Evapotranspiration (ET) Data

Stephen Hundt
USGS
November 15, 2023

USGS
science for a changing world

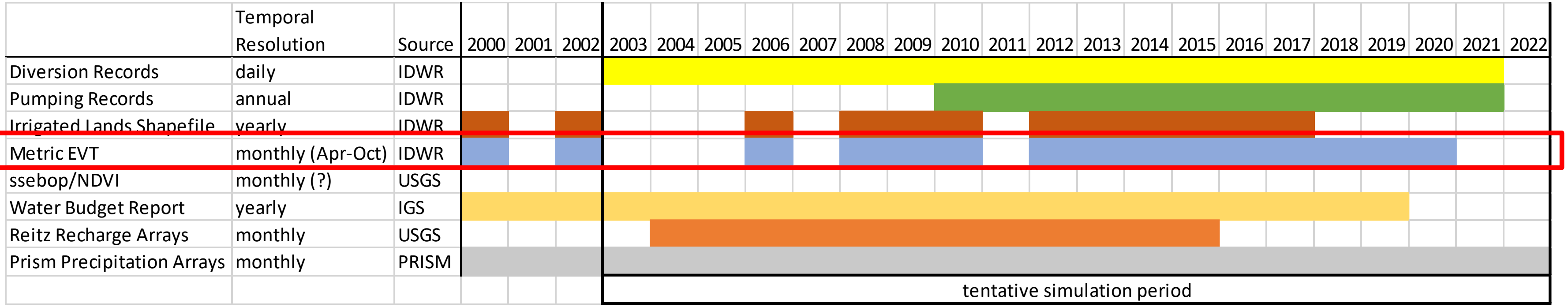
Goal of this talk

Briefly talk about ET, it’s use in the model, and data sources

Explain why (and how) I would like to use an alternative satellite-derived ET product to fill in gaps

Get feedback from you

We don’t have METRIC data for every year



It is nice to work with

We would like to fill the gaps with something similar

Role of ET data in the model

Clark, 2021

Table 10.4. Total estimated annual evapotranspiration volumes in the Big Lost River Basin, south-central Idaho, 2000–19.

[See table 10.1 for evapotranspiration data sources. All units are in acre-feet per year for calendar years 2000–19 over the irrigation season (April–October) and winter (January–March and November–December]

Year	Total basin		
	Irrigation season	Winter	Year
2000	949,005	125,179	1,074,184
2001	797,731	92,663	890,394
2002	778,247	92,008	870,255
2003	757,816	75,195	833,011
2004	1,048,651	102,249	1,150,900
2005	1,168,865	89,896	1,258,761
2006	1,160,915	101,467	1,262,382
2007	801,929	80,953	882,882
2008	600,925	90,846	691,771
2009	938,984	123,646	1,062,630
2010	861,678	128,211	989,889
2011	790,462	72,603	863,065
2012	830,510	137,498	968,009
2013	752,635	67,187	819,822
2014	845,469	126,859	972,328
2015	1,275,291	106,369	1,381,661
2016	994,587	134,833	1,129,420
2017	967,509	134,882	1,102,392
2018	880,600	159,102	1,039,702
2019	900,556	159,687	1,060,243
Mean	905,118	110,067	1,015,185

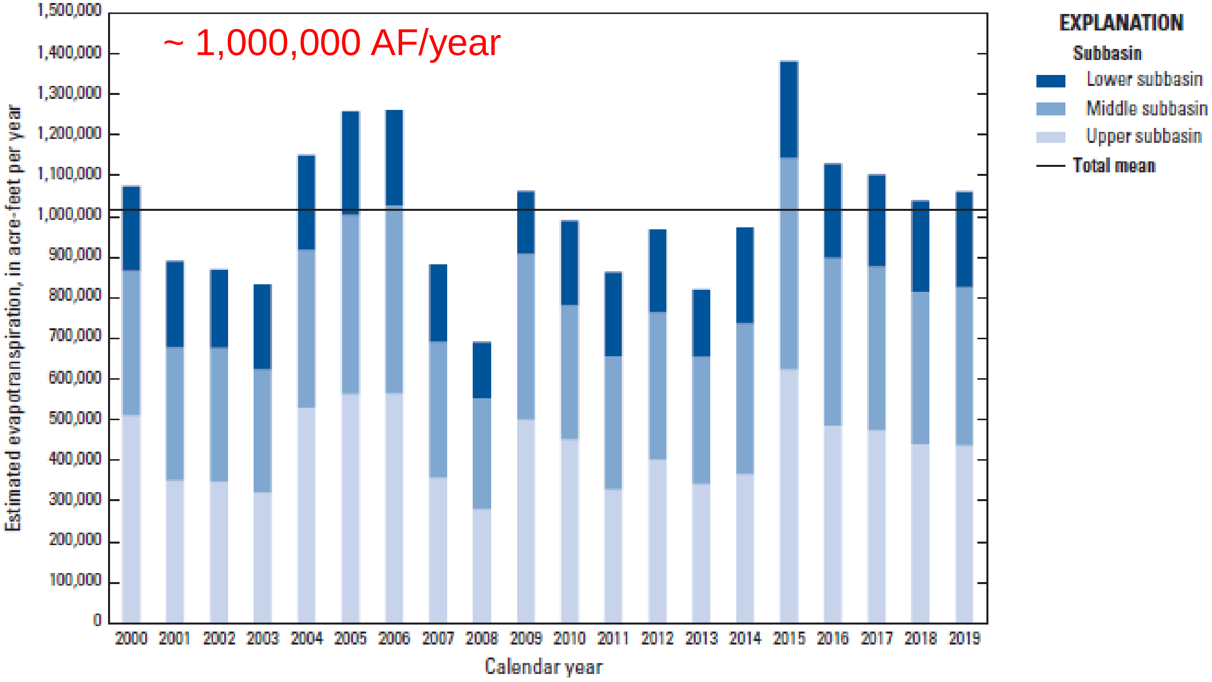


Figure 10.1. Total annual evapotranspiration, Big Lost River Basin, south-central Idaho, 2000–19. See table 10.1 for data sources used in calculations and tables 10.2 and 10.3 for evapotranspiration volumes.

Clark, 2021

~ 1,000,000 AF/year

Table 4. Estimated annual groundwater budgets for the Big Lost River Basin, south-central Idaho, for average conditions during 2000–19, 2014 (dry), and 2017 (wet).

[All values in acre feet per year (acre-ft/yr) are rounded up or down to the nearest 100]

Budget component	Entire basin			Above Mackay Dam			Below Mackay Dam		
	2000–19	2014	2017	2000–19	2014	2017	2000–19	2014	2017
Tributary canyon underflow	88,700	87,900	124,200	50,900	49,800	72,100	37,800	38,100	52,100
Areal recharge	99,700	116,200	146,800	36,800	44,200	62,500	62,900	72,000	84,300
Applied irrigation recharge	46,900	15,800	71,700	16,600	5,300	20,700	30,300	10,500	51,000
Canal seepage	55,300	43,000	70,800	19,000	18,600	23,000	36,300	24,400	47,800
Managed recharge (winter)	1,900	0	6,100	100	0	400	1,800	0	5,700
Septic system effluent	200	100	300	0	0	0	200	100	300
Losing river reaches	144,800	109,600	339,900	6,600	0	70,500	138,200	109,600	269,400
Mackay Reservoir seepage	1,600	1,300	2,300	1,600	1,300	2,300	0	0	0
Groundwater inflow (above dam residual)	0	0	0	0	0	0	100,400	96,700	248,300
Groundwater pumpage to canals	8,300	22,400	2,900	0	0	0	8,300	22,400	2,900
Irrigation pumpage	76,000	112,700	49,000	4,200	4,700	3,100	71,800	108,000	45,900
Domestic supply pumpage	500	400	800	100	100	100	400	300	700
Municipal supply pumpage	600	300	700	0	0	0	600	300	700
Gaining river reaches	26,900	17,700	0	26,900	17,700	0	0	0	0
Total inflow (recharge)	439,100	373,900	762,100	131,600	119,200	251,500	407,900	351,400	758,900
Total outflow (discharge)	112,300	153,500	53,400	31,200	22,500	3,200	81,100	131,000	50,200
Difference (residual)	326,800	220,400	708,700	100,400	96,700	248,300	326,800	220,400	708,700

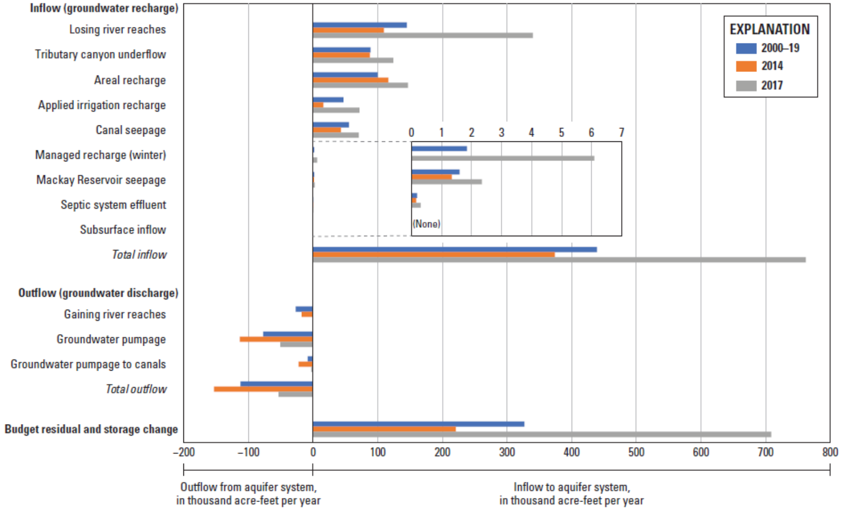
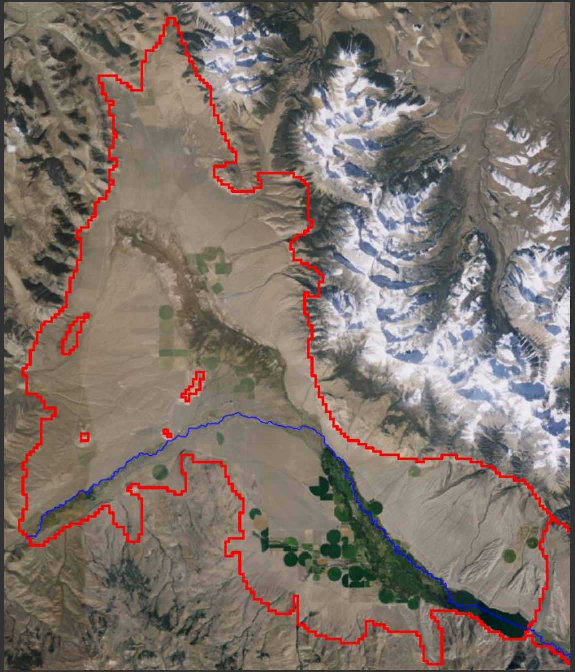
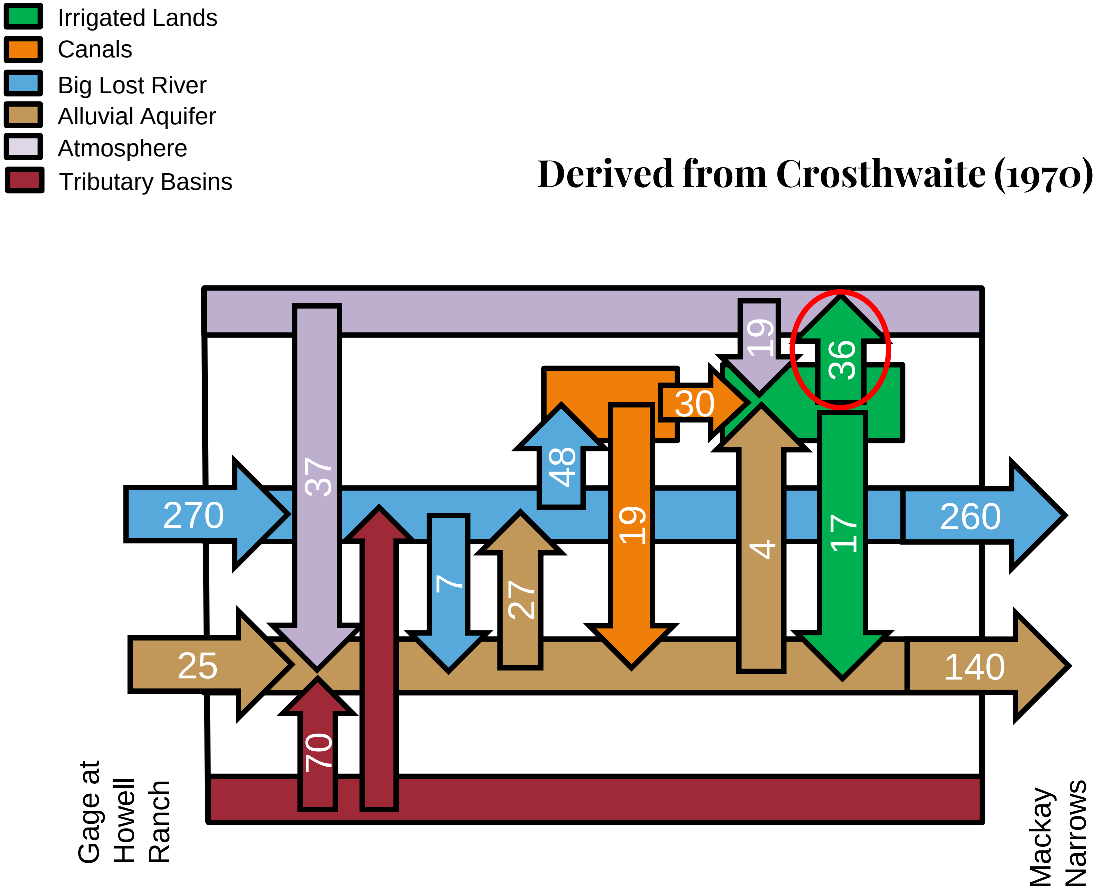


Figure 5. Average groundwater-budget components, as calculated in this report, for the Big Lost River Basin, south-central Idaho, 2000–19, 2014, and 2017. See table 4 for data.

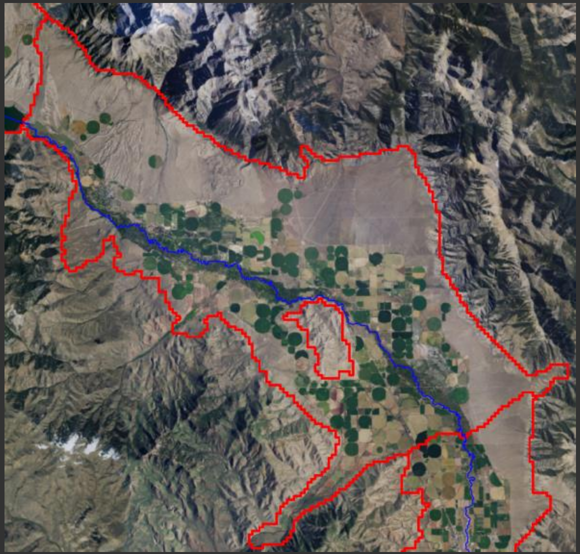
Upper Basin





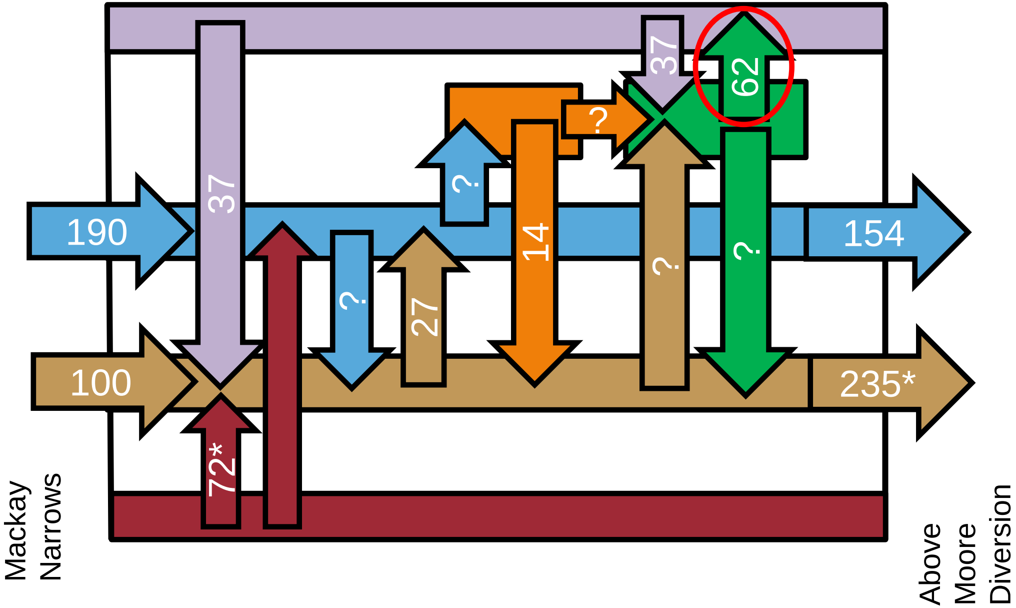
Derived from Crosthwaite (1970)

