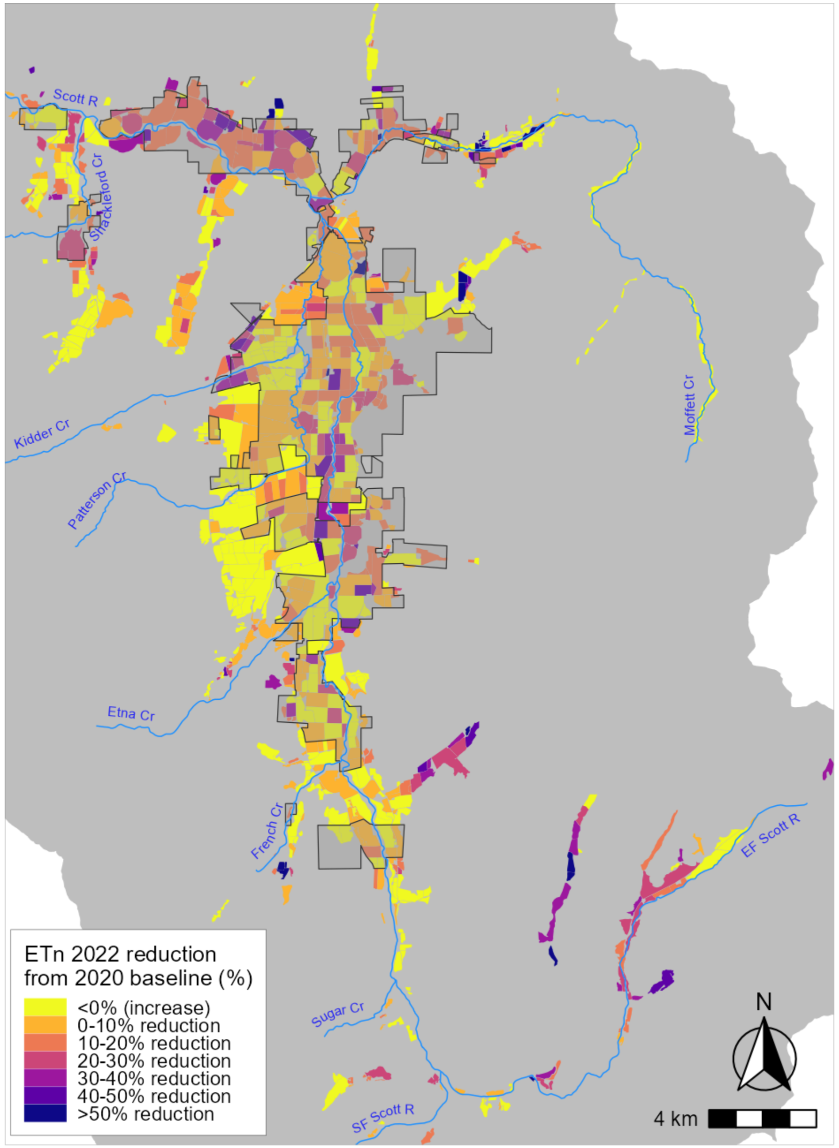
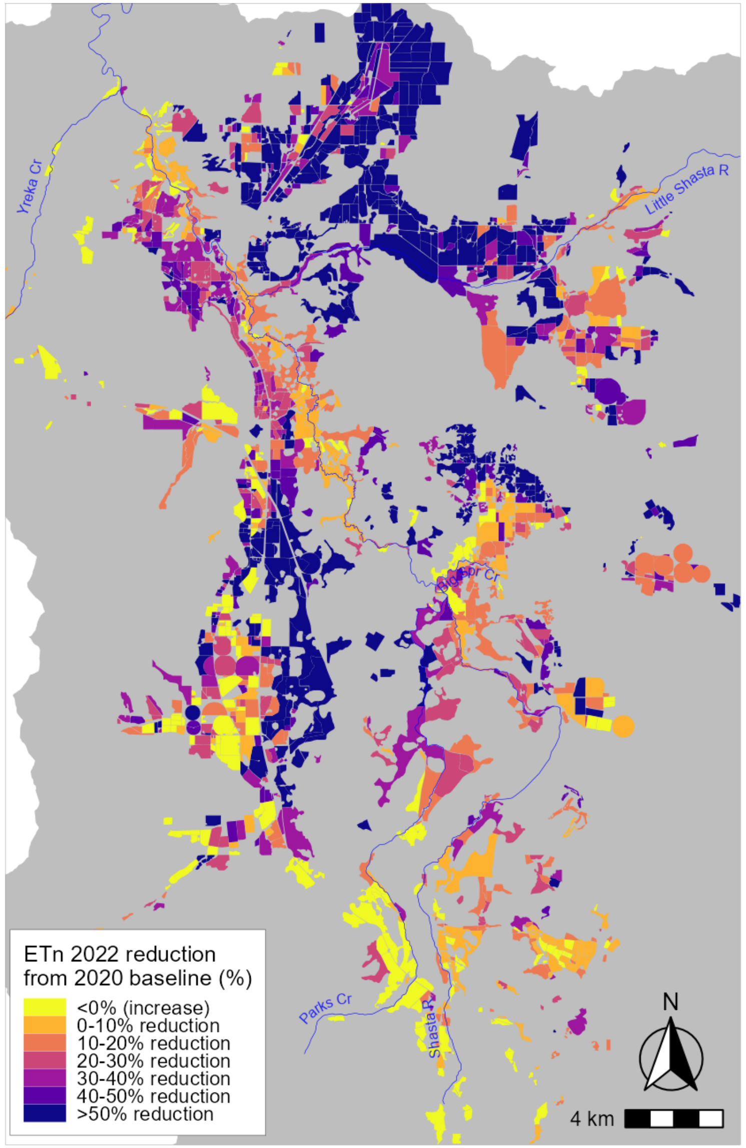
Contrasting hydrologic effects of irrigation curtailment in the Shasta and Scott valleys evaluated with remote sensing and streamflow gages

