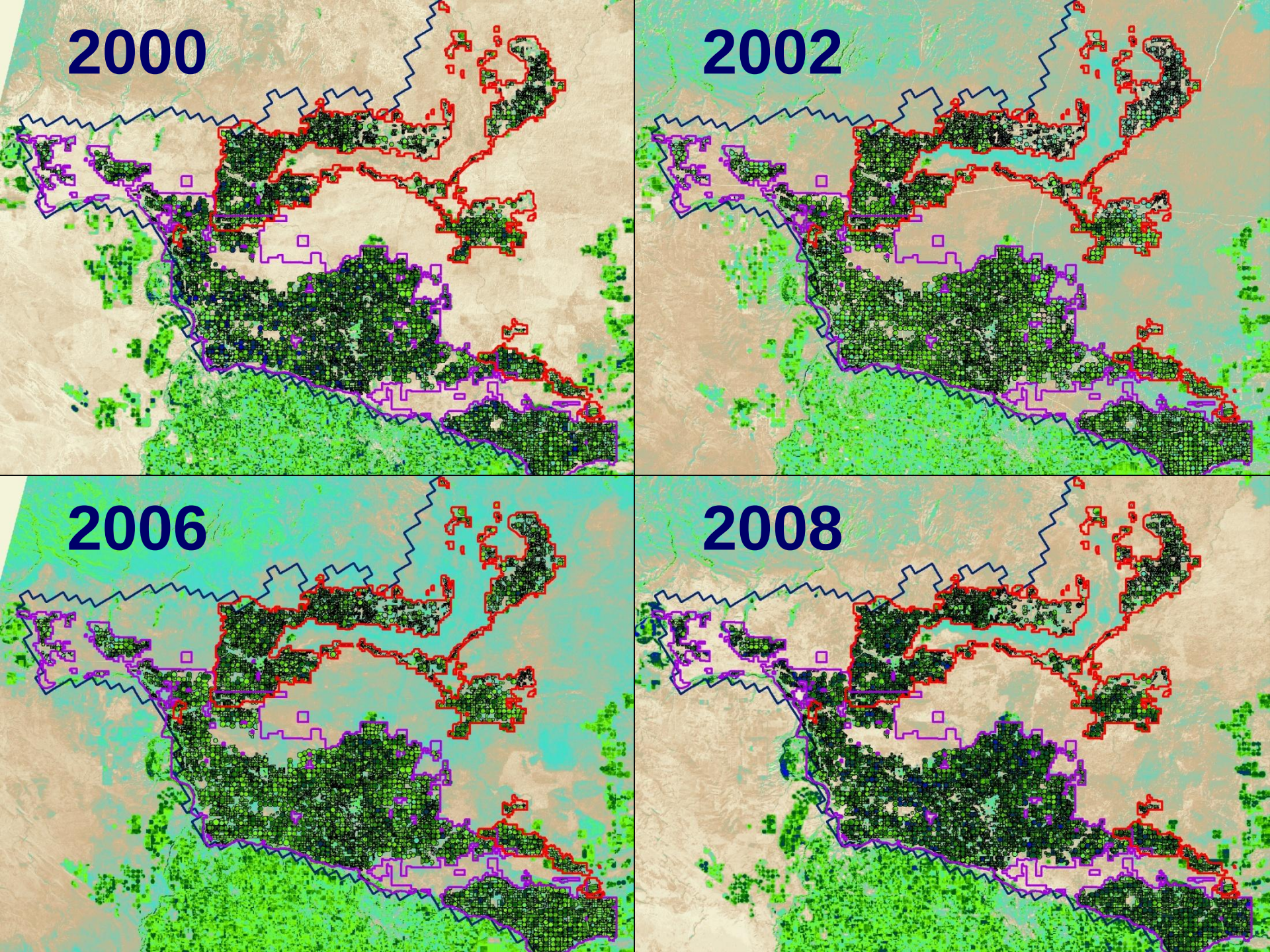
METRIC ET data

- More accurately calibrate the groundwater model
- Improve accuracy of depletions and recharge estimates
- Completed for: 1996, 2000, 2002, 2006, and 2008
- Shows long term trends in ET