Middle Basin

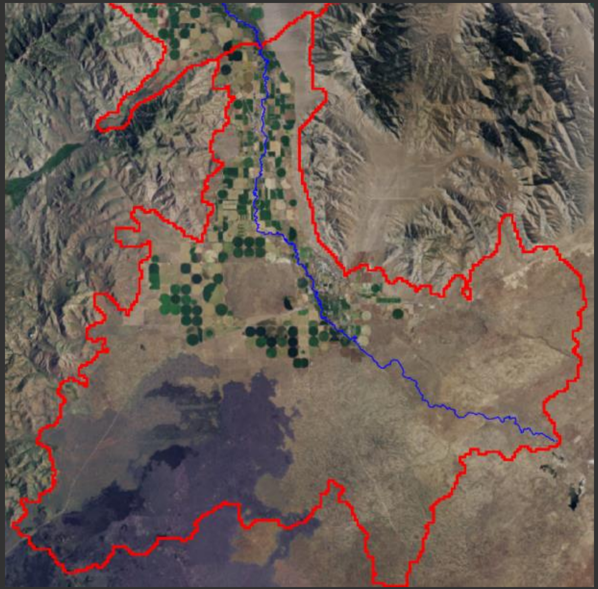


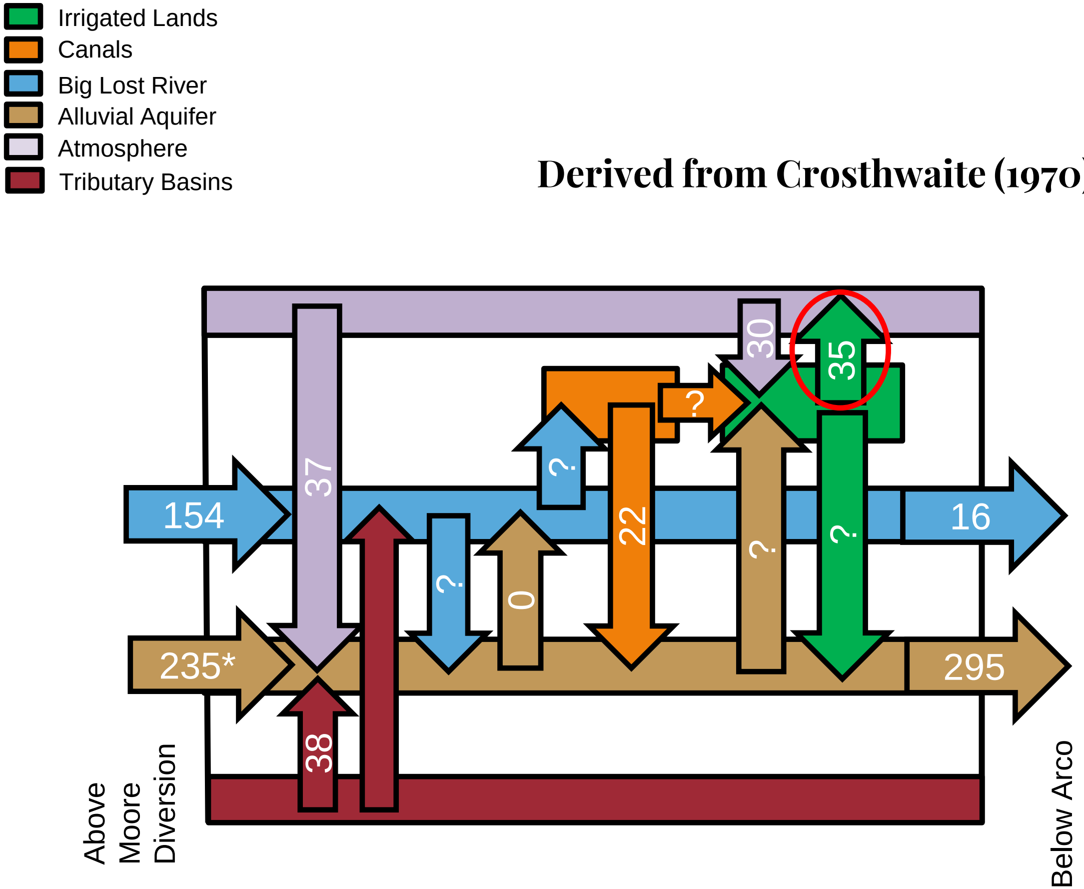
- Irrigated Lands
- Canals
- Big Lost River
- Alluvial Aquifer
- Atmosphere
- Tributary Basins

Derived from Crosthwaite (1970)



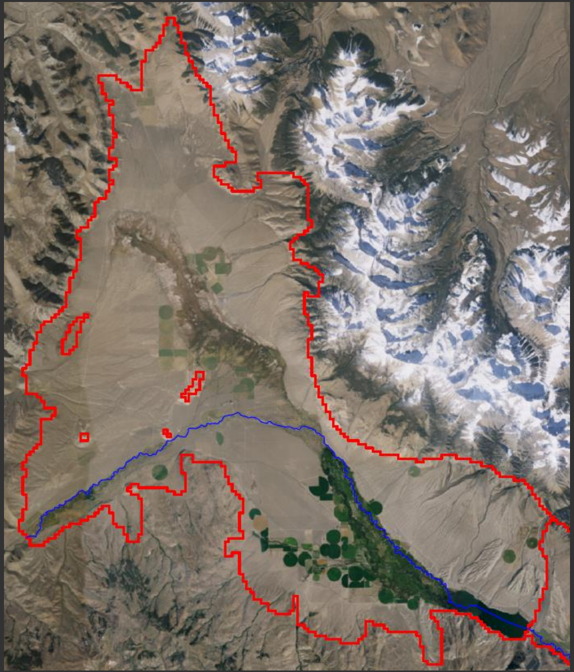
Lower Basin



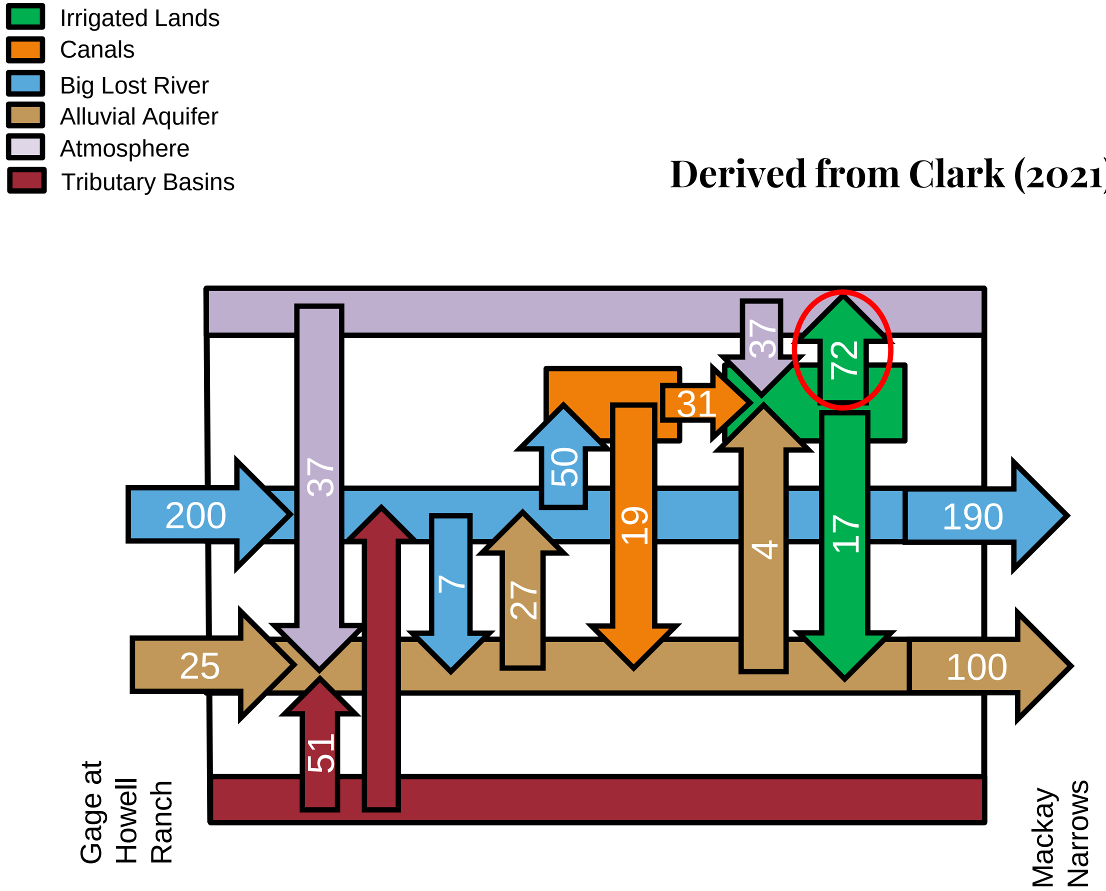


Irrigated Lands
Canals
Big Lost River
Alluvial Aquifer
Atmosphere
Tributary Basins
Derived from Crosthwaite (1970)
154
37
?
22
?
30
35
?
0
?
?
?
16
235*
295
38
Above Moore Diversion
Below Arco

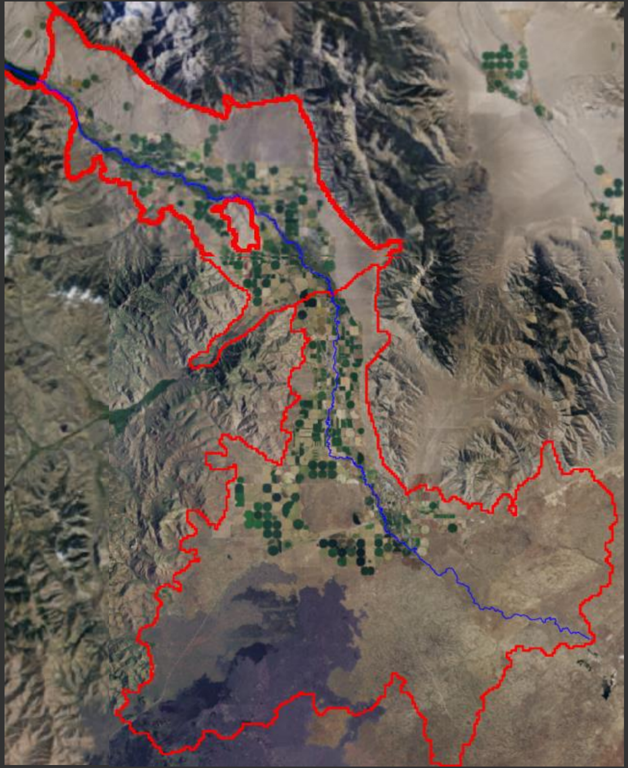
Upper Basin (above Mackay)

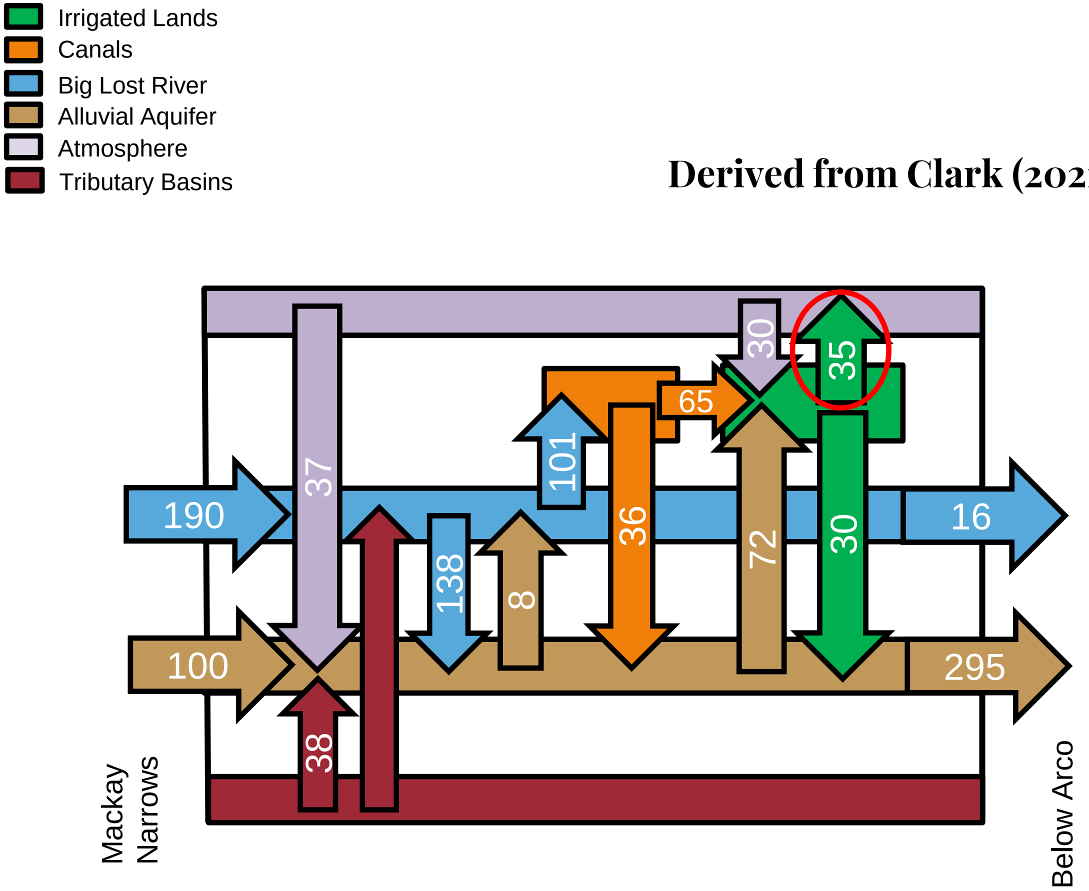


Derived from Clark (2021)



Lower Basin (below Mackay)



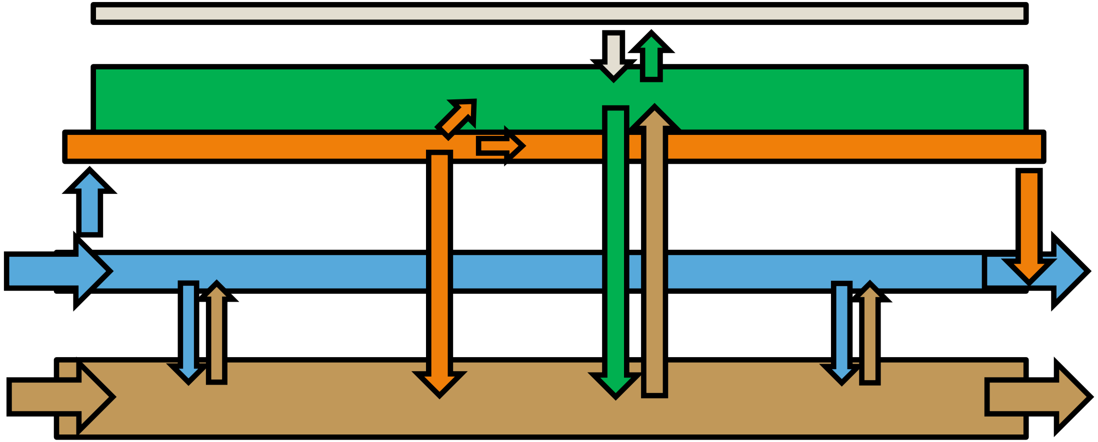


Derived from Clark (2021)

Service Area Irrigation Calculator

- **Model needs**
  - Monthly pumping at wells
  - Incidental recharge at model cell
  - Scenario sensitivity to ΔET
- **Approach:**
  - Use ET to get a crop-irrigation requirement
  - Compare to deliveries & losses
  - Calculate pumping needed
  - Apply incidental recharge

	Temporal Resolution	Source	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Diversion Records	daily	IDWR																							
Pumping Records	annual	IDWR																							
Irrigated Lands Shapefile	yearly	IDWR																							
Metric EVT	monthly (Apr-Oct)	IDWR																							
ssebop/NDVI	monthly (?)	USGS																							
Water Budget Report	yearly	IGS																							
Reitz Recharge Arrays	monthly	USGS																							
Prism Precipitation Arrays	monthly	PRISM																							
						tentative simulation period																			



Methods for deriving ET & crop irrigation demand

Satellite-derived Evapotranspiration

- METRIC is a ‘home-grown’ tool
- IDWR expertise & community buy-in
- Spatial detail

IDAHO Official Government Website Research

IDAHO DEPARTMENT OF WATER RESOURCES

Water Rights ▾ Wells ▾ Streams/Dams/Floods ▾ Forms ▾ Water Data ▾ Maps/Spatial Data ▾ Legal ▾ Board ▾ About IDWR ▾

Home / Maps and Spatial Data / Mapping Evapotranspiration

Explore Data

Explore Maps

Story Maps

Mapping Evapotranspiration ▾

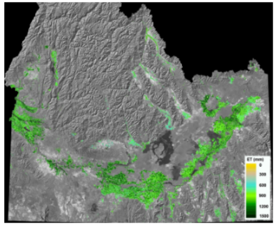
National Hydrography Dataset and Watershed Boundary Dataset ▾

IDTM ▾

Mapping Evapotranspiration

IDWR is responsible for the administration and management of Idaho waters which include the measurement and the accounting of consumptive and non-consumptive uses of water. Evapotranspiration (ET) from Idaho's 3.4 million acres of irrigated agriculture accounts for more than 95% of the consumptive use in the state.

IDWR and the University of Idaho worked from 2000 to 2005 under a NASA grant to develop procedures to map ET from Landsat data and to apply the ET data to water resource problems. The Mapping EvapoTranspiration using high Resolution and Internalized Calibration (METRIC) energy balance model was developed to compute and map ET using Landsat images. Landsat is used because it is the only operational satellite that collects thermal data and has a pixel size small enough to map individual agricultural fields. Landsat thermal data are a critical part of the model and are needed to compute the surface temperature required in ET computations. IDWR uses Landsat-based evapotranspiration data in hydrology, water resources planning, and water administration.



Seasonal ET for cropland 2000

Evapotranspiration Resources

- METRIC in Other States
- Kimberly R&E Center
- Evapotranspiration Data
- Evapotranspiration Viewer

How to use the Evapotranspiration Viewer

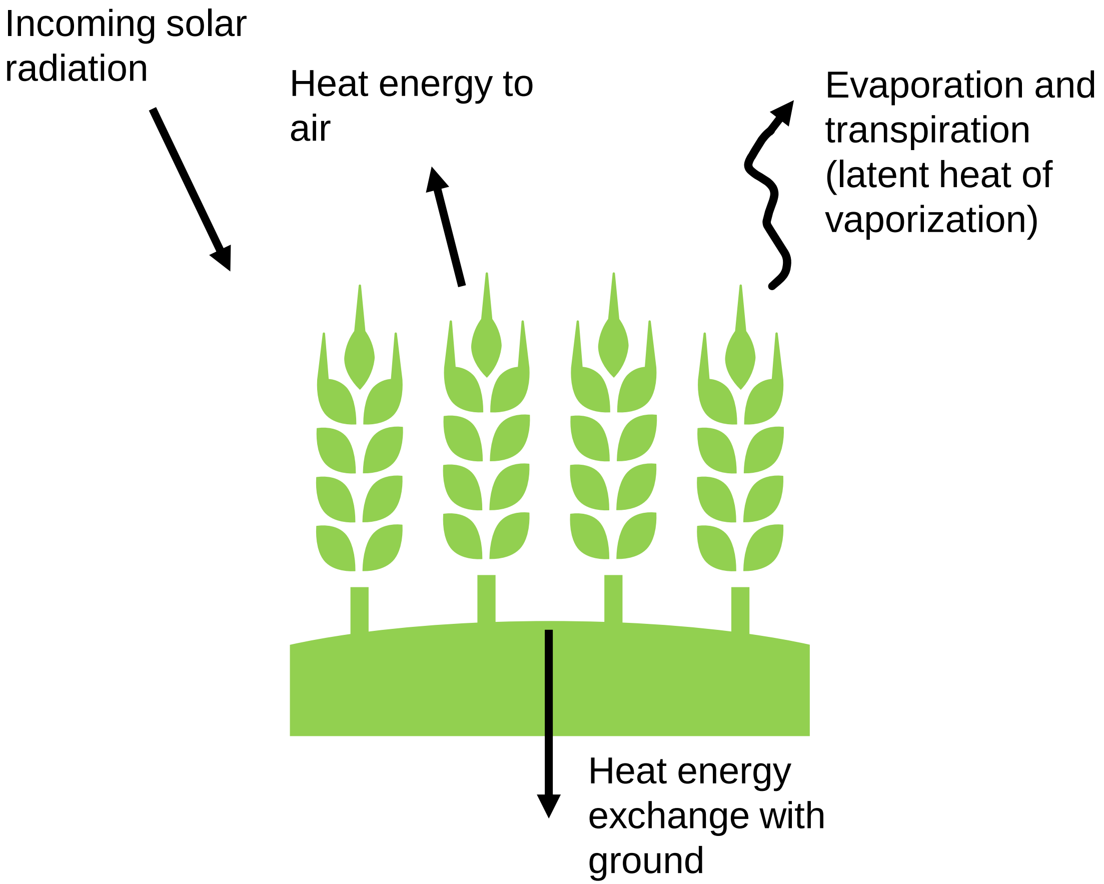
Examples of Applying METRIC at IDWR

- Hydrological Modeling
- Water Delivery Call
- Curtailment Order
- Water Planning
- Endangered Species
- Water Rights Buy-Back