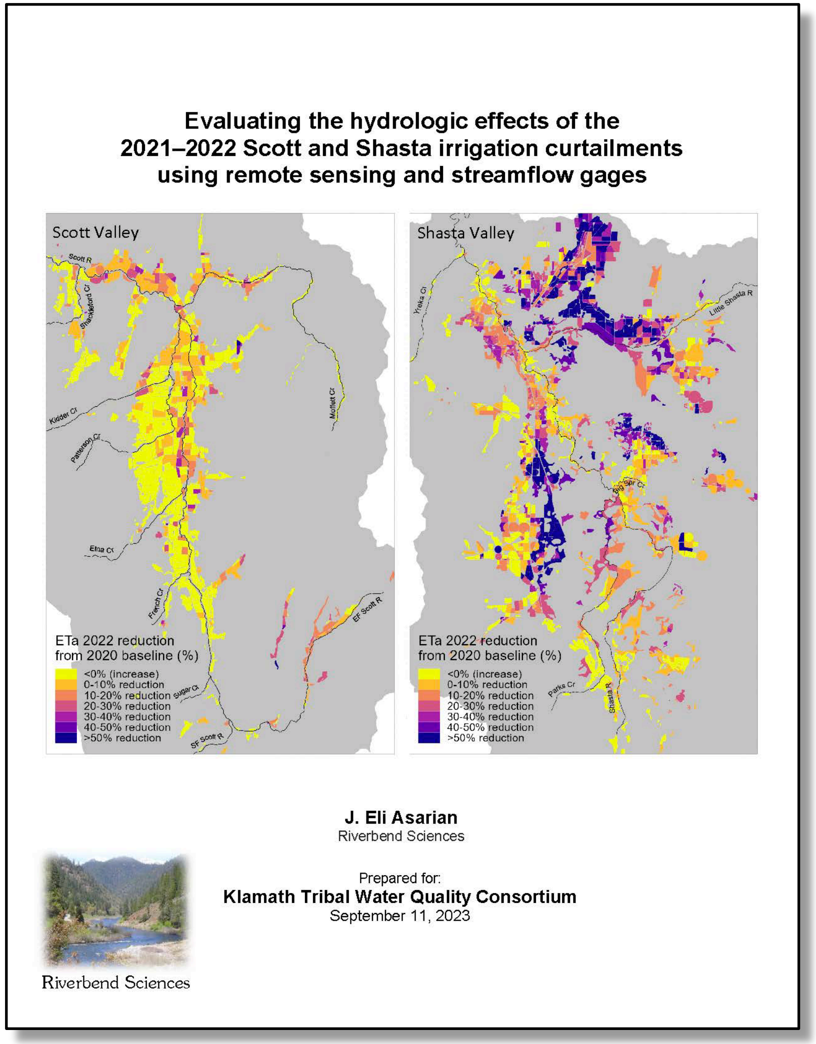
Eli Asarian
Riverbend Sciences





California Environmental Flows Workgroup
2/13/2024 virtual meeting

Technical report
completed 9/11/2023
https://www.riverbendsci.com/reports-and-publications


Evaluating the hydrologic effects of the
2021–2022 Scott and Shasta irrigation curtailments
using remote sensing and streamflow gages

J. Eli Asarian
Riverbend Sciences