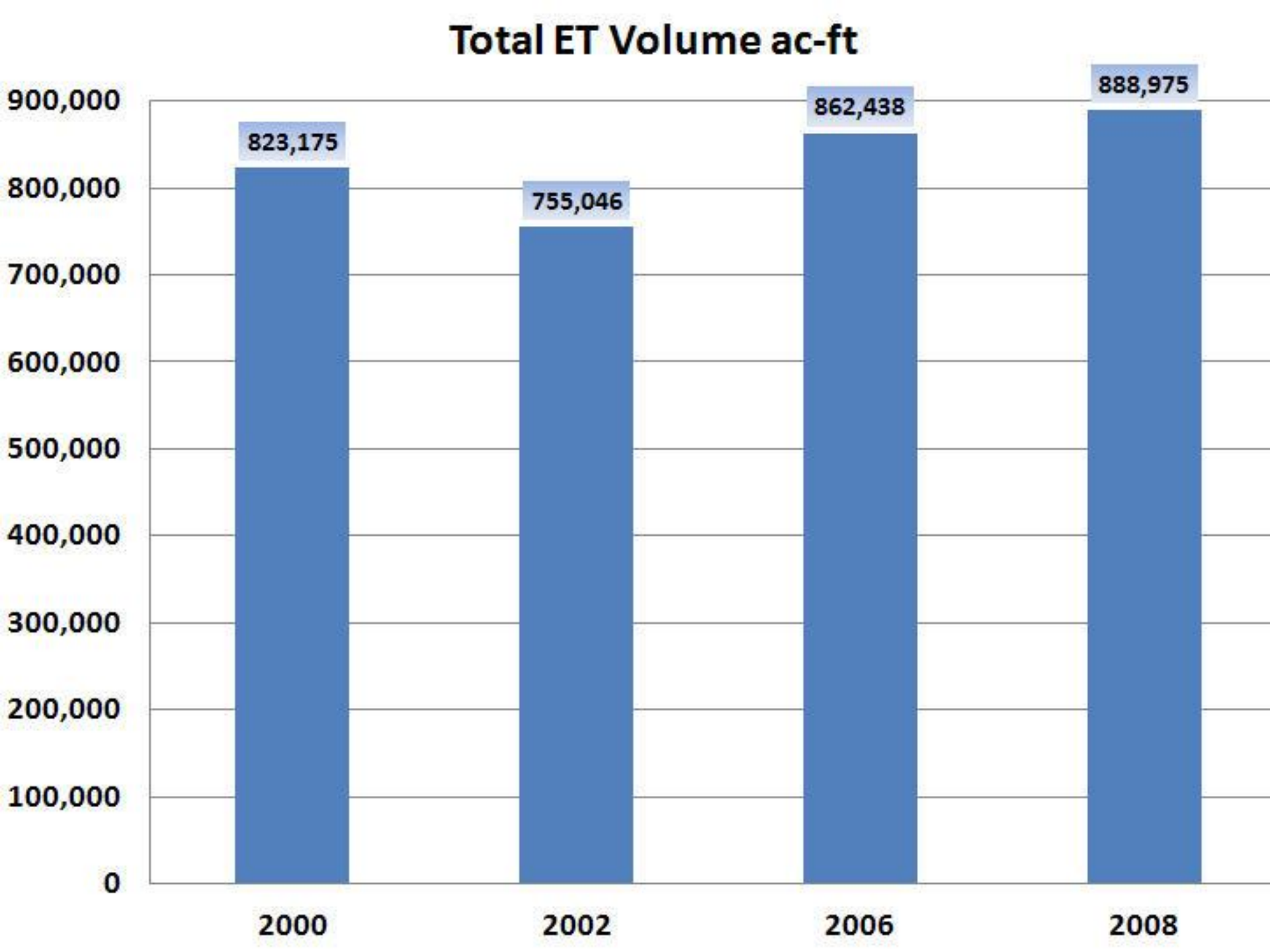
Eastern Snake Plain




2000
2002
2006
2008

METRIC ET for Irrigated Land by Irrigation Entity

Irrigation Entity	Mean ET mm	Acres	ET Volume ac-ft	ET ac-ft/acre
2000				
American Falls Reservoir Dist #2	815	86,932	232,592	2.68
North Side Canal Co LTD	859	204,558	576,611	2.82
Irrigation Entities Overlap Area	828	5,146	13,971	2.72
Total		296,636	823,175	2.78
2002				
American Falls Reservoir Dist #2	657	97,590	210,332	2.16
North Side Canal Co LTD	768	210,827	530,939	2.52
Irrigation Entities Overlap Area	779	5,389	13,775	2.56
Total		313,805	755,046	2.41
2006				
American Falls Reservoir Dist #2	796	100,004	261,306	2.61
North Side Canal Co LTD	831	215,011	586,337	2.73
Irrigation Entities Overlap Area	837	5,385	14,795	2.75
Total		320,399	862,438	2.69
2008				
American Falls Reservoir Dist #2	843	91,441	252,816	2.76
North Side Canal Co LTD	915	206,796	620,615	3.00
Irrigation Entities Overlap Area	927	5,109	15,545	3.04
Total		303,346	888,975	2.93
Note: The analysis used final irrigated land use data for 2002, 2006, and 2008, and preliminary irrigated land use data for 2000.				


Total ET Volume ac-ft
900,000
800,000
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
823,175
755,046
862,438
888,975
2000
2002
2006
2008

Potential METRIC Processing ESPA

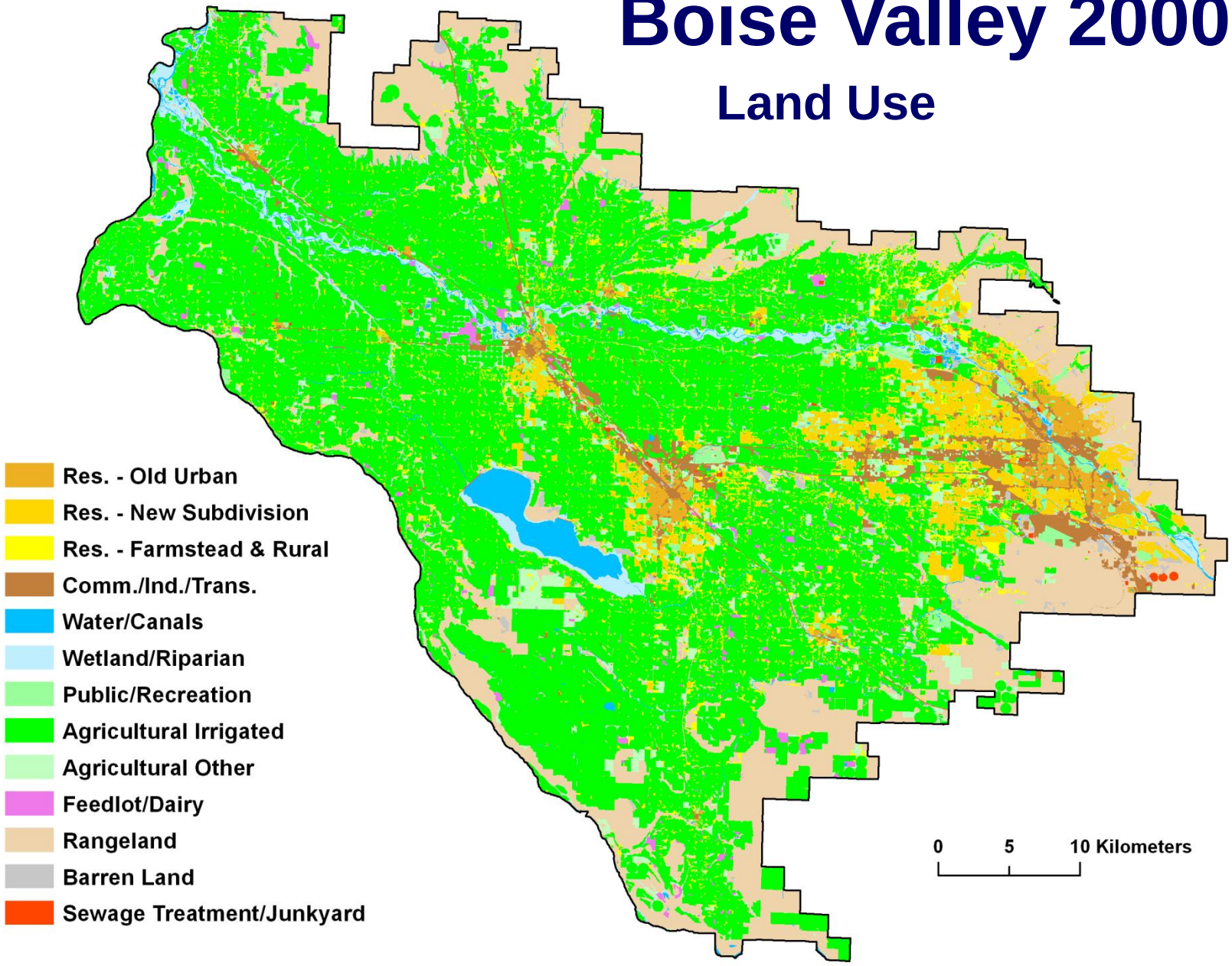
1984 - too sparse
1985 - too sparse
1986 - yes (METRIC in Progress)
1987 - not as populated as 1986, but possible for METRIC
1988 - no April-May for METRIC on path 40
1989 - no Sept-Oct for METRIC on path 40, poor on path 39
1990 - possible METRIC on 40, not on 39
1991 - no
1992 - possible METRIC for 40 and 39
1993 - possible for METRIC, no April-May on 39
1994 - no May-June for METRIC path 40
1995 - no
1996 - yes (METRIC DONE)
1997 - yes, iffy METRIC for June-July on 39
1998 - no May for METRIC on 40 and 39
1999 - no for METRIC in spring
2000 - yes (METRIC DONE)
2001 - yes for METRIC on both paths
2002 - yes (METRIC DONE)
2003 - iffy for METRIC for both paths (path 40 DONE through August (no images after that))
2004 - yes for METRIC on both paths
2005 - iffy for METRIC
2006 - yes (METRIC DONE)
2007 - possible, but challenging for METRIC on path 40
2008 - yes (METRIC DONE)
2009 - yes (METRIC in Progress)
2010 - yes (METRIC in Progress)
2011 - yes for METRIC on both paths

Water Planning
ET by Land Use

- Used for estimates of future water demand
- Year 2000 land use data analyzed with year 2000 seasonal ET data