USGS science for a changing world

Satellite-derived Evapotranspiration

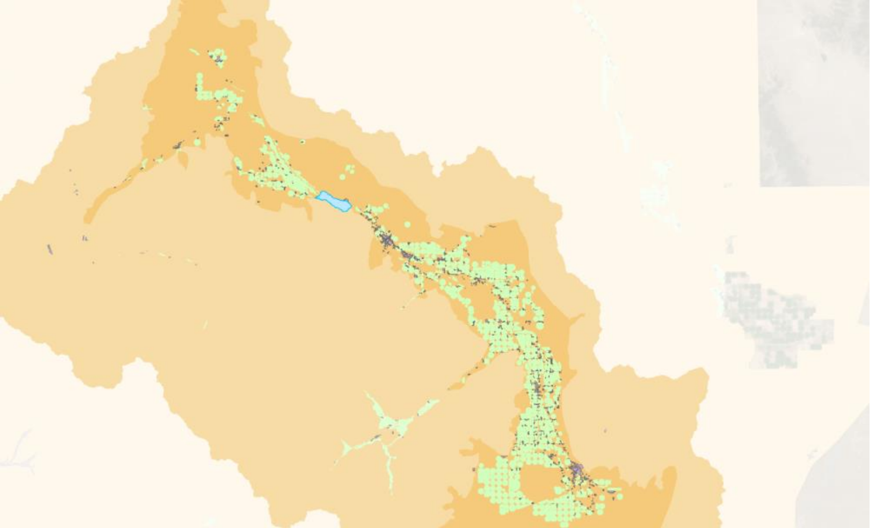
- Uses Landsat thermal sensor
- Land-surface energy model
- Evapotranspiration is calculated as residual of energy budget
- Not going to pretend to understand any more deeply…

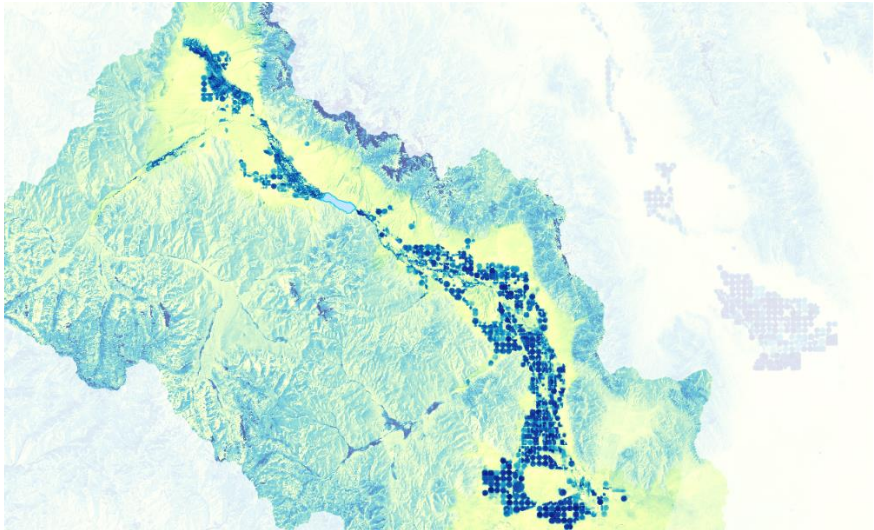


USGS
science for a changing world

Satellite-derived ET: Process

- Monthly ET raster
- Match (< annual) irrigated lands map to ET raster months
- Clip ET for irrigated / semi-irrigated lands
- *Buffer???*
- Get total ET requirement for field / service area / basin
- Compare to reported water deliveries





USGS
science for a changing world

Table 10.1. Assignment of irrigated lands for the water-budget analysis of the Big Lost River Basin, south-central Idaho, 2000–19.

[ET_{Idaho}: Searchable database (Allen and Robison, 2017; University of Idaho, 2018) providing evapotranspiration and irrigation data by land-cover type for weather stations across Idaho. The use of CDL or NLCD datasets corresponds with ET_{Idaho}-derived ET as opposed to METRIC-derived ET.: **Abbreviations:** CDL, cropland data layer (CropScape); METRIC, Mapping EvapoTranspiration at high Resolution and Internalized Calibration; NLCD, National Land Cover Database; NDVI, Normalized Difference Vegetation Index

Year	Irrigated lands dataset	Irrigation season	Winter land cover	ET_{Idaho}
2000	2000	2000 METRIC	2001 NLCD	2000
2001	2002	2001 NLCD	2001 NLCD	2001
2002	2002	2002 METRIC	2001 NLCD	2002
2003	2002	2004 NLCD	2004 NLCD	2003
2004	2004	2004 NLCD	2004 NLCD	2004
2005	2006	2006 NLCD[1,2]	2006 NLCD	2005
2006	2006	2006 METRIC	2006 NLCD	2006
2007	2008	2007 CDL	2007 CDL	2007
2008	2008	2008 METRIC	2008 CDL	2008
2009	2009	2009 METRIC	2009 CDL	2009
2010	2010	2010 METRIC	2010 CDL	2010
2011	2011	2011 METRIC	2011 CDL	2011
2012	2012	2012 CDL	2012 CDL	2012
2013	2013	2013 METRIC	2013 CDL	2013
2014	2014	2014 NDVI[3]	2014 CDL	2014
2015	2015	2015 METRIC	2015 CDL	2015
2016	2016	2016 METRIC	2016 CDL	2016
2017	2017	2017 METRIC	2017 CDL	2016[7]
2018	2017[4]	2018 METRIC	2018 CDL	2016[7]
2019	2017[5]	2019 CDL[6]	2019 CDL	2016[7]

[1]CDL coverage for 2005 covers only the southern part of the basin. CDL datasets were obtained from National Agricultural Statistics Service (2020a, 2020b).

[2]NLCD datasets were accessed from Multi-Resolution Land Characteristics Consortium (2019).

3NDVI datasets were accessed from U.S. Geological Survey (2017).

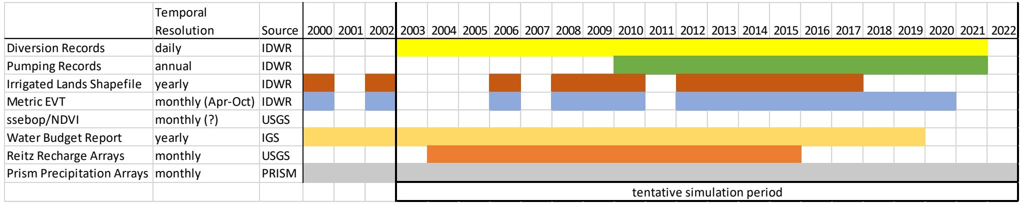
[4]2018 was drier than 2017 but Mackay Reservoir storage was comparable to that of 2017.

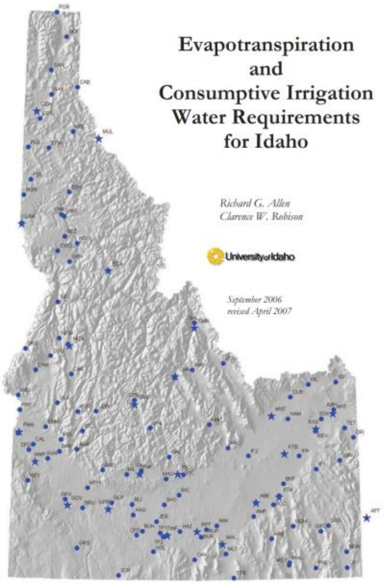
[5]2019 precipitation, snow accumulation, and reservoir storage are similar to that of 2012.

[6]METRIC datasets for 2019 were not available in time for inclusion in the water budget. METRIC datasets were accessed from the IDWR (2021b).

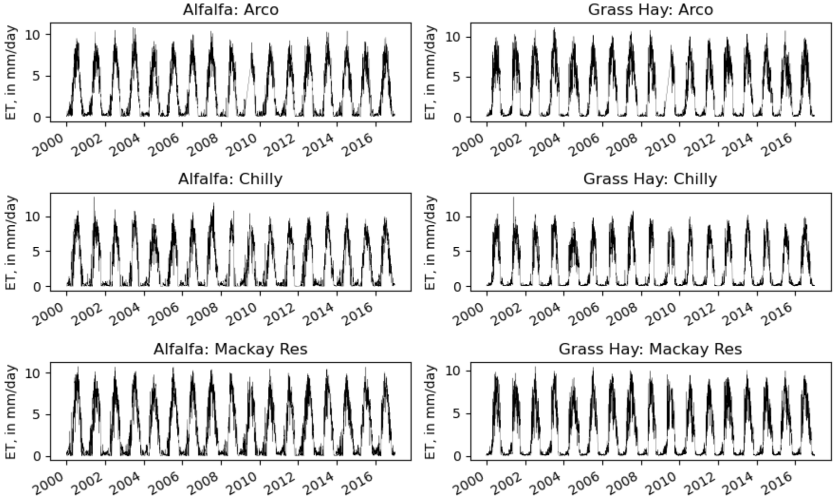
[7]ET_{Idaho} values were not available after 2016.

Clark, 2021



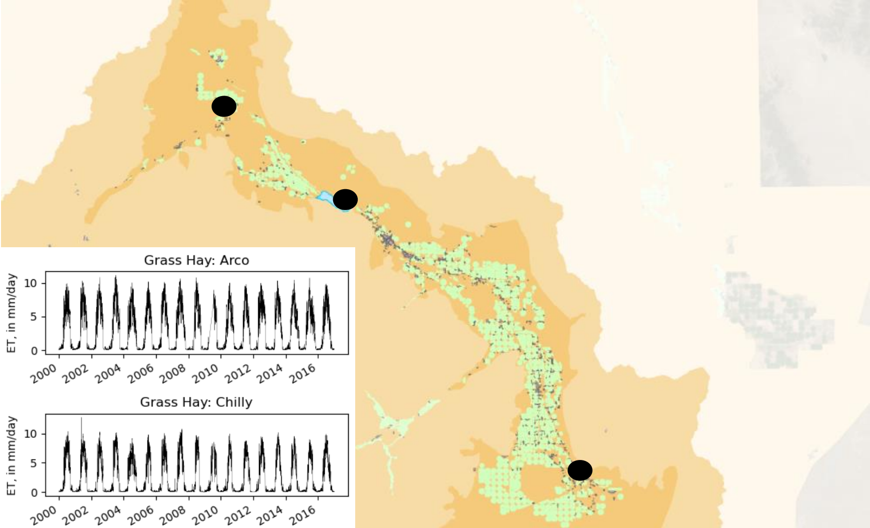


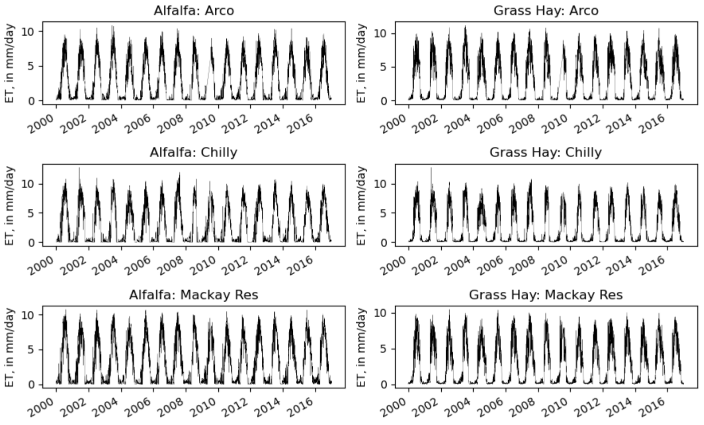
University of Idaho
Kimberly Research and Extension Center

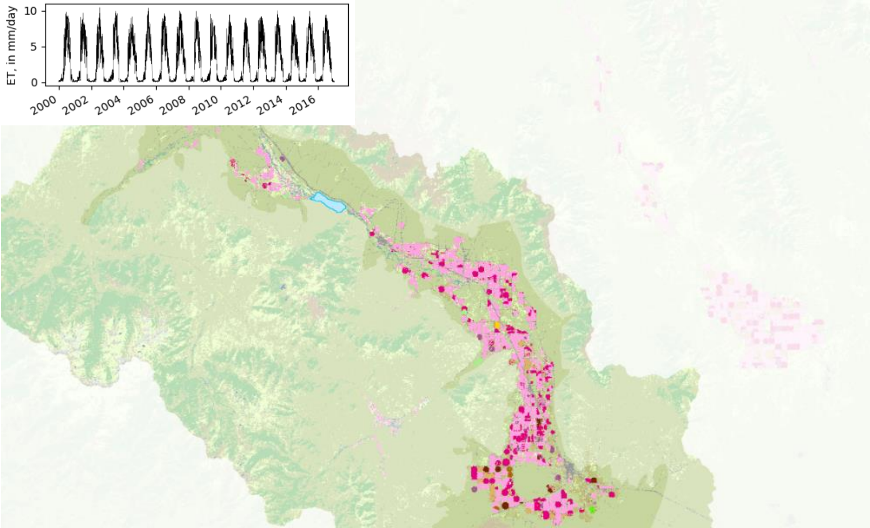


Alternative ET: Process

- Modelled pET from meteorological variables
  - (wave hands)
- Get daily crop ET from nearby stations (Arco, Mackay, Chilly)
- Get crop type and crop type area from NLCD and CDL
- Assign each irrigated acre a crop type and station (or mix of stations)
- Apply daily ET to areas of crops
- Get total ET requirement for field / service area / basin







USGS
science for a changing world

Table 10.1. Assignment of irrigated lands for the water-budget analysis of the Big Lost River Basin, south-central Idaho, 2000–19.

[ET_{Idaho}: Searchable database (Allen and Robison, 2017; University of Idaho, 2018) providing evapotranspiration and irrigation data by land-cover type for weather stations across Idaho. The use of CDL or NLCD datasets corresponds with ET_{Idaho}-derived ET as opposed to METRIC-derived ET.: **Abbreviations:** CDL, cropland data layer (CropScape); METRIC, Mapping EvapoTranspiration at high Resolution and Internalized Calibration; NLCD, National Land Cover Database; NDVI, Normalized Difference Vegetation Index

Year	Irrigated lands dataset	Irrigation season	Winter land cover	ET_{Idaho}
2000	2000	2000 METRIC	2001 NLCD	2000
2001	2002	2001 NLCD	2001 NLCD	2001
2002	2002	2002 METRIC	2001 NLCD	2002
2003	2002	2004 NLCD	2004 NLCD	2003
2004	2004	2004 NLCD	2004 NLCD	2004
2005	2006	2006 NLCD[1,2]	2006 NLCD	2005
2006	2006	2006 METRIC	2006 NLCD	2006
2007	2008	2007 CDL	2007 CDL	2007
2008	2008	2008 METRIC	2008 CDL	2008
2009	2009	2009 METRIC	2009 CDL	2009
2010	2010	2010 METRIC	2010 CDL	2010
2011	2011	2011 METRIC	2011 CDL	2011
2012	2012	2012 CDL	2012 CDL	2012
2013	2013	2013 METRIC	2013 CDL	2013
2014	2014	2014 NDVI[3]	2014 CDL	2014
2015	2015	2015 METRIC	2015 CDL	2015
2016	2016	2016 METRIC	2016 CDL	2016
2017	2017	2017 METRIC	2017 CDL	2016[7]
2018	2017[4]	2018 METRIC	2018 CDL	2016[7]
2019	2017[5]	2019 CDL[6]	2019 CDL	2016[7]

[1]CDL coverage for 2005 covers only the southern part of the basin. CDL datasets were obtained from National Agricultural Statistics Service (2020a, 2020b).

[2]NLCD datasets were accessed from Multi-Resolution Land Characteristics Consortium (2019).

3NDVI datasets were accessed from U.S. Geological Survey (2017).

[4]2018 was drier than 2017 but Mackay Reservoir storage was comparable to that of 2017.

[5]2019 precipitation, snow accumulation, and reservoir storage are similar to that of 2012.

[6]METRIC datasets for 2019 were not available in time for inclusion in the water budget. METRIC datasets were accessed from the IDWR (2021b).

[7]ET_{Idaho} values were not available after 2016.

Clark, 2021

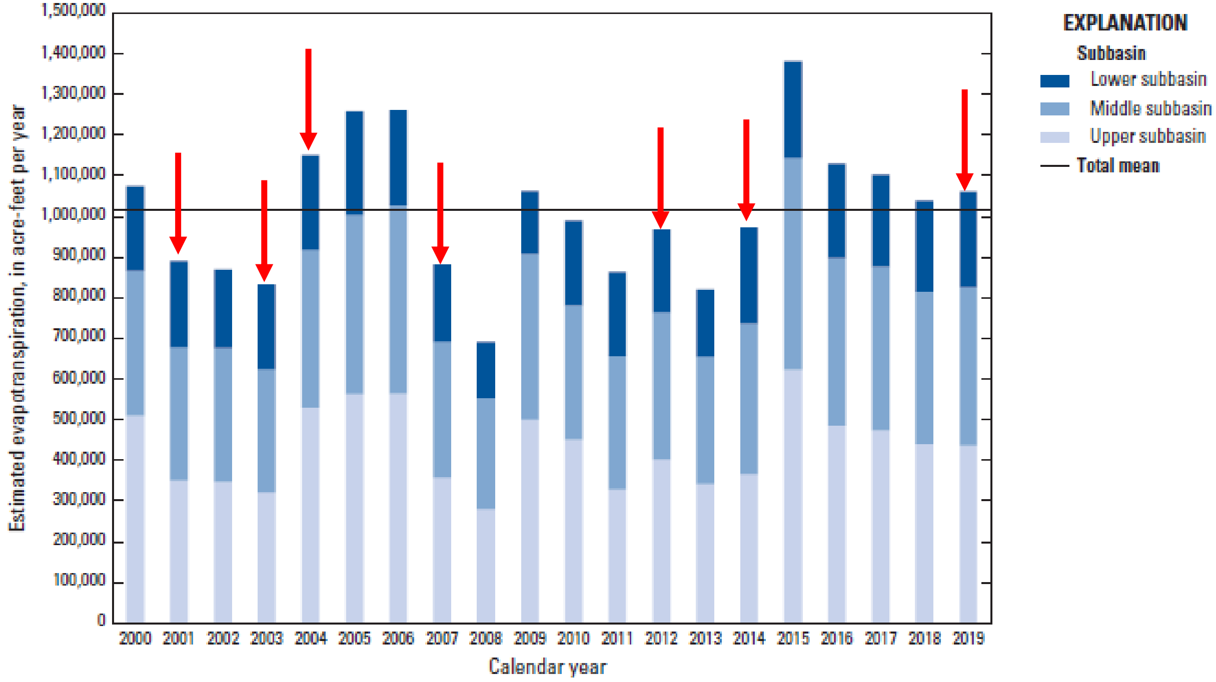


Figure 10.1. Total annual evapotranspiration, Big Lost River Basin, south-central Idaho, 2000–19. See table 10.1 for data sources used in calculations and tables 10.2 and 10.3 for evapotranspiration volumes.