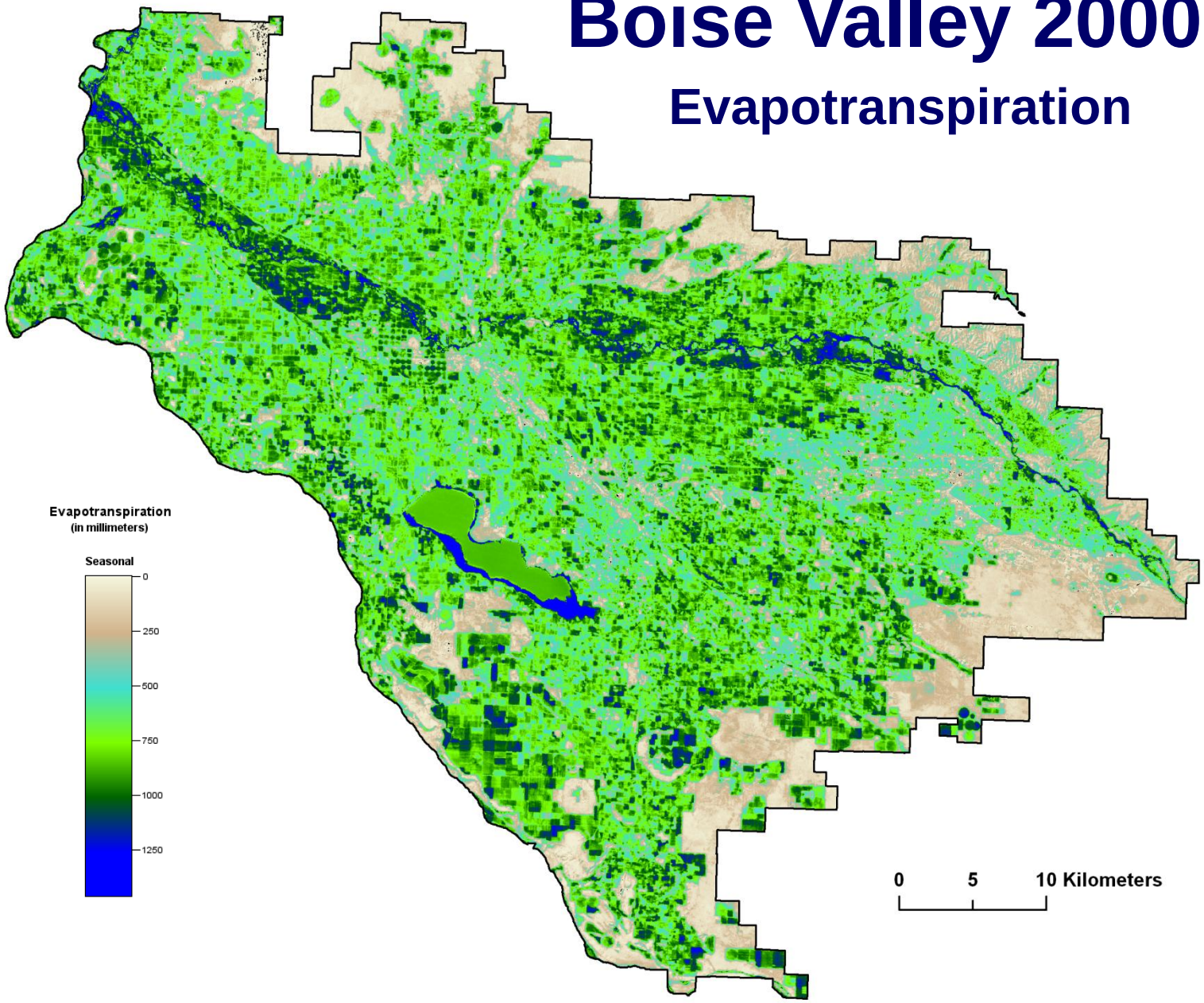
Boise Valley 2000

Land Use

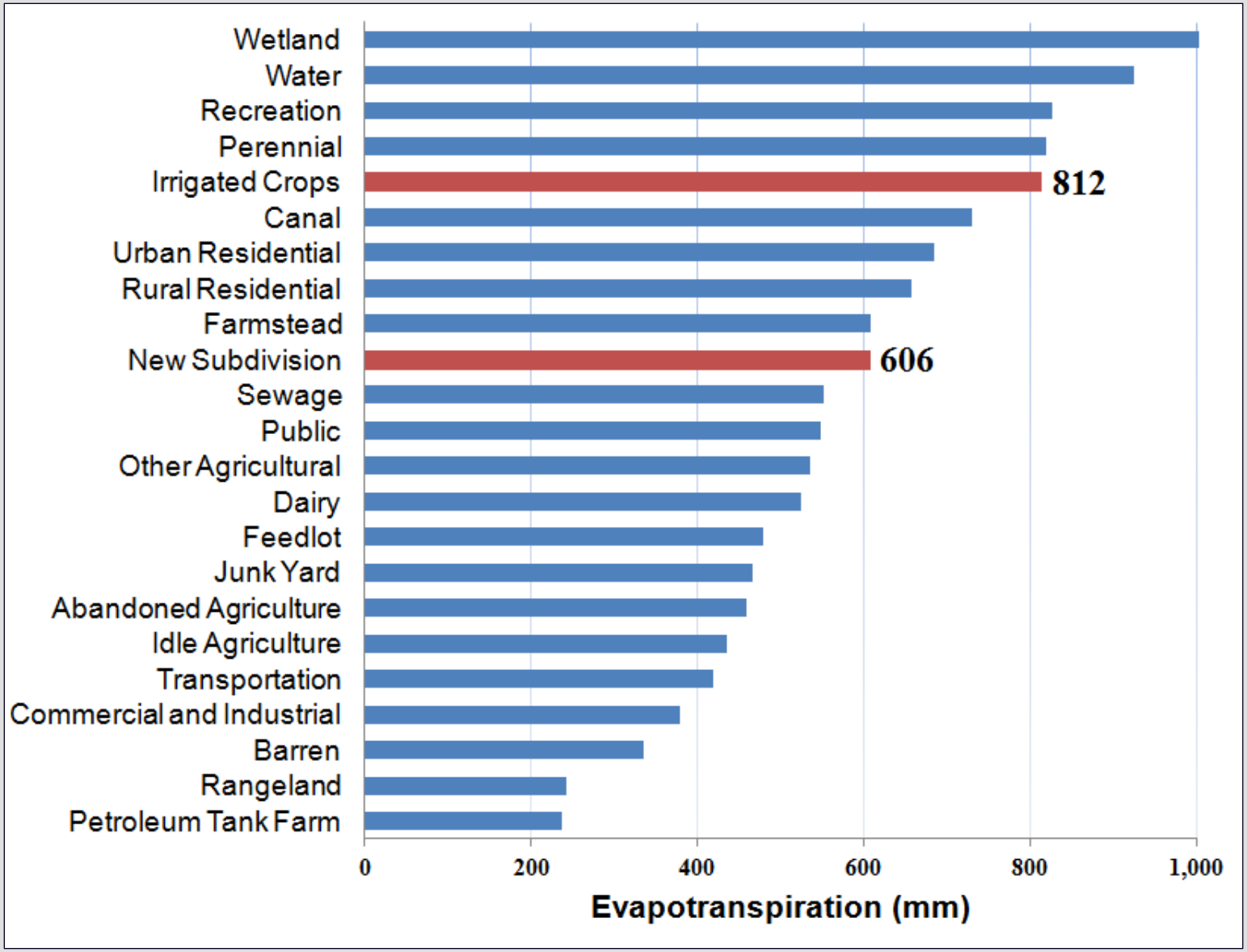


Boise Valley 2000

Evapotranspiration



Seasonal ET by land use



Water Administration
Litigation

- A&B Irrigation District water call
- Clear Springs Foods water call

Water Law Terms

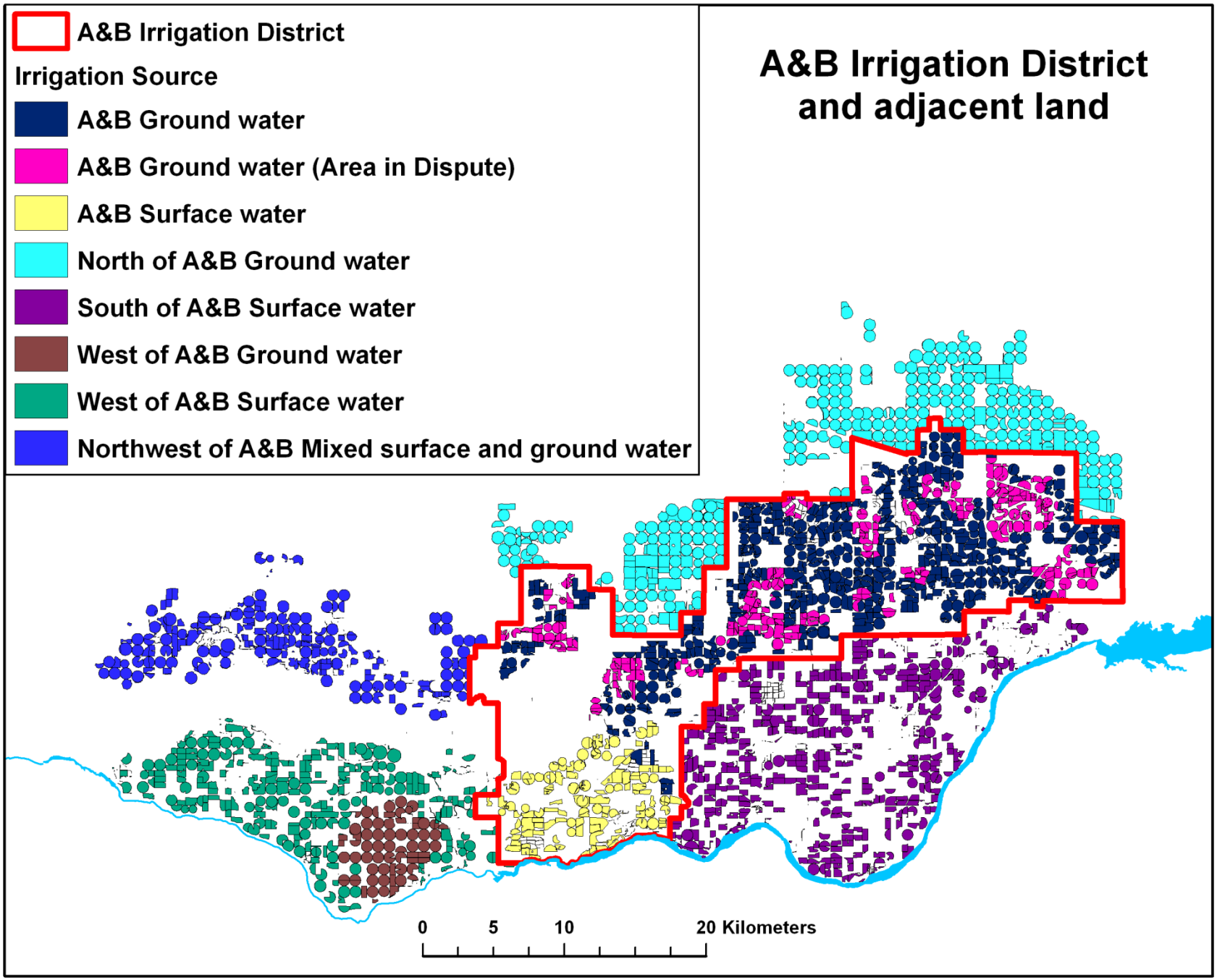
- Water Right
  - Authorization to use water
  - Includes priority date and rate of flow/volume
- Call
  - When a senior water right holder experiences a water shortage they may place a call
- Curtailment Order
  - Defines how the state directs junior water right holders to stop diverting water in response to a call
- Mitigation Plan
  - Junior users response to a curtailment order

A&B Irrigation District Water Call

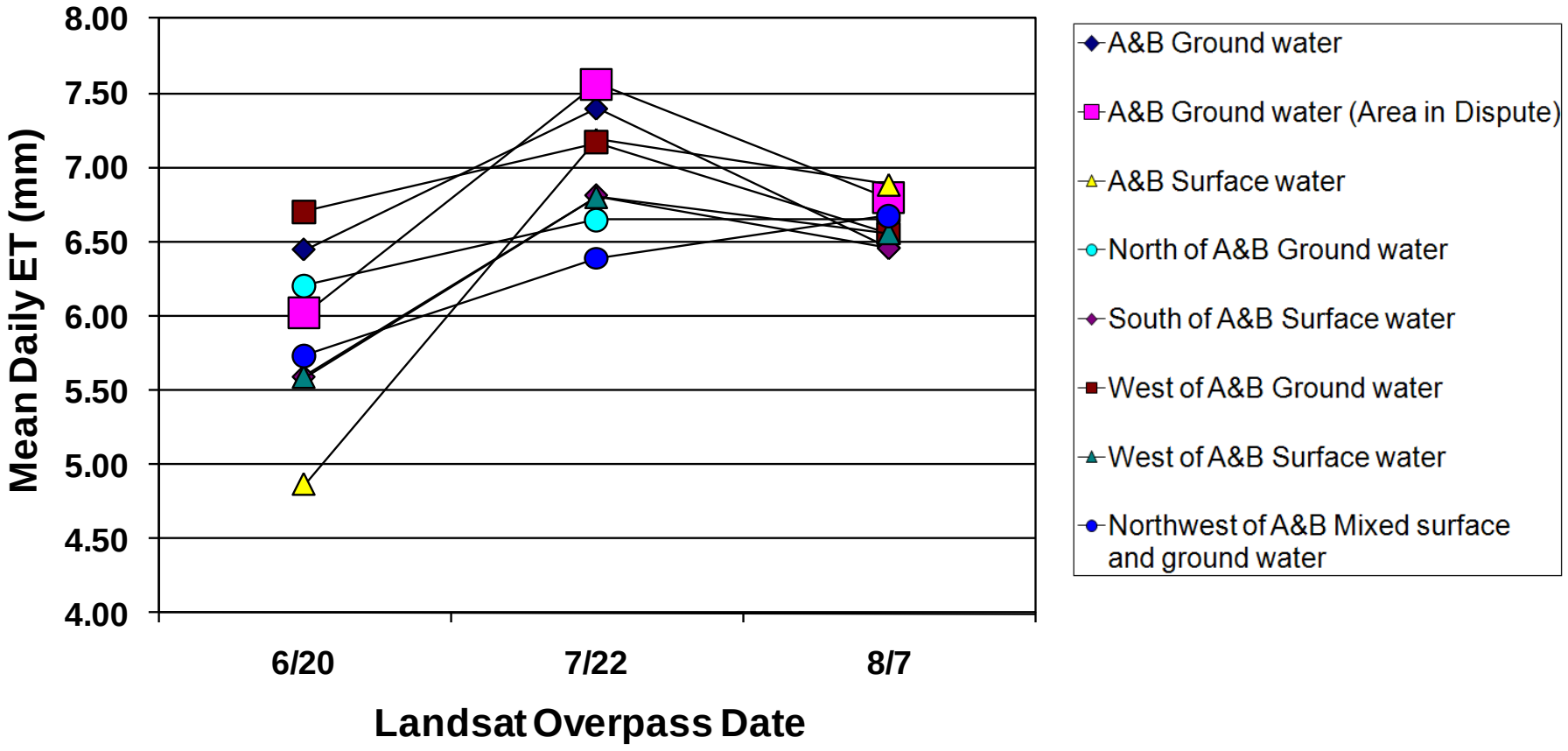
- A&B claimed that certain fields were short of water in 2006 due to diversions from junior ground water users