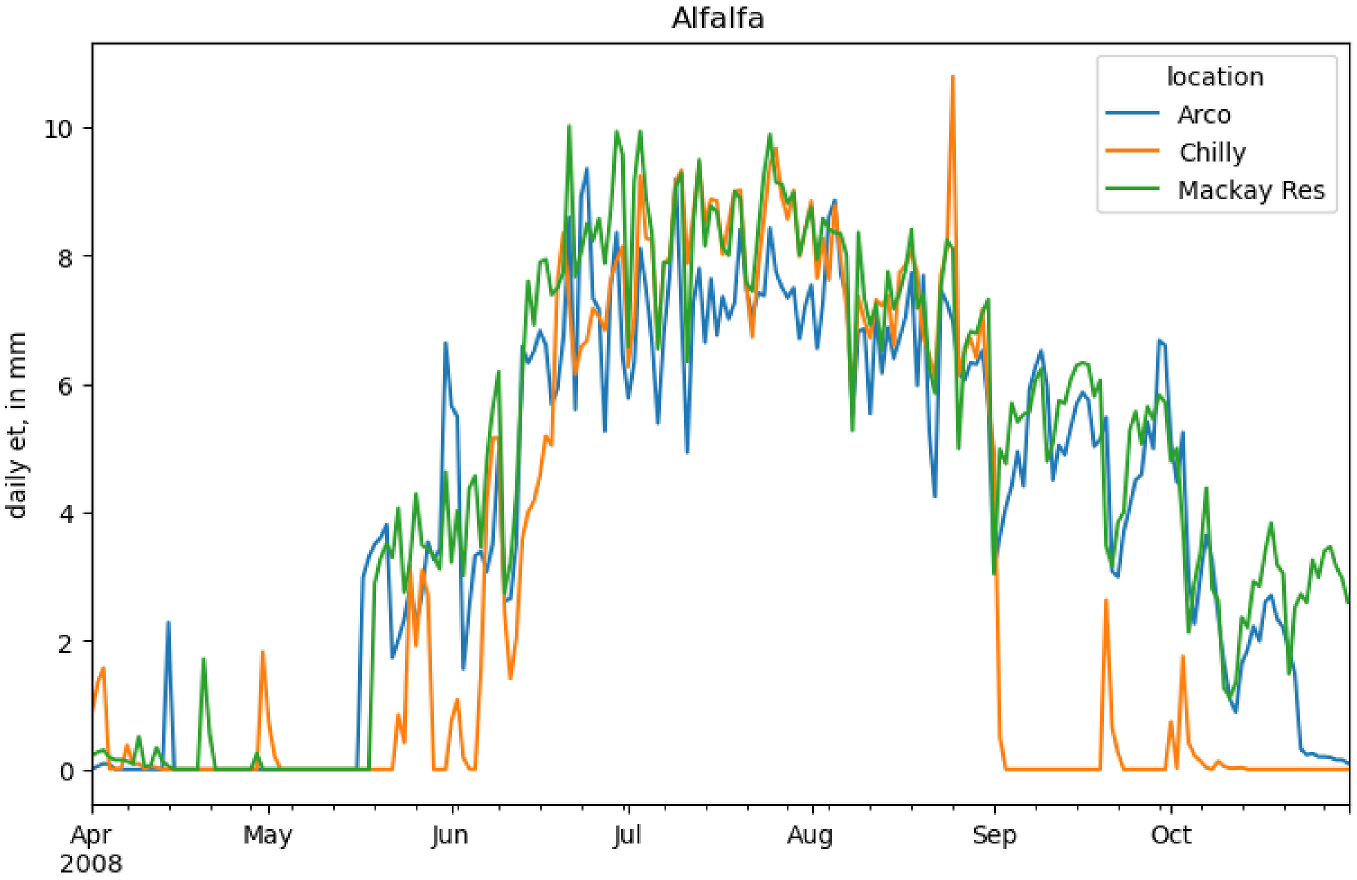
USGS
science for a changing world

Example Comparison

Example Comparison: Crop Type 2008

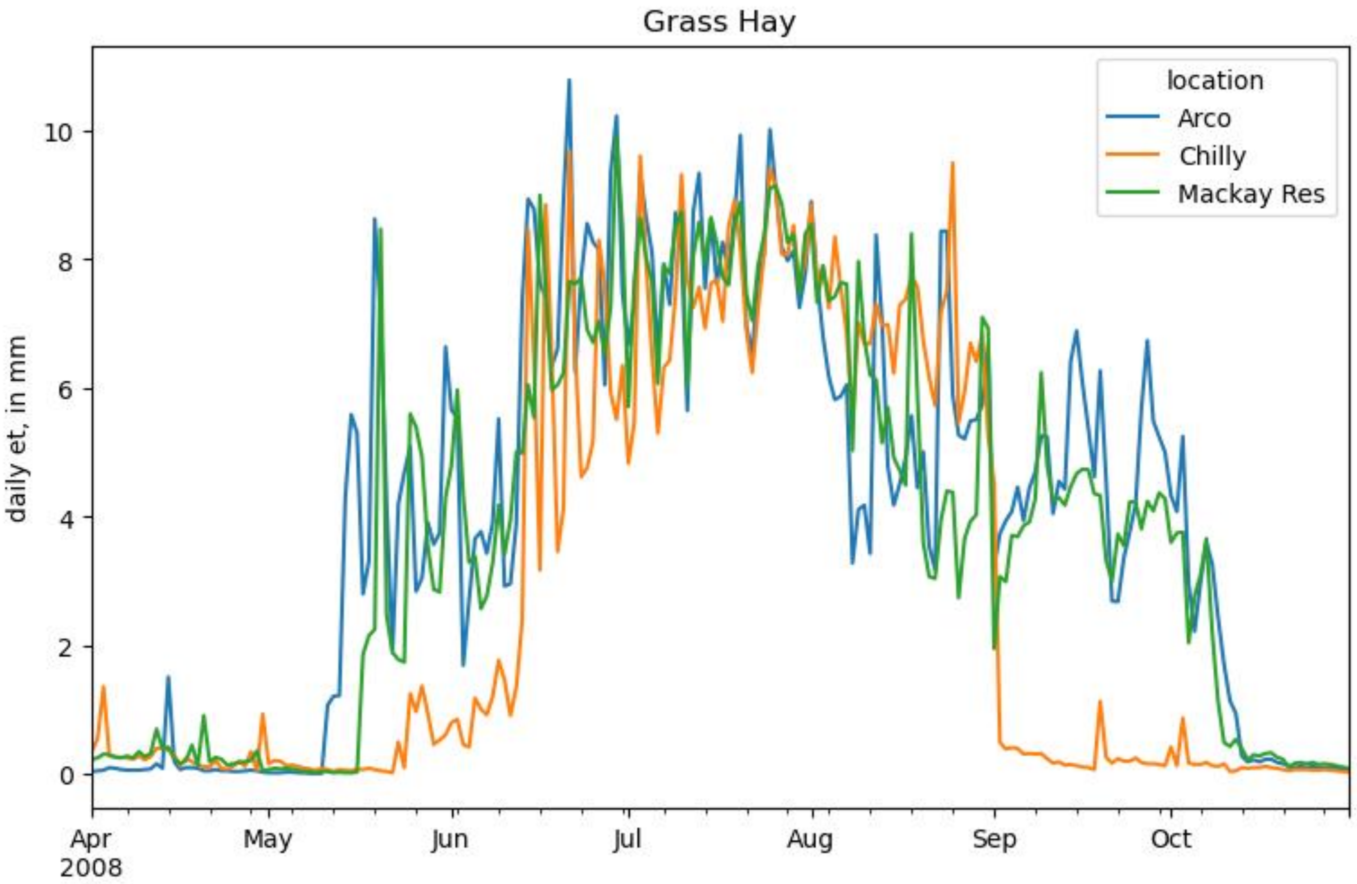
USGS
science for a changing world

Example Comparison: ET Idaho 2008



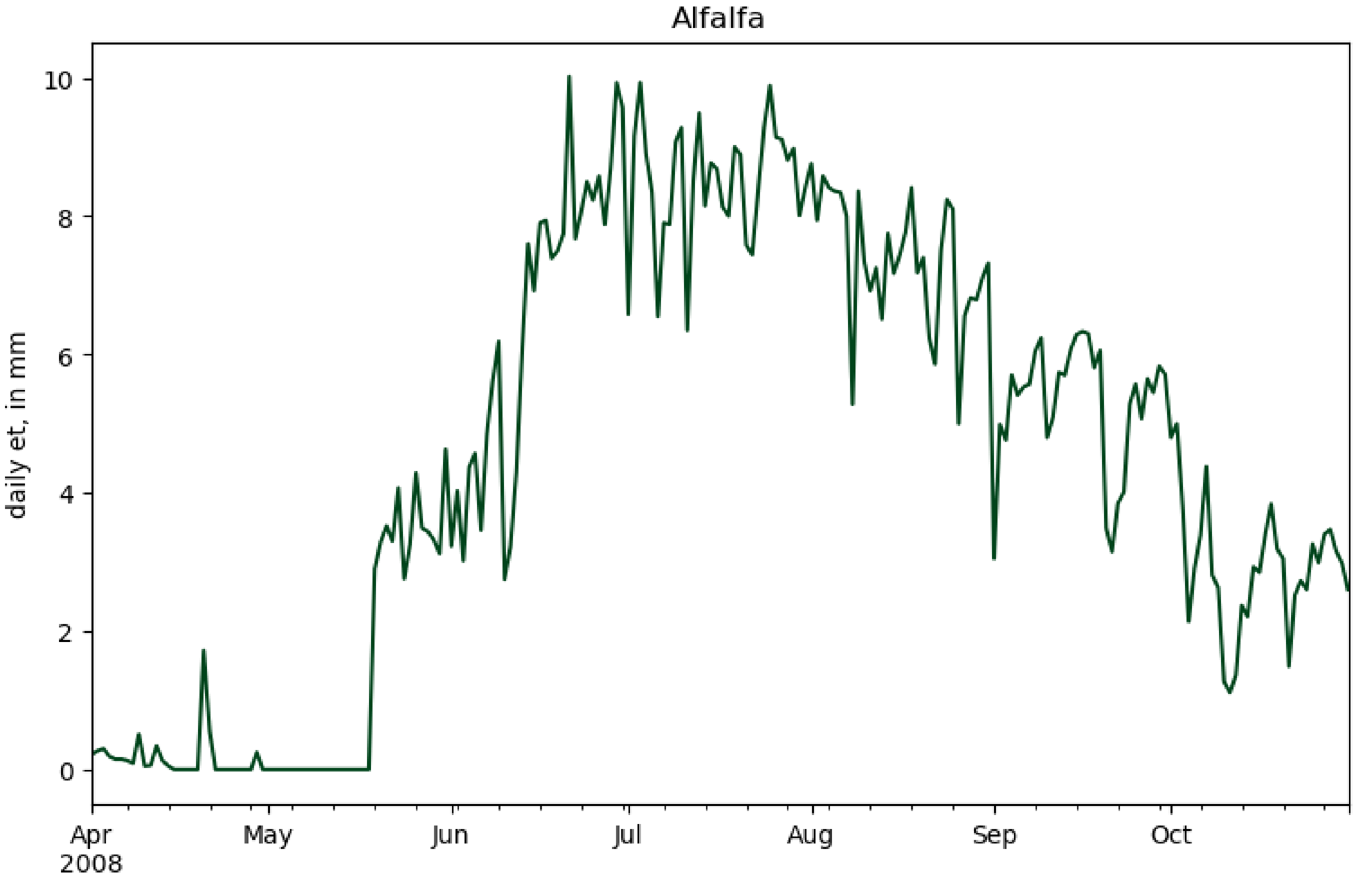
USGS
science for a changing world

Example Comparison: ET Idaho 2008

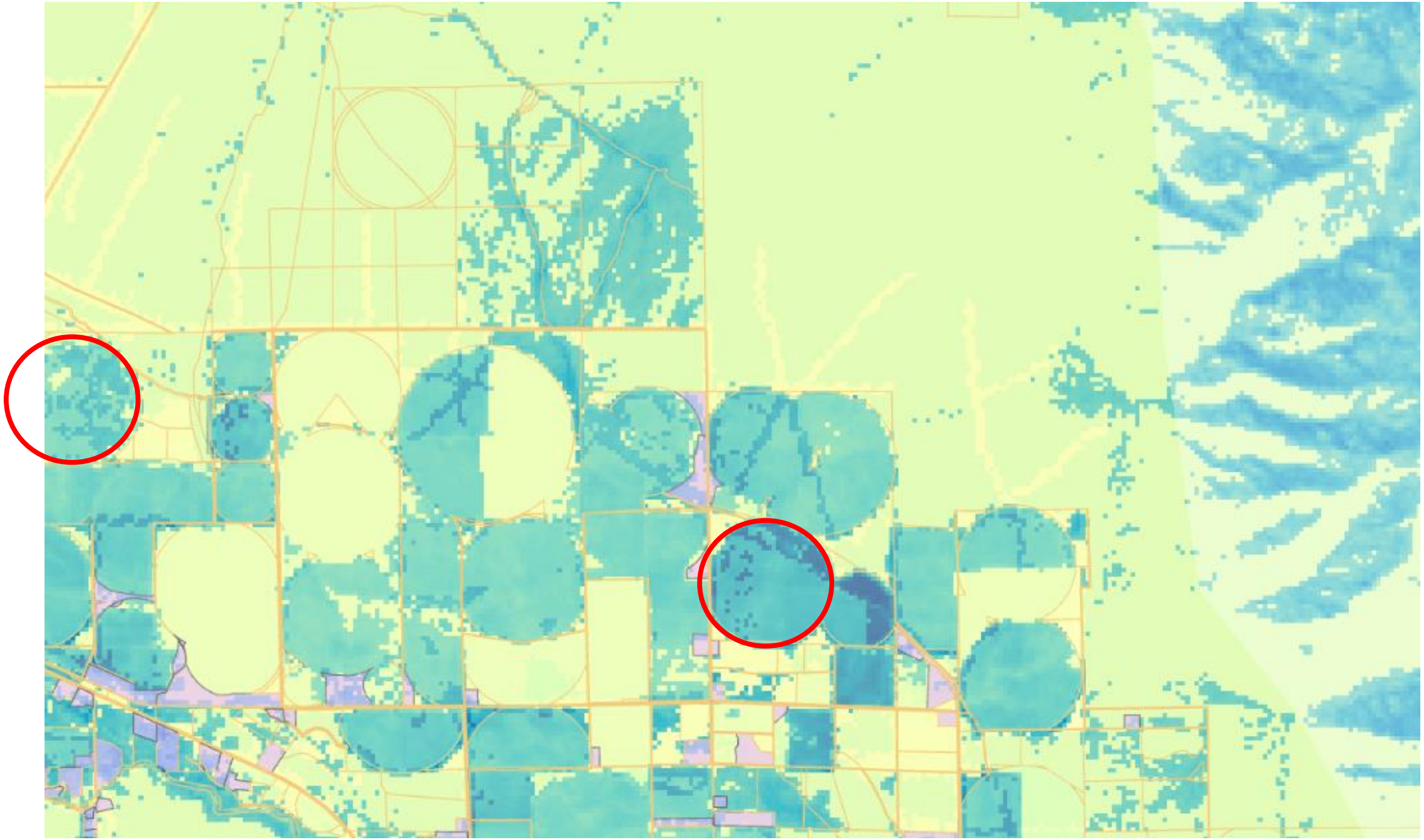


USGS
science for a changing world

Example Comparison: ET Idaho 2008



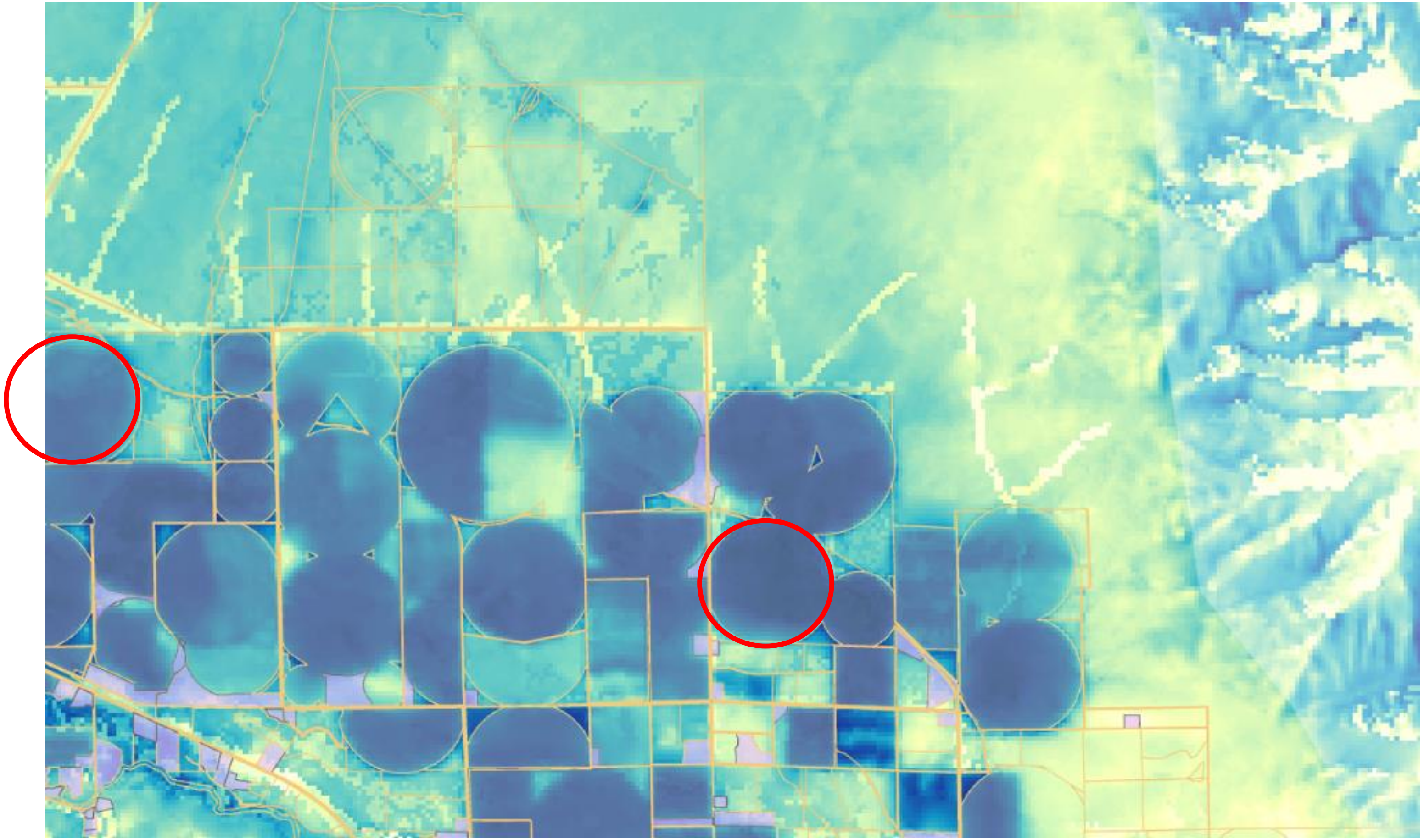
Example Comparison: METRIC April 2008



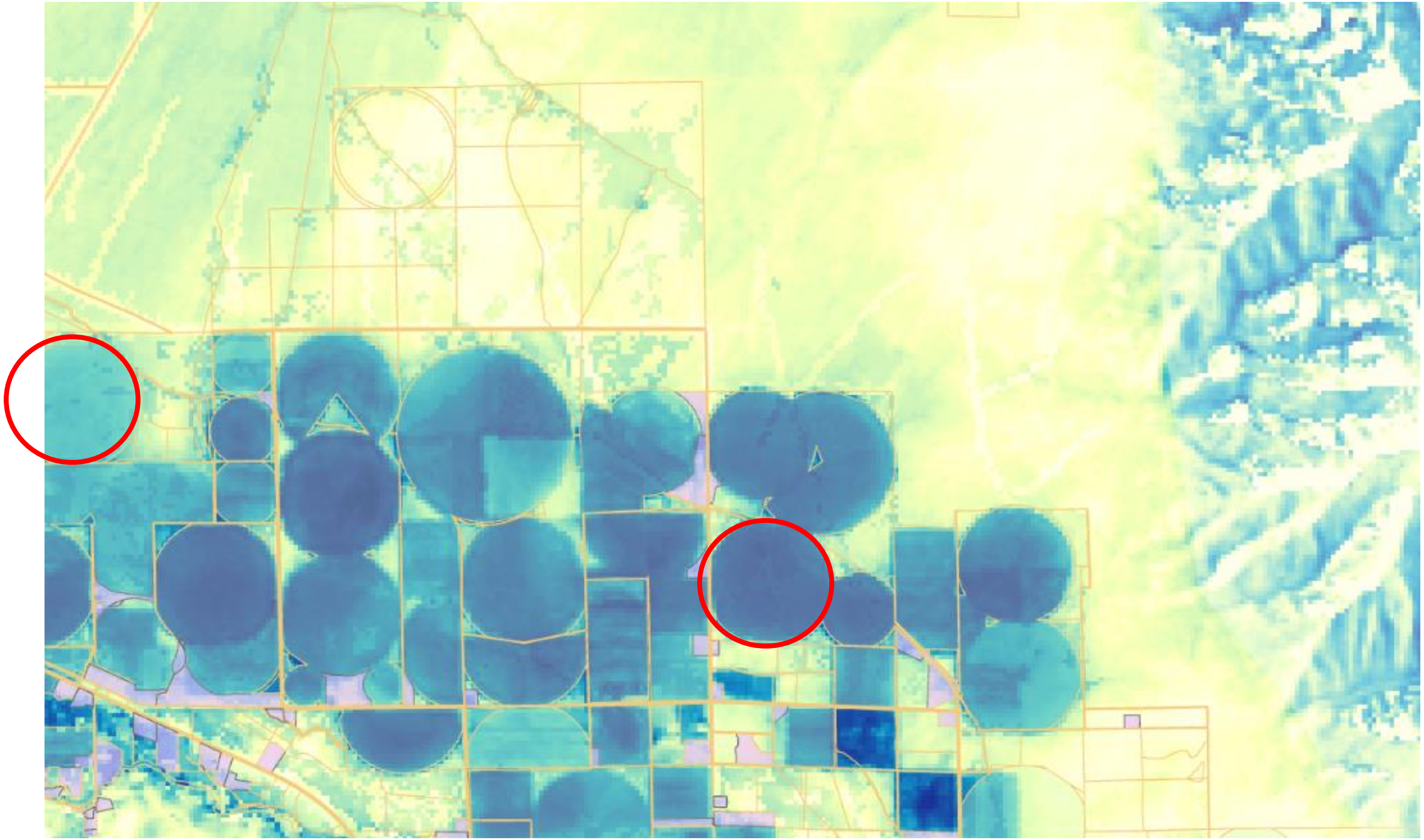
Example Comparison: METRIC May 2008

USGS
science for a changing world

Example Comparison: METRIC June 2008

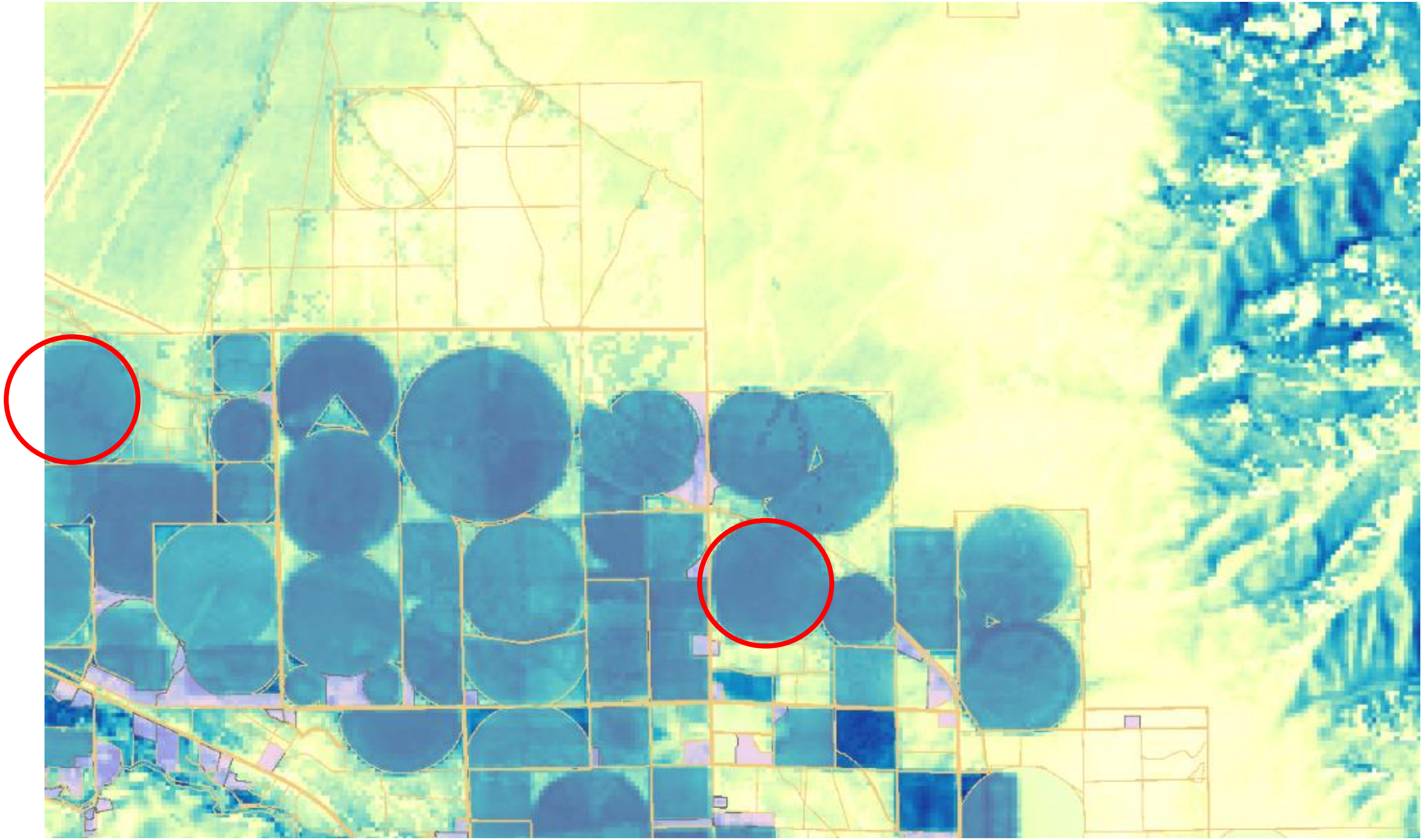


Example Comparison: METRIC July 2008



science for a changing world

Example Comparison: METRIC August 2008