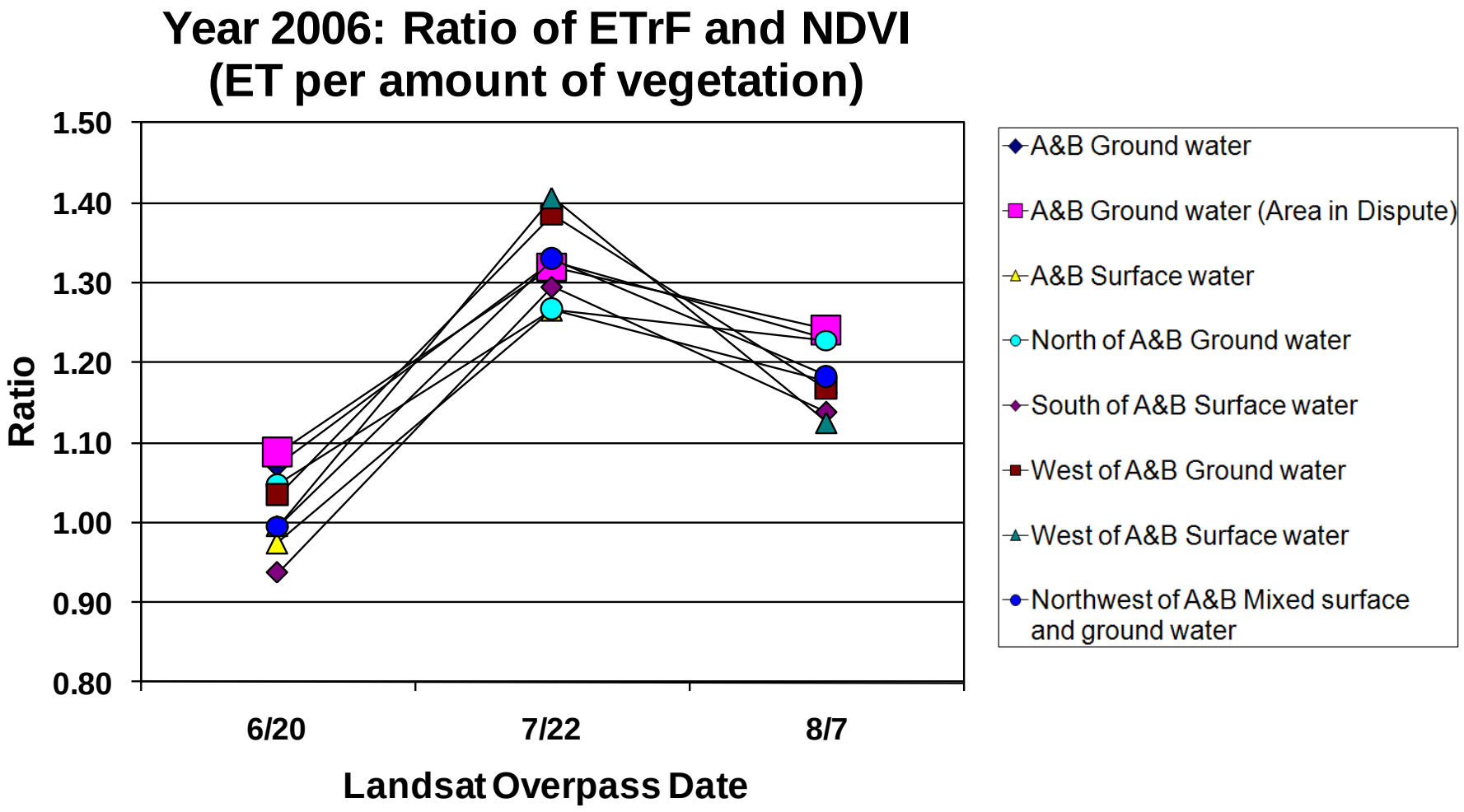
- METRIC ET showed that the fields had ET rates as high as surrounding fields that were not identified as water short

A&B Irrigation District and adjacent land



Year 2006: Mean Daily Evapotranspiration (ET)




Year 2006: Ratio of ETrF and NDVI
(ET per amount of vegetation)
Ratio
1.50
1.40
1.30
1.20
1.10
1.00
0.90
0.80
6/20
7/22
8/7
Landsat Overpass Date
A&B Ground water
A&B Ground water (Area in Dispute)
A&B Surface water
North of A&B Ground water
South of A&B Surface water
West of A&B Ground water
West of A&B Surface water
Northwest of A&B Mixed surface and ground water

A&B Irrigation District Water Call

Summary

- Director issued order denying the call
- Hearing Officer agreed with the Director's decision
- District Court affirmed the Director's decision
- Idaho Supreme Court
  - Argued on February 28, 2012
  - Waiting for decision

Clear Springs Foods Water Call

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.

State goes ahead with first large-scale well closure of more than 300 water rights in M.V. 7/31/2009

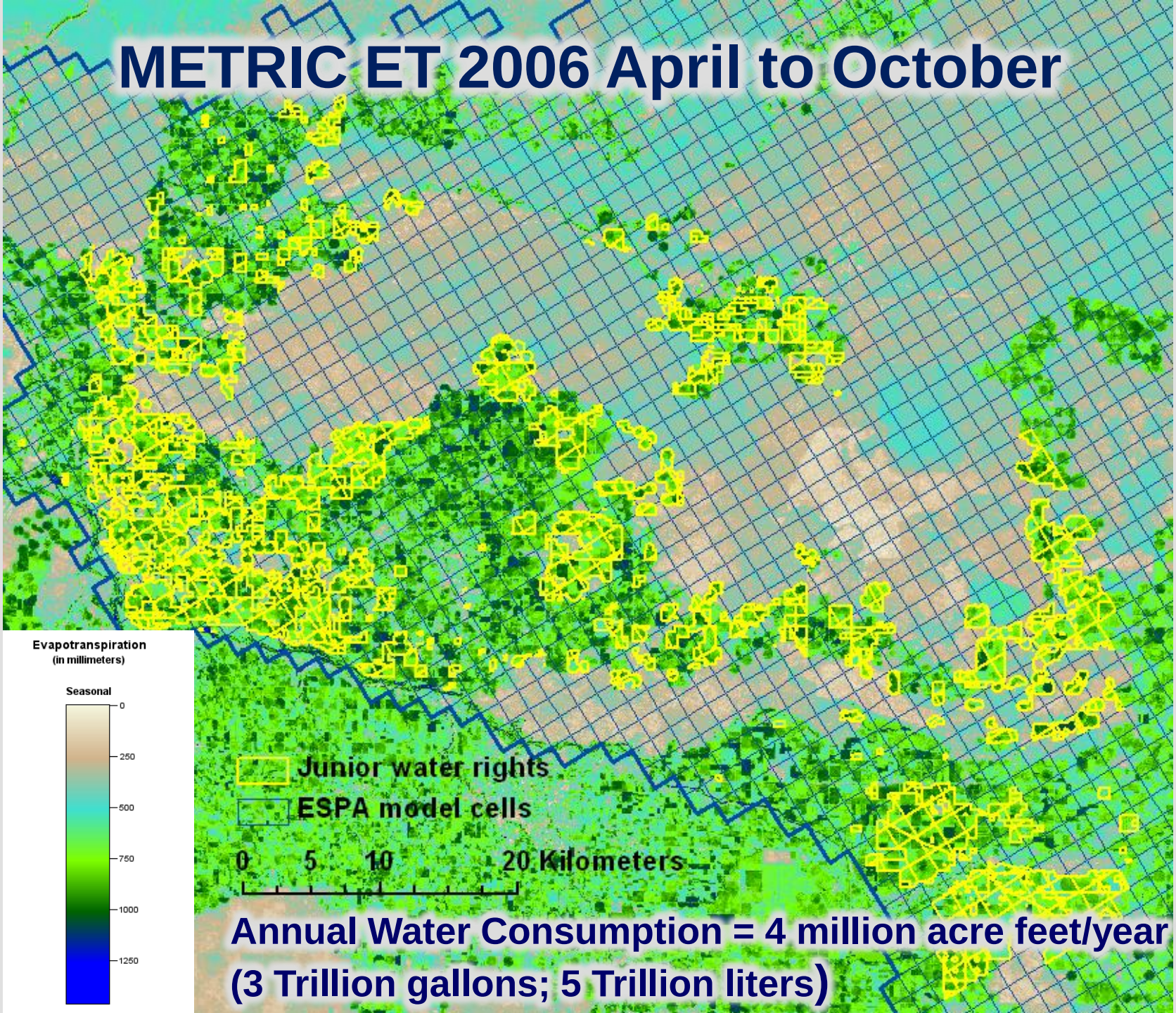
Water districts have limited options, could file a stay

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.