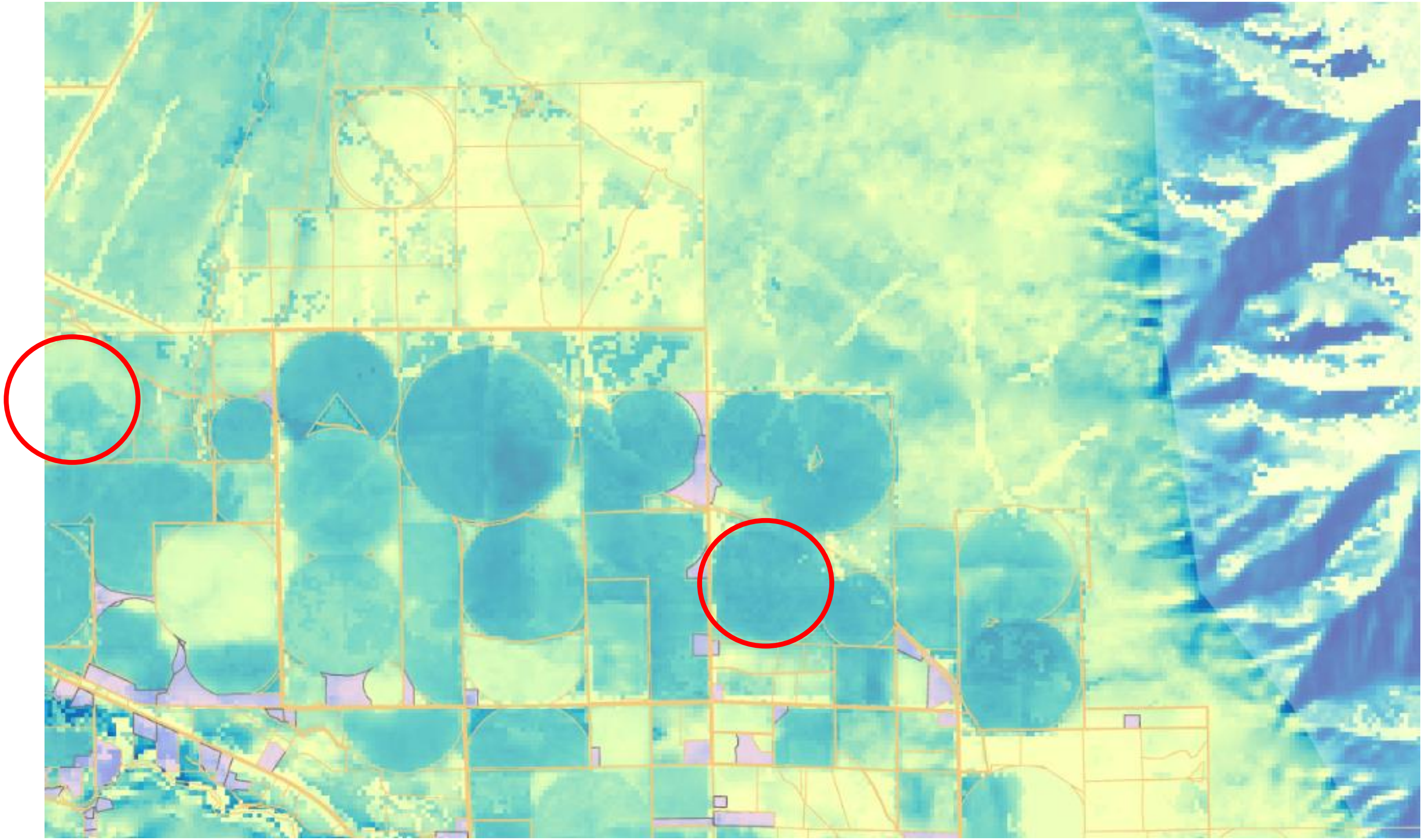


USGS
science for a changing world

Example Comparison: METRIC September 2008

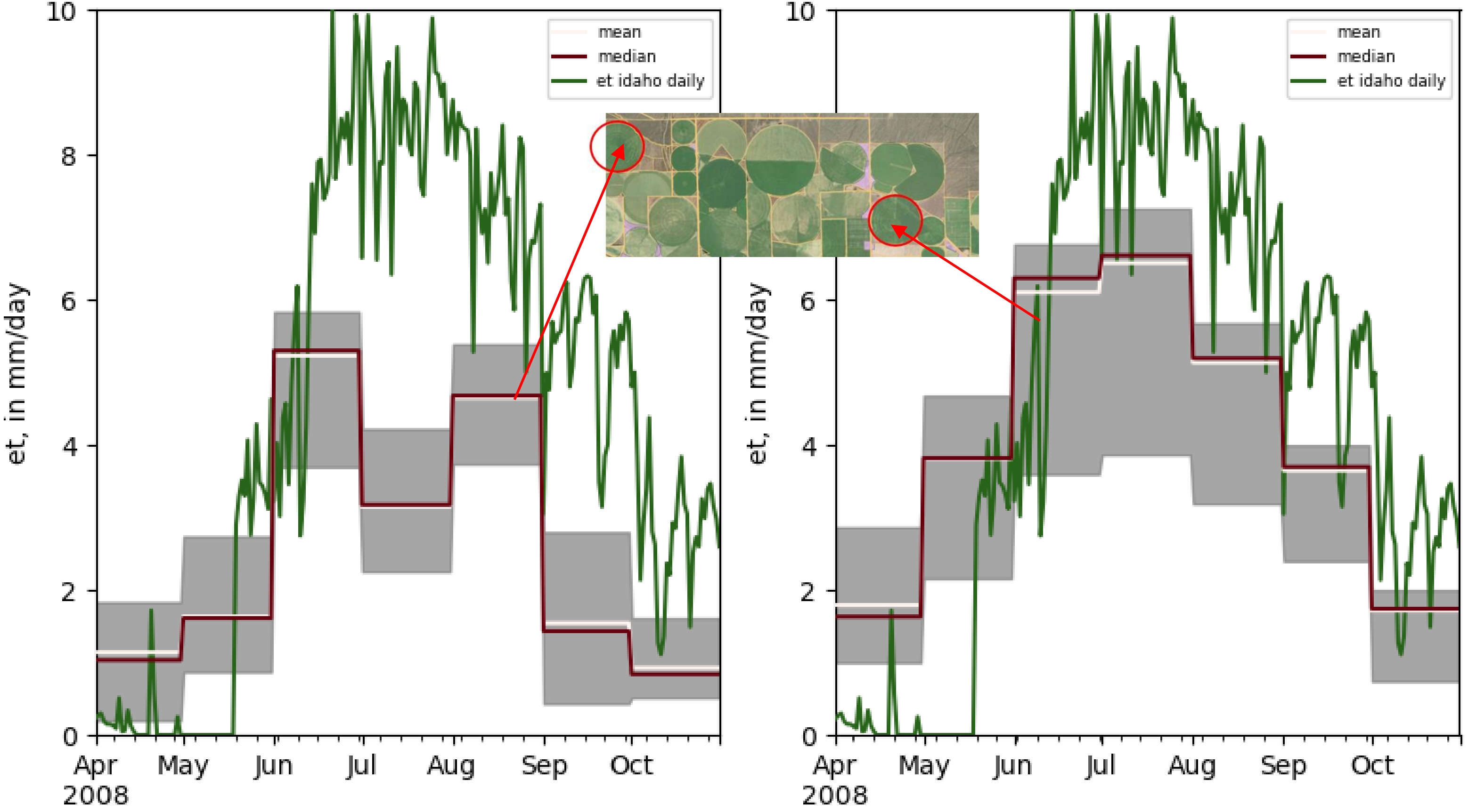
USGS
science for a changing world

Example Comparison: METRIC October 2008

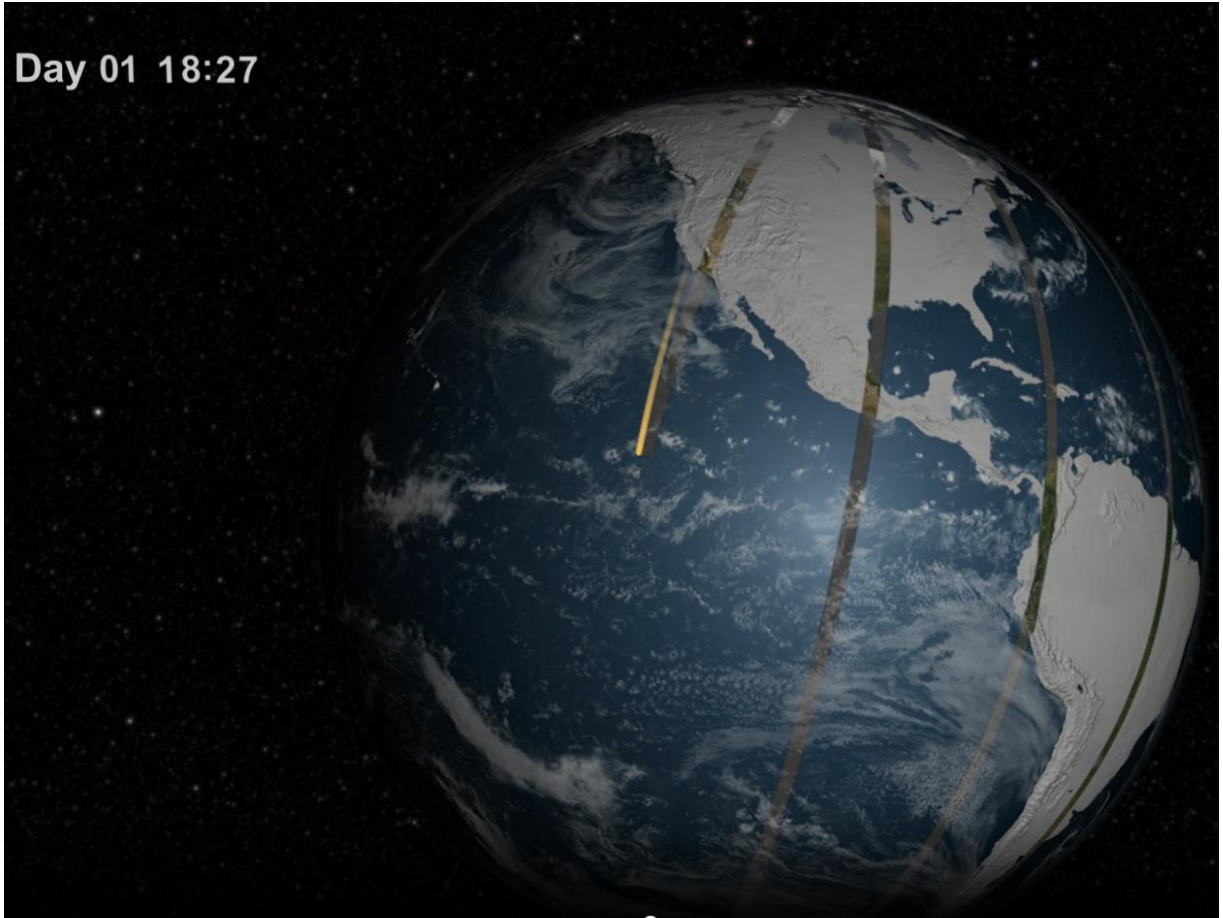


USGS
science for a changing world

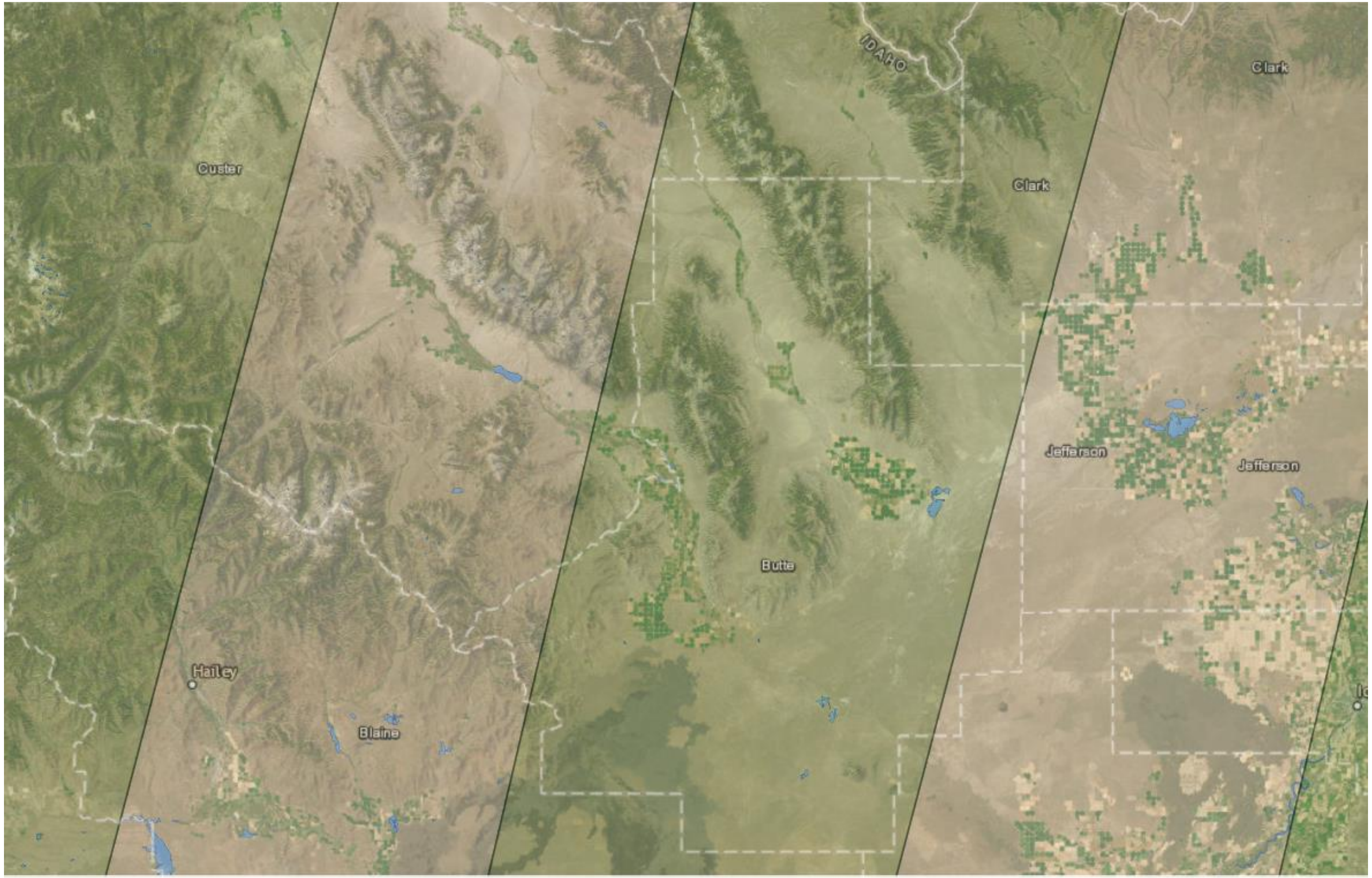
Example Comparison



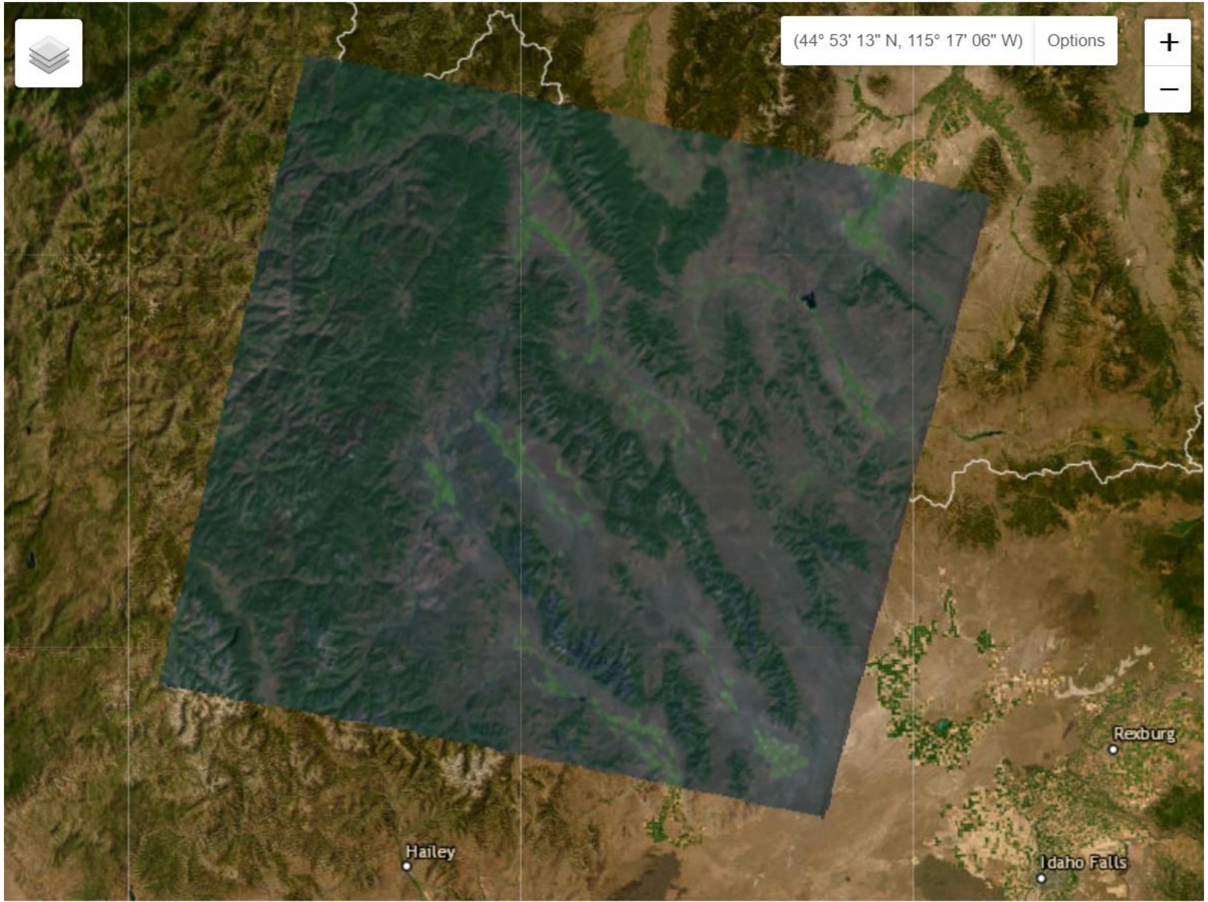
Quick Landsat / Satellite Refresher



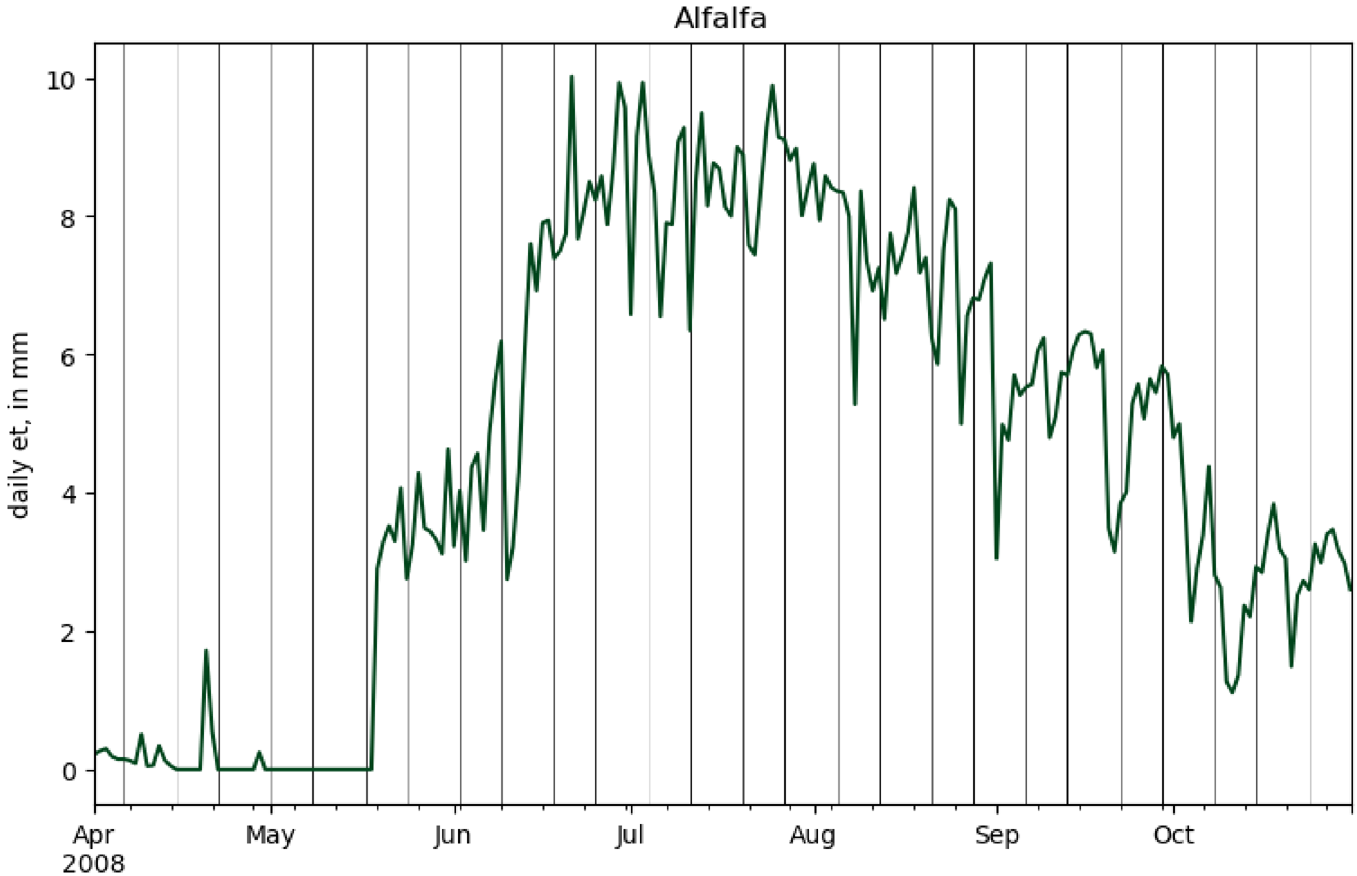
Quick Landsat / Satellite Refresher



Quick Landsat / Satellite Refresher



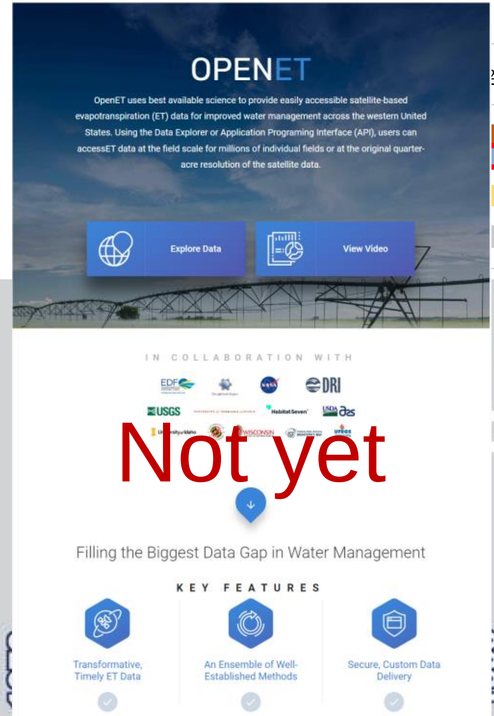
Quick Landsat / Satellite Refresher

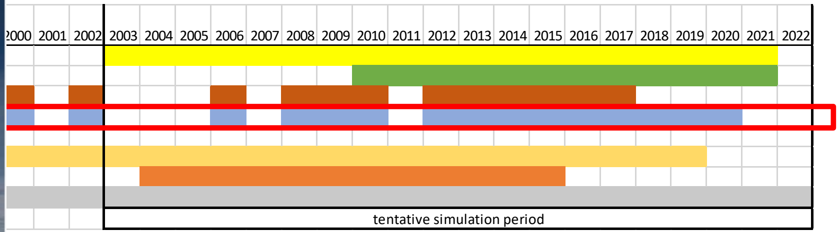


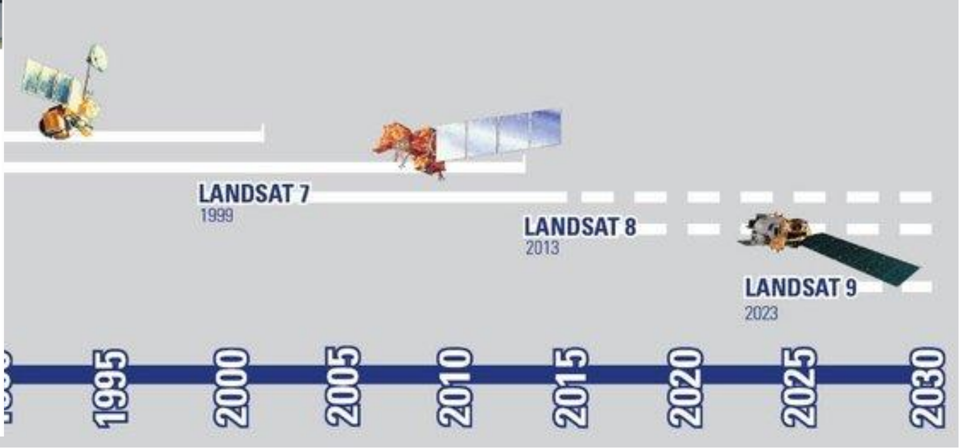
Using ‘provisional’ USGS Landsat Actual ET product

USGS science for a changing world

Other Landsat-derived products exist

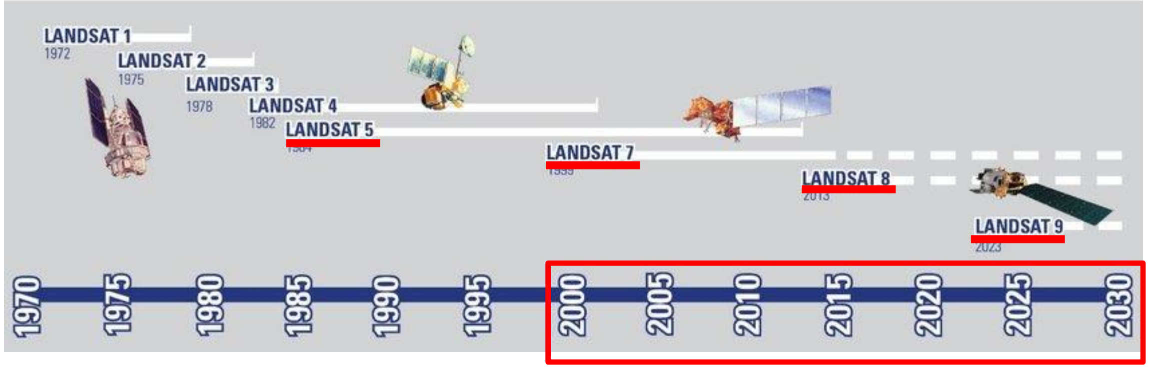






Data Availability

- Similar approach to METRIC
  - Similar energy balance model: SSEBop (simplified surface energy balance – operational)
  - Landsat-based
- Automated
  - Available for (almost) every Landsat image
  - less QA/QC
- Hasn't been used yet in IDWR model



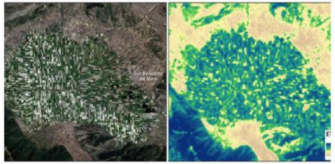
Landsat Provisional Actual Evapotranspiration

By Landsat Missions

- HOME
- LANDSAT MISSIONS
- SCIENCE
- PRODUCT INFORMATION
- DATA
- GLOSSARY AND ACRONYMS
- MULTIMEDIA
- PUBLICATIONS
- WEB TOOLS
- DOCUMENTS
- NEWS
- CONNECT
- PARTNERS
- ABOUT

The Landsat Provisional Actual Evapotranspiration (ETa) Science Product is generated by calculating the latent heat flux based on surface energy balance principles using a robust model and can be fundamental in the understanding of the spatiotemporal dynamics of water use over land surfaces.