Clear Springs Foods, Inc.

METRIC ET 2006 April to October



Annual Water Consumption = 4 million acre feet/year

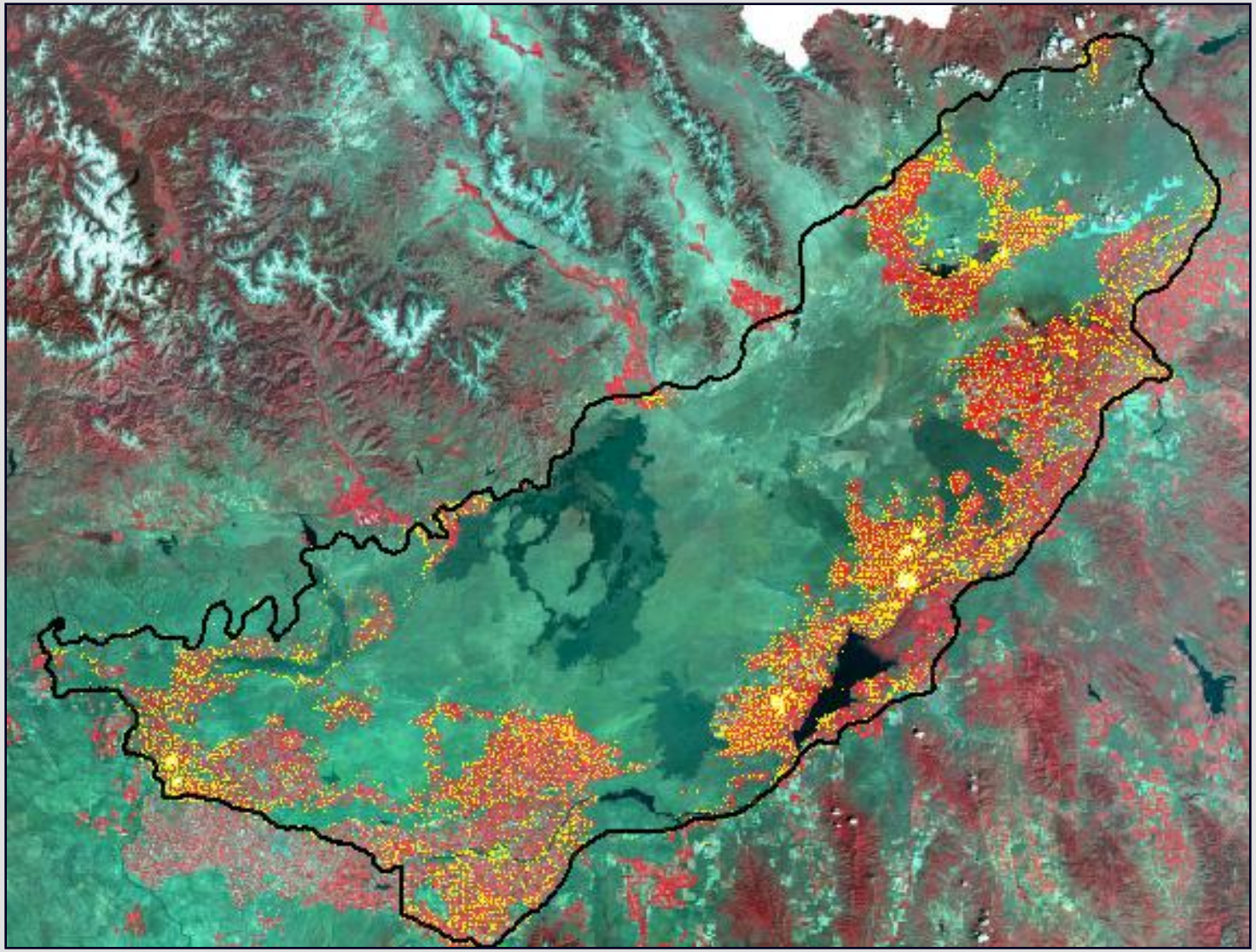
(3 Trillion gallons; 5 Trillion liters)

Clear Springs Foods Water Call

Summary

- ESPA GW model used METRIC ET data
  - For model calibration
  - To select water rights to curtail
- No complaints from junior users about GW model or METRIC ET data

Aquifer Depletion



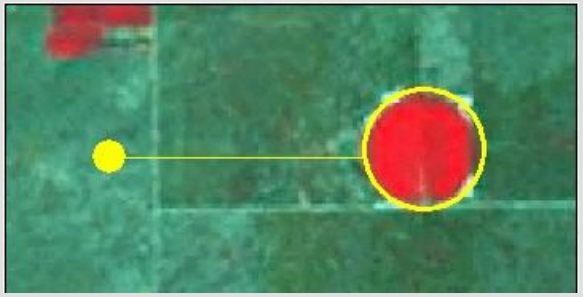
Aquifer Depletion

ESPA has ~ 4,000 monitored irrigation wells

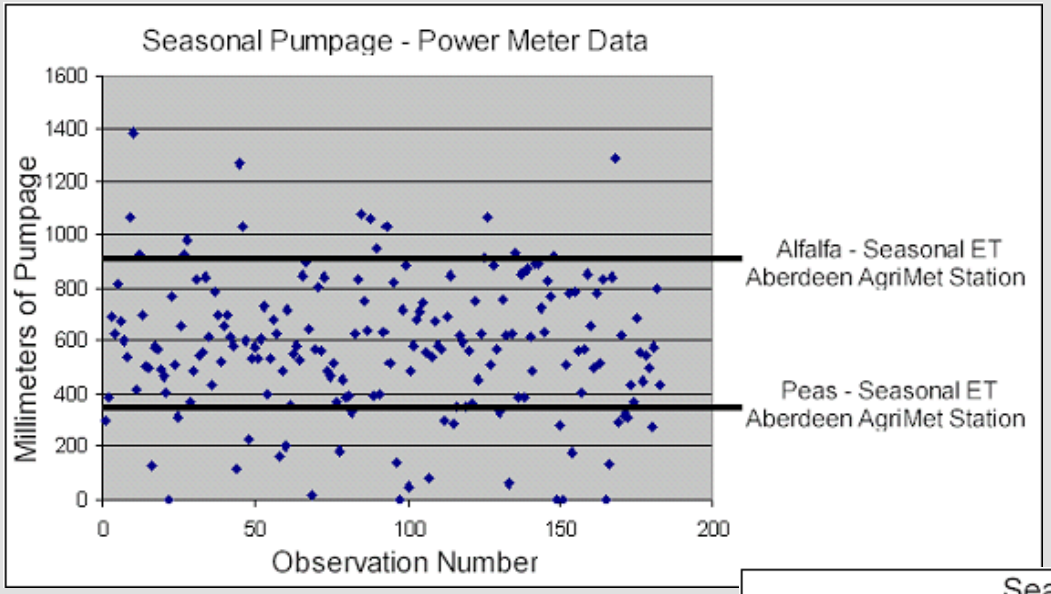
What is the most efficient monitoring method?