Collection 2



Products created from Landsat 4-5 TM, Landsat 7, Landsat 8, and Landsat 9 scenes that successfully process to a Collection 2 Surface Temperature product.
Global coverage

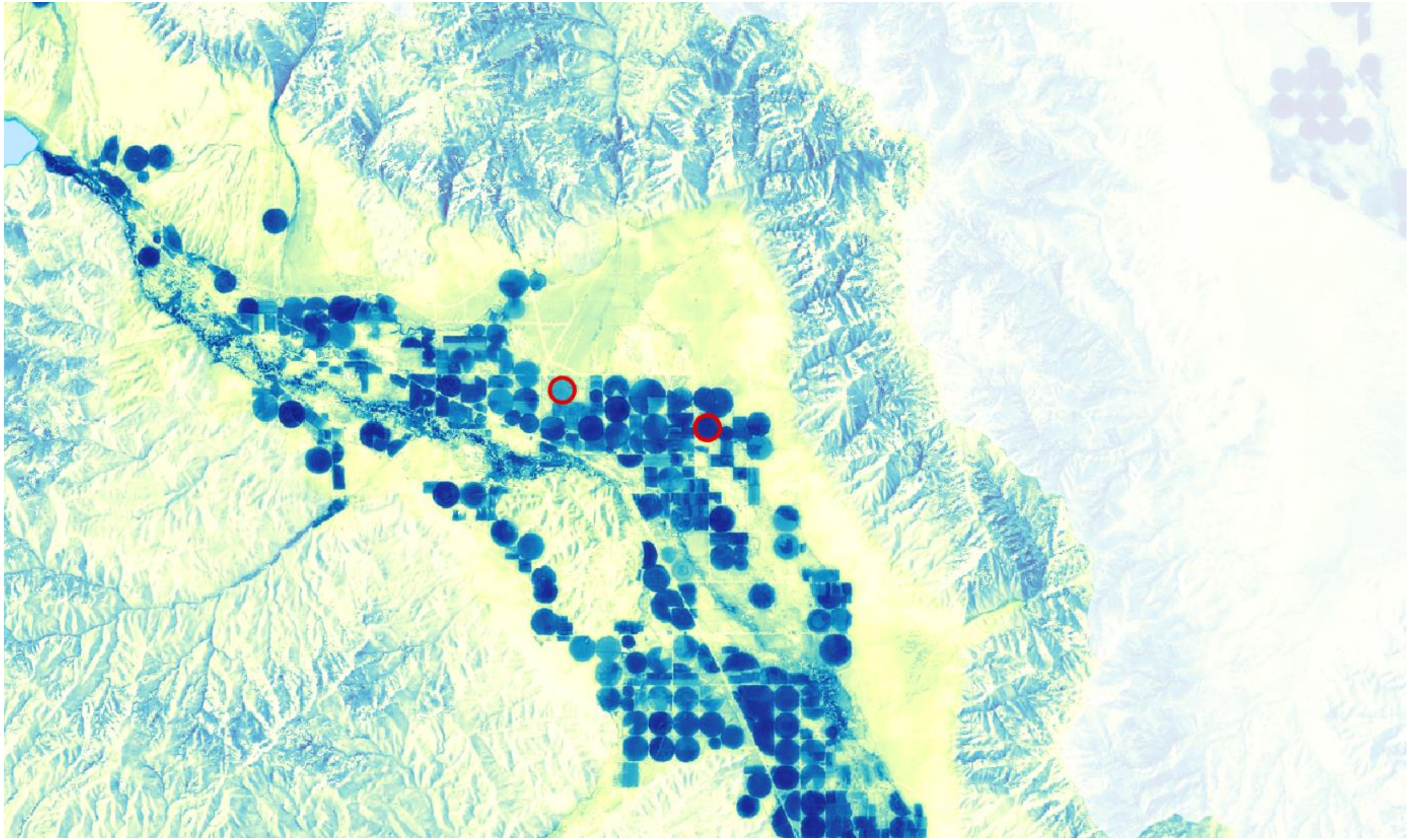
Access Collection 2 Information

Previous Landsat Collections

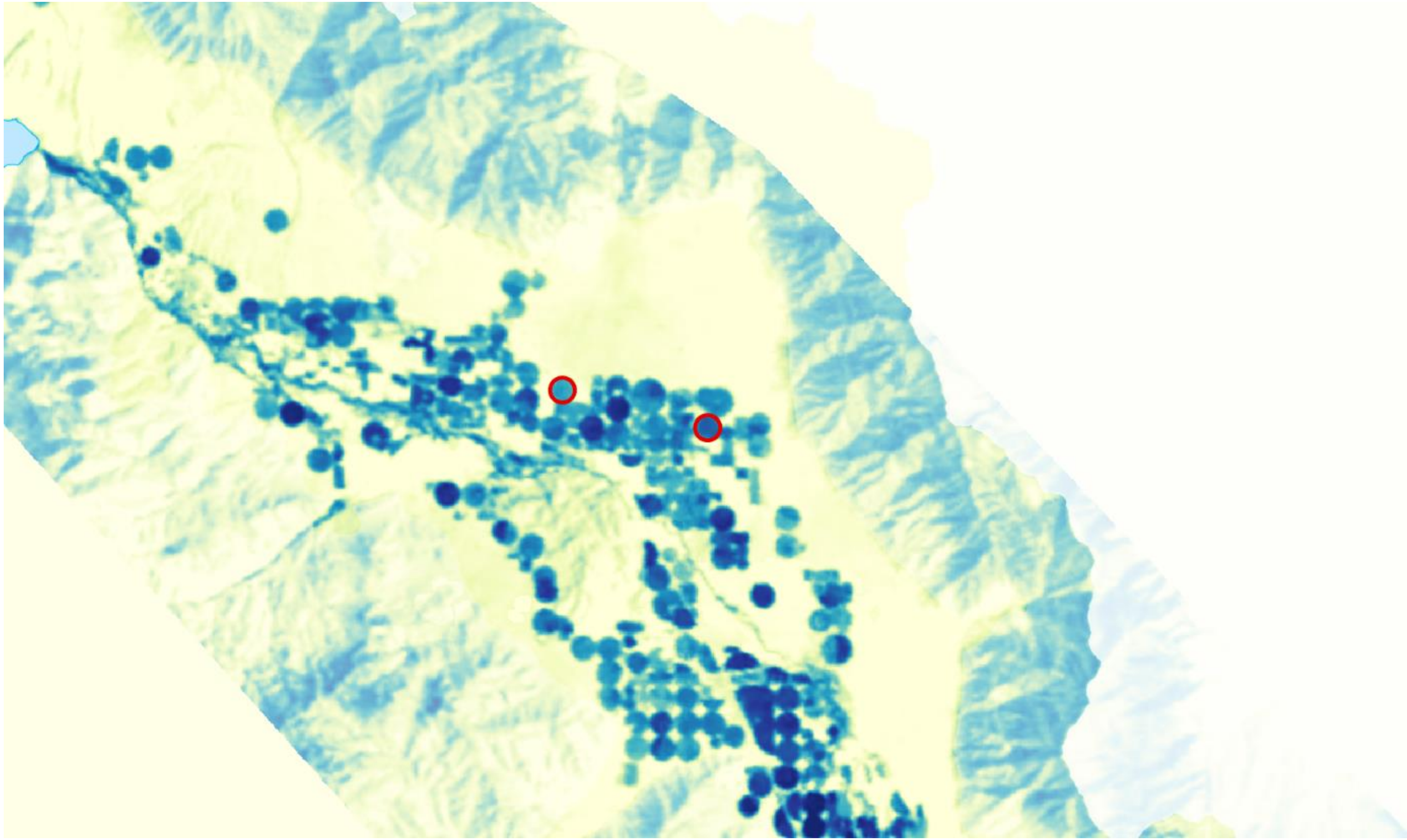
Landsat Collection 1 Provisional Actual Evapotranspiration

USGS
science for a changing world

METRIC

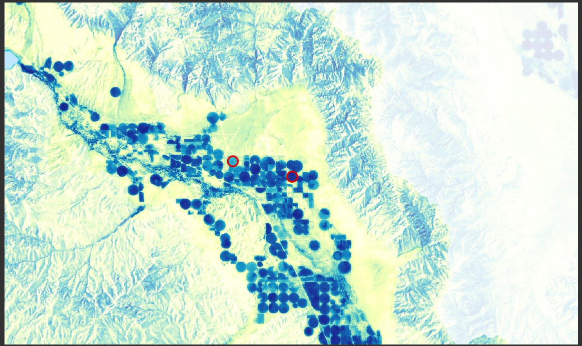


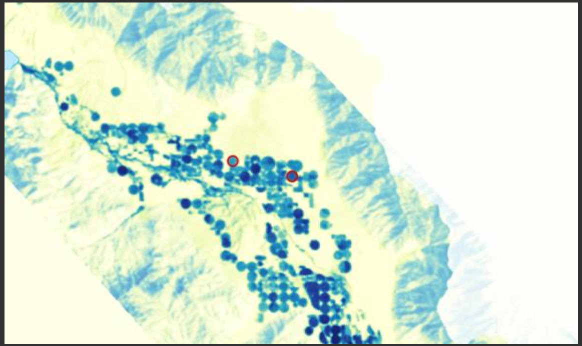
USGS Landsat 'Actual ET'



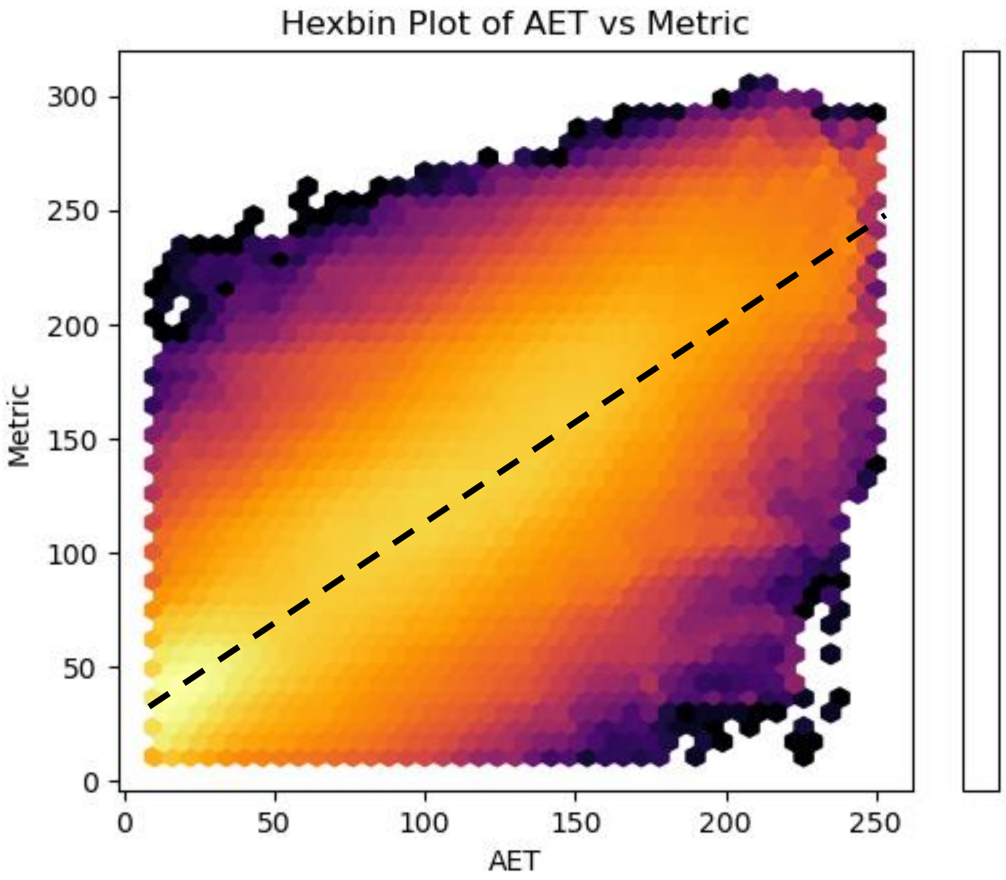
USGS
science for a changing world

Method



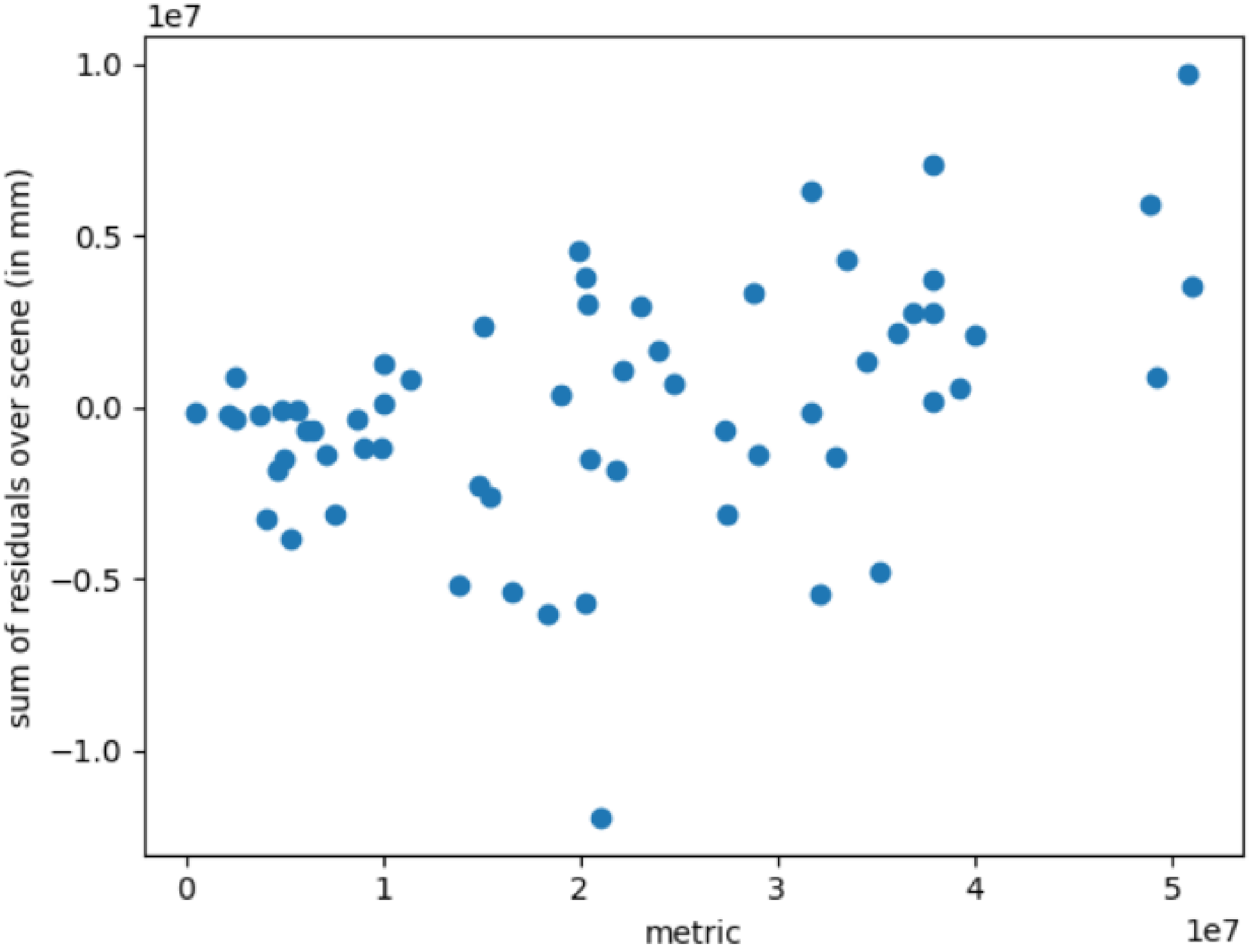


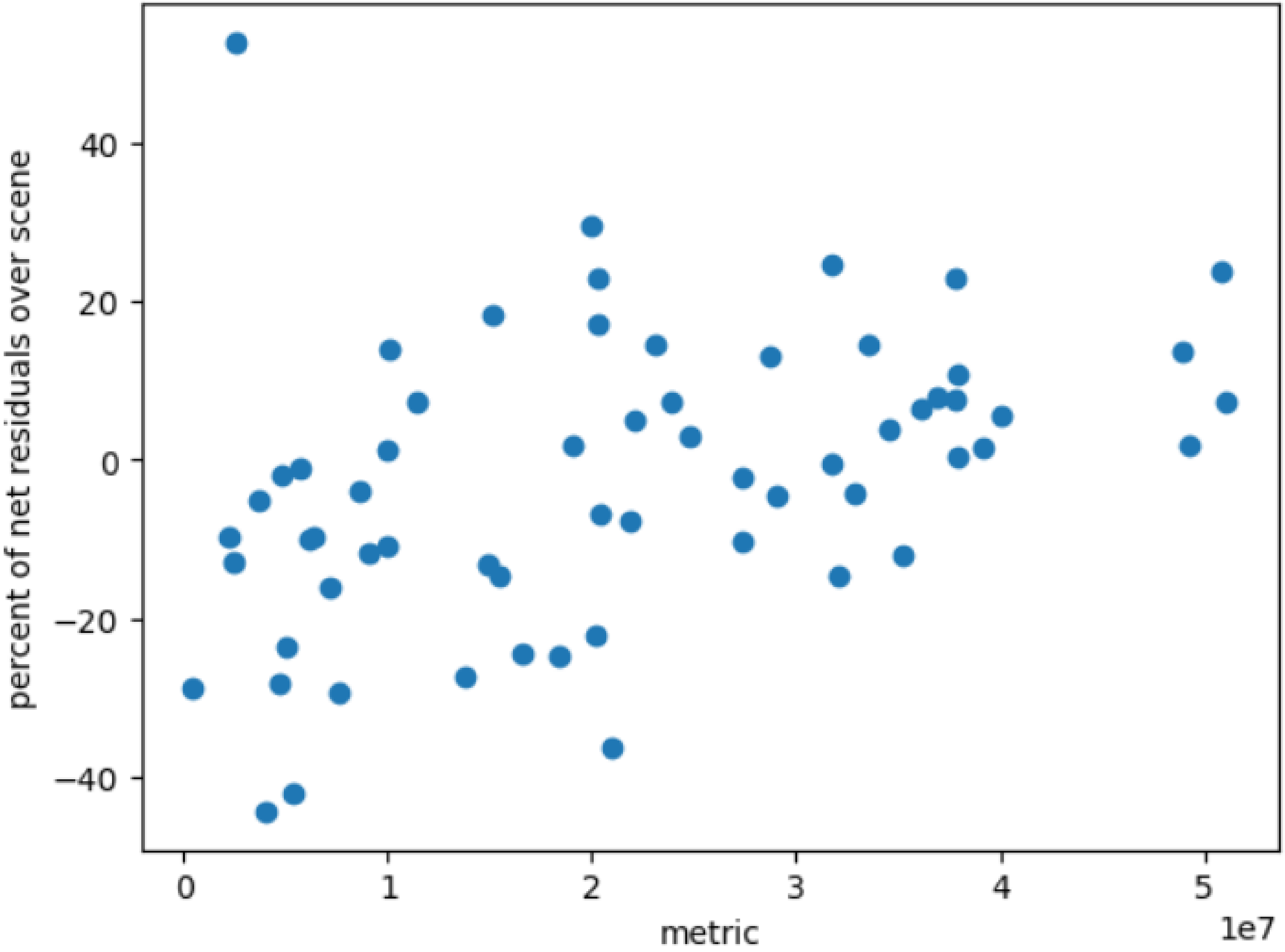
1. I
2.
3.
4.
5.
6.
7.
8.
9.