Present method: power consumption coefficients
Alternative method: METRIC and Landsat

Compared 180 well-field combinations



Result

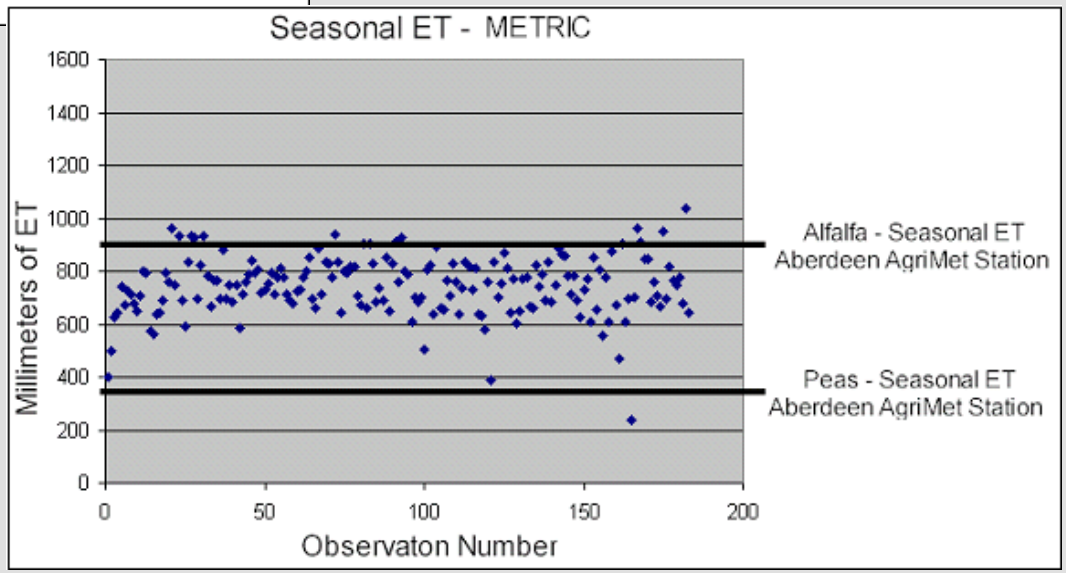


PCC

Cost: $119 per well

METRIC

Cost: $32 per field



Other states using METRIC

- Nevada
  - Water transfers to Reno and Las Vegas
- Nebraska
  - Over pumping of the Ogallala Aquifer
- Colorado
  - Kansas vs. Colorado over Arkansas River
  - Nebraska vs. Colorado over S. Platte River
- Wyoming
  - Nebraska vs. Wyoming over N. Platte River
- Oregon
  - Klamath Basin water shortages
- California
  - Imperial Irrigation District: water consumption by irrigation
- New Mexico
  - Middle Rio Grande: water consumption by agriculture and riparian systems
- Montana
  - Flathead Indian Reservation and ground water areas east of Helena: for improved irrigation water management and management of total depletion

ET Investigations involving METRIC/Landsat -- Applications for Water Management

University of Idaho and Associates/Partners

Richard Allen (UI), Ricardo Trezza (UI), Bill Kramber (IDWR), Tony Morse (SAG), Jan Hendrickx (NMT), Ayse Irmak (UNL), Justin Huntington (DRI), Clarence Robison (UI), Carlos Kelly (UI), Jeppe Kjaersgaard (UI), Jeremy Greth (UI), Masahiro Tasumi (UI), Tim Martin (RTI)

UI: University of Idaho
IDWR: Idaho Department of Water Resources
SAG: Spatial Analysis Group (Morse)
NMT: New Mexico Tech
UNL: University of Nebraska, Lincoln
DRI: Desert Research Institute

RTI: Riverside Technologies, Inc, Fort Collins CO
SHA: Soil Hydrology Associates, Los Lunas NM (Hendrickx)
MDNRC: Montana Department of Natural Resources and Cons
OSE: Office of State Engineer
NRD: Natural Resource District

ET+: Evapotranspiration Plus, Twin Falls ID (Allen)
MBMG: Montana Bureau of Mining and Geology
SNA: SEBAL North America
NMSU: New Mexico State University
CSU: Colorado State University

Flathead Valley, MT

Yakima River Basin -- calibration of large scale energy balance models for assessing climate change. (Univ. Wash.)

Klamath Basin -- water for grazing and local ecosystem interactions, ground water balance, irrigated areas (UI, ET+ for USGS, USFS)

Lemhi River -- irrigation management for salmon recovery (IDWR, UI for IDWR)

Boise River Valley -- agricultural to urban land use change (IDWR for IDWR)

Richard Allen
University of Idaho

Justin Huntington
DRI

Eastern Snake Plain -- irrigation transfers, ground water model calibration (UI for IDWR)

Owens Valley -- ET of Desert (NMSU)

Bear River -- Interstate Compact (UI for IDWR)

Western Nevada -- water transfers between irrigated agriculture, municipalities, and playas (DRI, UI, NV-OSE for NV-OSE)

Imperial Irrigation District - impacts of water conservation measures, salinity, and timing of ET (UI, SNA)

Imperial Irrigation District, CA

Middle Rio Grande -- water consumption by invasive vegetation (UI for USDOJ)

Lower Rio Grande -- water use by irrigated agriculture (NMSU, UI, for NM-OSE)

Palo Verde Irrigation District - intercomparison of ET methods (USU, USGS, USBR, UI)

Jan Hendrickx
NMT

Walker River, NV

Middle Rio Grande, NM

Eastern Snake Plain, ID

Flathead Indian Reservation -- irrigation water consumption for managing streamflows (UI for MDNRC)

Ground water recharge estimation in four basins: Helena, White Sulphur Springs, Dillon, and Bozeman (UI for USGS, MBMG)

Green River/Upper Colorado River (UWYO, SHA, RTI, ET+ for WY-OSE)

Upper North Platte -- water decree compliance (RTI, ET+)

Ogallala aquifer -- ground water management, mitigation and Riparian ET (UNL, UI for NRD's)

Tim Martin
RTI

South Platte -- conjuctive management of ground water and surface water (RTI, UI)

Ayse Irmak
UNL

Central Nebraska -- comparison to measured ET (UNL)

Arkansas River -- assessment of water shortage and salinity impacts (CSU)

Amarillo Area (USDA-ARS, UI)

Lubbock Region (SHA)

Texas

Southern Idaho Fields

Upper North Platte River, WY

Central Iowa -- ET from Agriculture (USDA-ARS, UI)

Martha Anderson
USDA-ARS

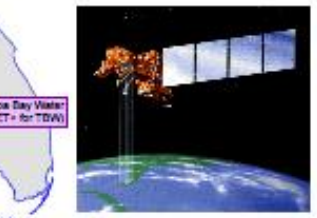
Tampa Bay Water (ET+ for TBW)