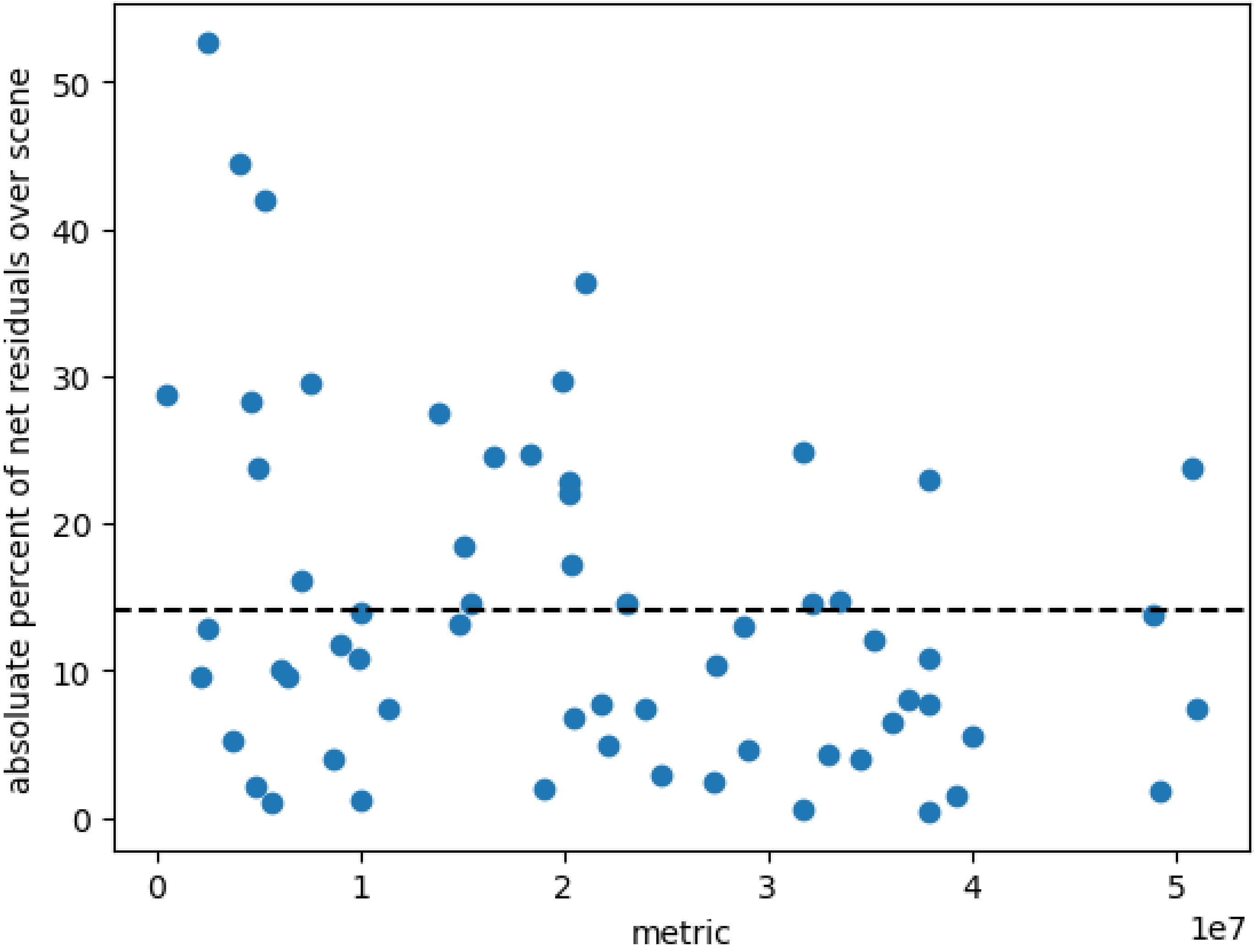
Slope: 0.8762926574084203
Intercept: 28.110619953659622
R-value: 0.8373813839967554
P-value: 0.0
Standard Error: 0.00016555602757634672

RMSE: 32.99716389279677
RMSE for 0 - 50: 23.828129028422655
RMSE for 50 - 100: 35.15844371504542
RMSE for 100 - 150: 36.73583121866991
RMSE for 150 - 200: 37.38675862395469
RMSE for 200 - 250: 32.880712400598874
RMSPE: 67.49454589264239
Percent RMSE for 0 - 50: 74.91404362941559
Percent RMSE for 50 - 100: 87.35413506950236
Percent RMSE for 100 - 150: 54.727620630308216
Percent RMSE for 150 - 200: 32.49130941020926
Percent RMSE for 200 - 250: 23.4554164770264

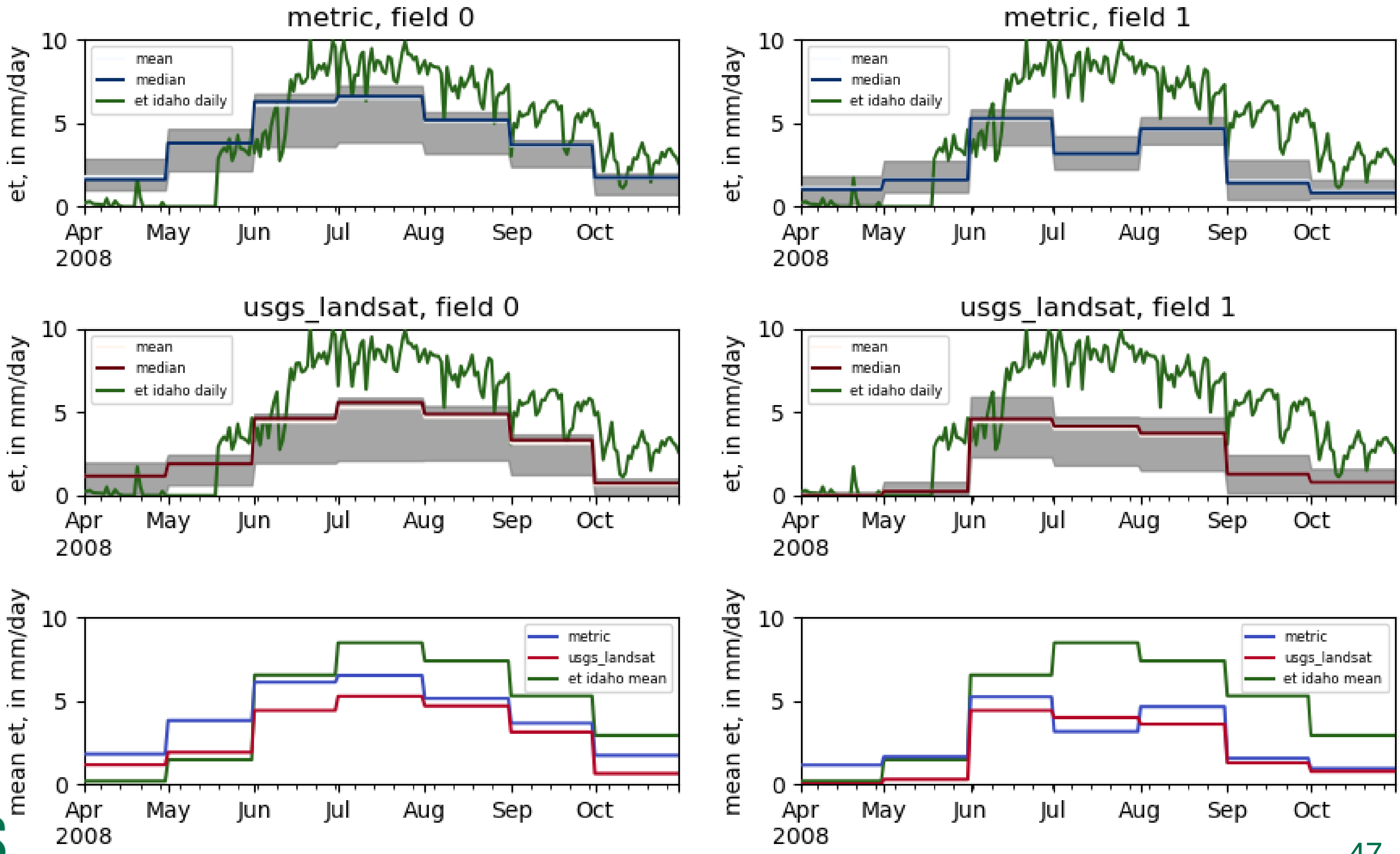

1e7
1.0
0.5
0.0
−0.5
−1.0
sum of residuals over scene (in mm)
0
1
2
3
4
5
metric
1e7



USGS
science for a changing world



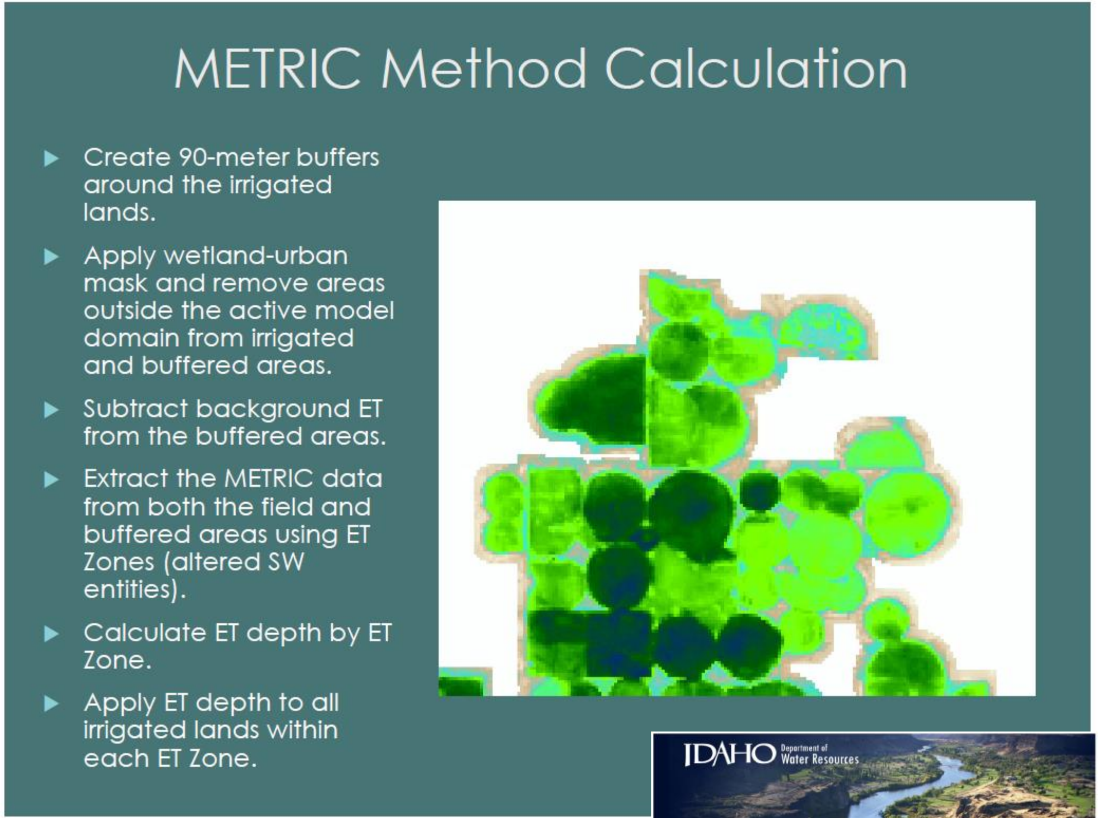
USGS
science for a changing world

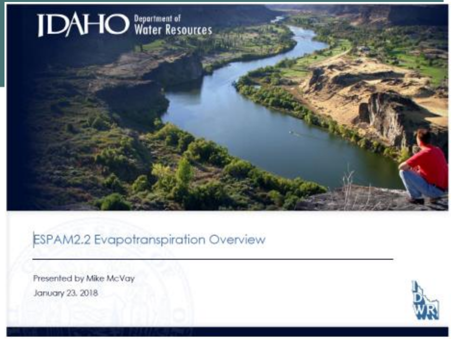


USGS
science for a changing world

ET “Buffer”

- ESPAM and other models have used a ‘buffer’ algorithm to capture ET outside of fields
- To capture the impact of irrigation beyond the boundary of field
- Sprinklers, wind, thermal diffusion, and artifacts of sensor resolution
    - L5 – 120m
    - L7- 60m
    - L8,9 – 100m





From McVay, January 2018 ESHMC meeting

ET "Buffer"

- ESPAM and other models have used a 'buffer' algorithm to capture ET outside of fields
- To capture the impact of irrigation beyond the boundary of field
- Sprinklers, wind, thermal diffusion, and artifacts of sensor resolution
  - L5 – 120m
  - L7- 60m
  - L8,9 – 100m

Evapotranspiration Buffers

The irrigation drift phenomenon is apparent when comparing METRIC ET datasets, CDL and NLCD land-use classifications, and to some extent, aerial photographs. For example, METRIC ET datasets show elevated values (typically greater than about 400 millimeters) adjacent to some irrigated fields. Wind may cause applied irrigation to drift beyond the field. Ideally, this additional ET could be directly attributed to irrigation practices that could then be used to estimate groundwater pumpage and CIR volumes. However, actual applied irrigation is only one potential component of the elevated ET effects that may also include evaporation owing to cooler air temperatures next to irrigated fields or differences in Landsat satellite-based sensor resolution used in preparing METRIC datasets (McVay, 2018).

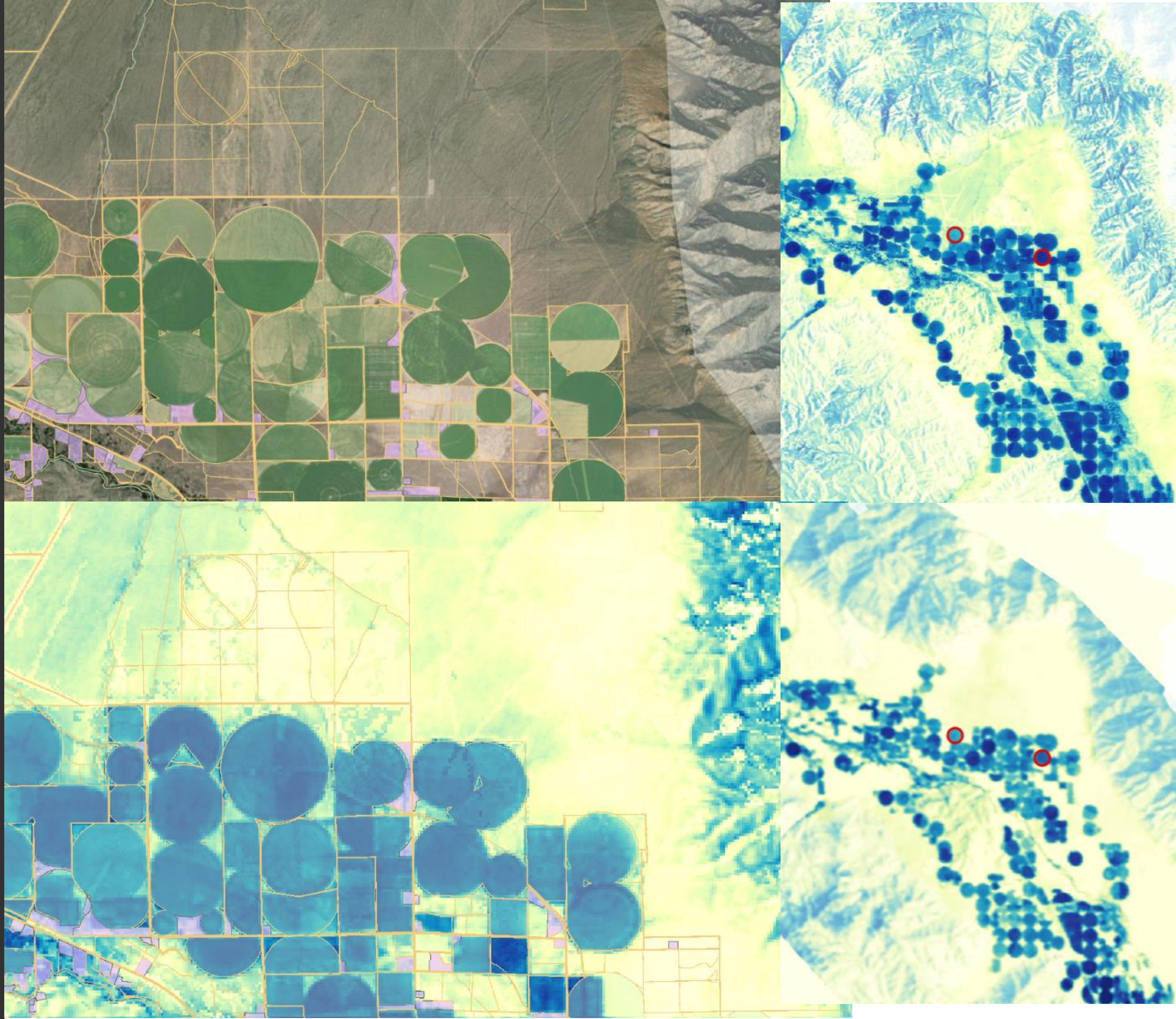
Elevated ET just beyond the irrigated fields may be readily distinguished from the surrounding areas, such as bare soil or shrubland with lower ET compared to crops, or may be less easily distinguished from wetlands with higher ET. CDL land-use classifications on some non-irrigated lands include crops (such as alfalfa, barley, and potatoes) and "other hay/non alfalfa" or "grass/pasture." Similarly, NLCD land-cover types within non-irrigated lands adjacent to irrigated fields include "cultivated crops" and "hay/pasture," suggesting that irrigation is occurring beyond the irrigated fields. Aerial imagery (National Agricultural Imagery Program, or NAIP[4], or Google Earth imagery [Google LLC, 2020]) sometimes supports

<u>Buffer effect (METRIC years)</u>
Mean: ~ +3.3%
SD: ~ 1.3%

USGS science for a changing world

ET "Buffer"

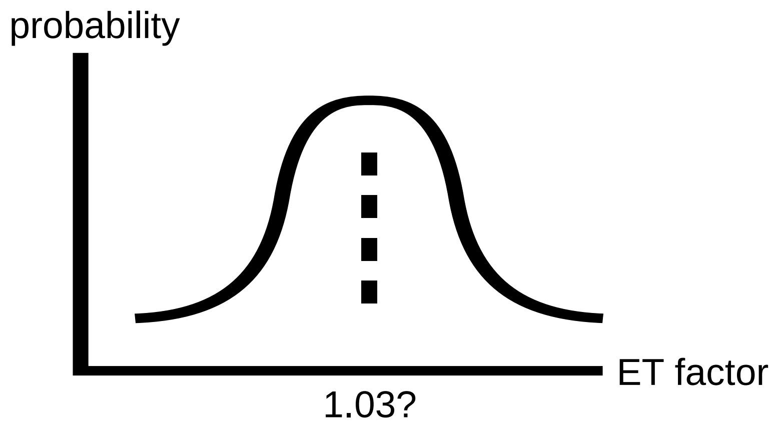
- My question:
  - Can we get away without it?

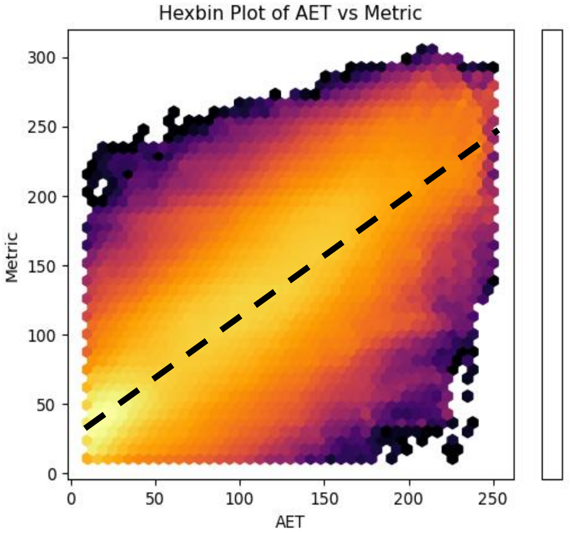


USGS
science for a changing world

ET "Buffer"

- My question:
  - Can we get away without it?
- ET factor
  - Adjustable parameter
  - Use for other sources of uncertainty in ET
  - Can make a 'bias' the null hypothesis to (crudely) replace buffer?






```
Slope: 0.8762926574084203
Intercept: 28.110619953659622
R-value: 0.8373813839967554
P-value: 0.0
Standard Error: 0.00016555602757634672
```

```
RMSE: 32.99716389279677
RMSE for 0 - 50: 23.828129028422655
RMSE for 50 - 100: 35.15844371504542
RMSE for 100 - 150: 36.73583121866991
RMSE for 150 - 200: 37.38675862395469
RMSE for 200 - 250: 32.880712400598874
RMSPE: 67.49454589264239
Percent RMSE for 0 - 50: 74.91404362941559
Percent RMSE for 50 - 100: 87.35413506950236
Percent RMSE for 100 - 150: 54.727620630308216
Percent RMSE for 150 - 200: 32.49130941020926
Percent RMSE for 200 - 250: 23.45541664770264
```

USGS
science for a changing world

Thanks!

Jacob Knight
jknight@usgs.gov
520-670-3336

Stephen Hundt
shundt@usgs.gov
208-387-1390