Tampa Bay Area, FL

Landsat

MODIS

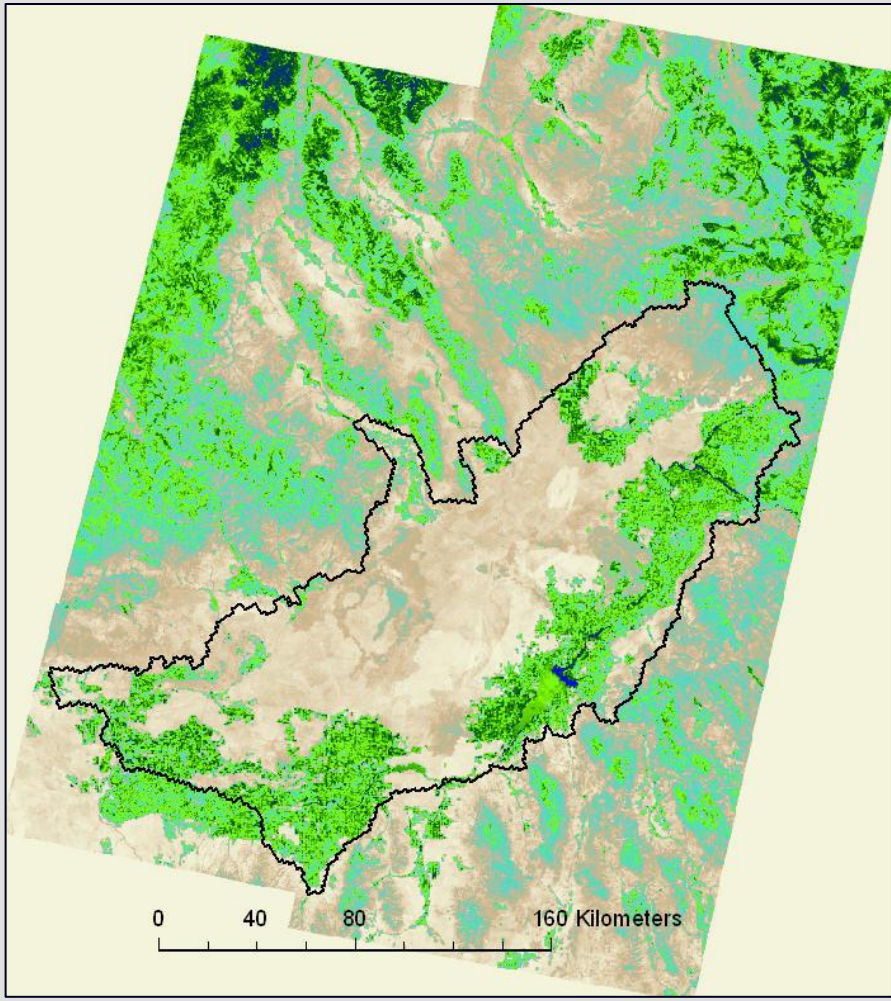
Minidoka, ID



University of Idaho
A LEGACY OF LEADING

Cost of METRIC

- About one year to develop monthly ET for 100,000 square kilometers (4 Landsat images)
- Cloudy areas require extra effort
- Other costs if you do it yourself
  - training
  - image processing and GIS software
  - disks for processing and storage



Concern about Landsat's future

- Landsat 5 is 28 years old
  - Imaging halted November 2011 due to electronic component problem
- Landsat 7 is 13 years old
  - Scan line corrector failed March 2003
  - About 22% of each image is missing
  - Missing areas are filled in using ArcGIS tools
- Landsat 8 scheduled to launch January 2013
- Funding for Landsat 9 is uncertain

The Landsat Archive

- USGS EROS Data Center, Sioux Falls, SD
- ~ 3 million scenes
- July 1972 to present (thermal since 1984)
- Free
- http://earthexplorer.usgs.gov/

Summary

- METRIC computes “Actual ET”
  - Over 90% accurate
  - ET at the field level
  - ET by day, month, and year
  - ET from bare soil and vegetation
- Idaho and other states use METRIC operationally
- Landsat is the best satellite for mapping ET at the field level

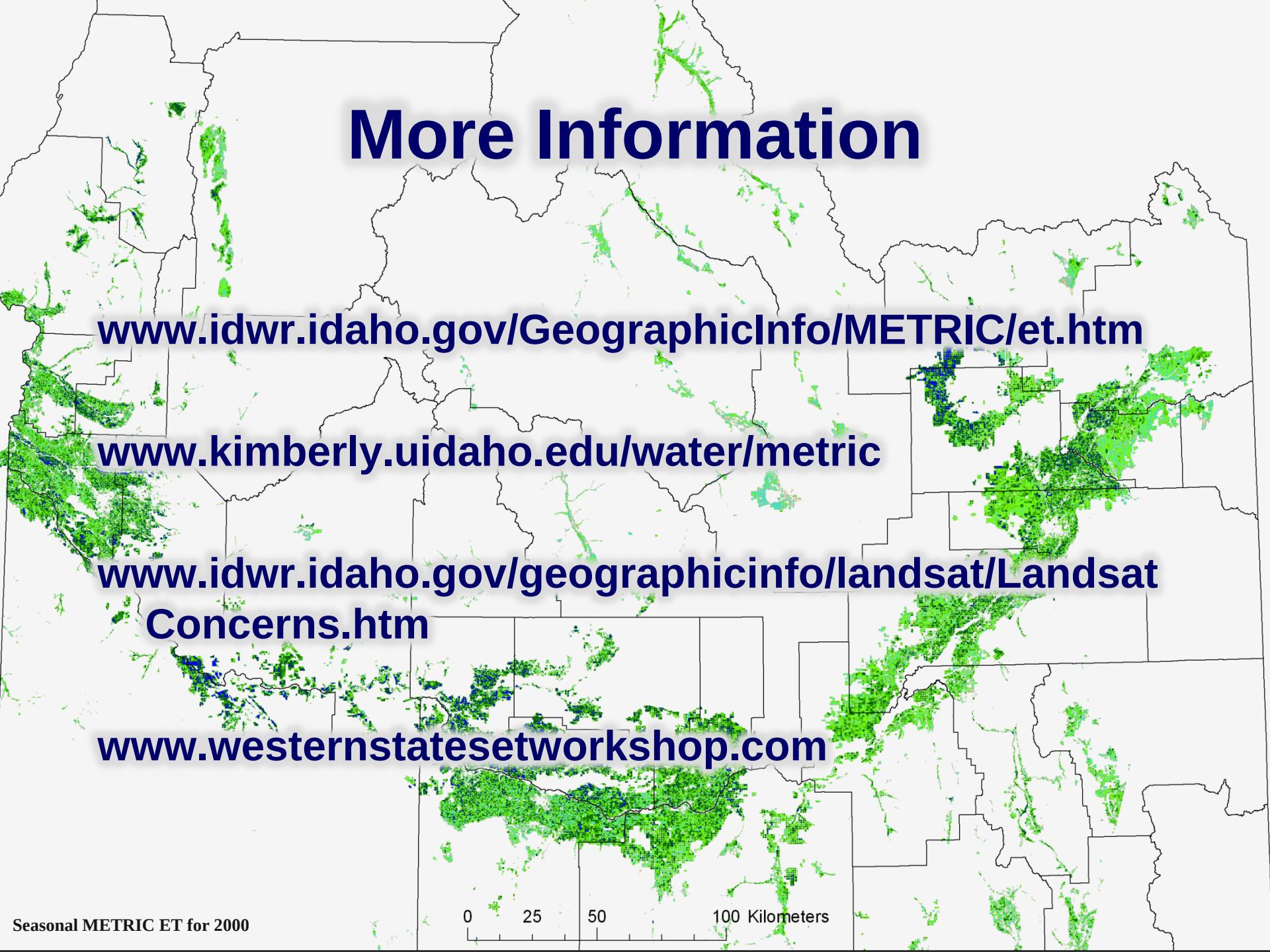
More Information

www.idwr.idaho.gov/GeographicInfo/METRIC/et.htm

www.kimberly.uidaho.edu/water/metric

www.idwr.idaho.gov/geographicinfo/landsat/LandsatConcerns.htm

www.westernstatesetworkshop.com



Seasonal METRIC ET for 2000