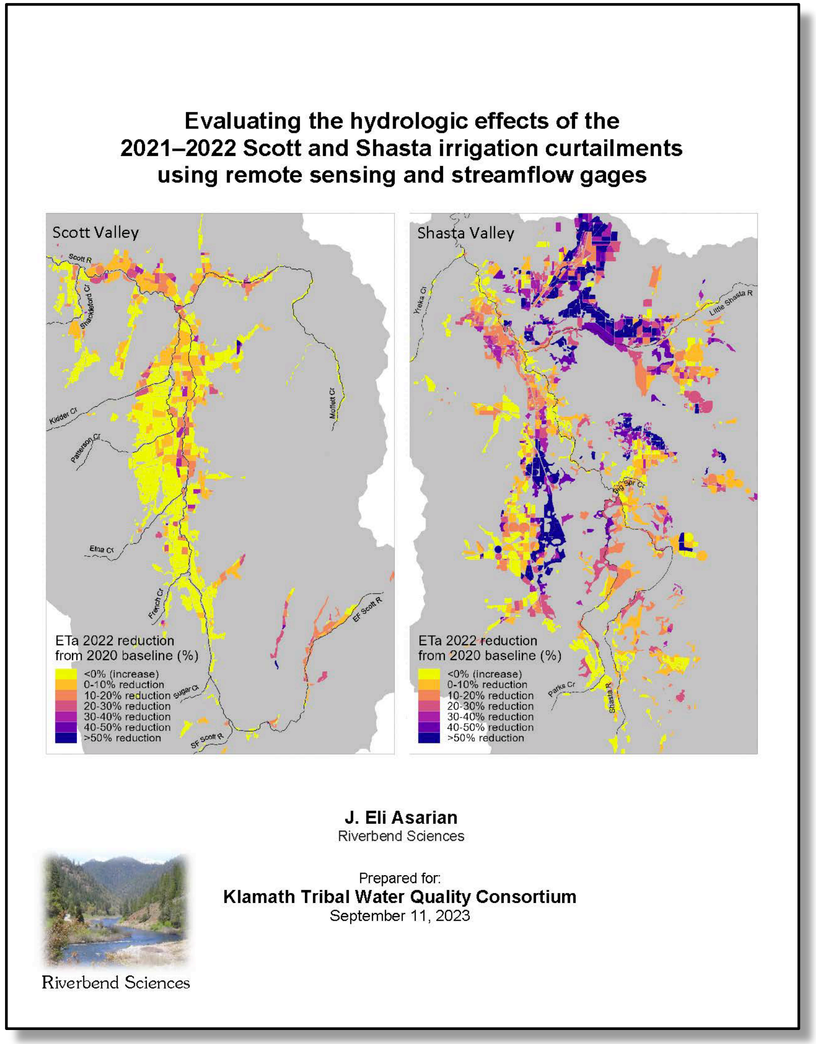
Prepared for:
Klamath Tribal Water Quality Consortium
September 11, 2023

Riverbend Sciences

Technical report

completed 9/11/2023

https://www.riverbendsci.com/reports-and-publications


Evaluating the hydrologic effects of the
2021–2022 Scott and Shasta irrigation curtailments
using remote sensing and streamflow gages

J. Eli Asarian
Riverbend Sciences

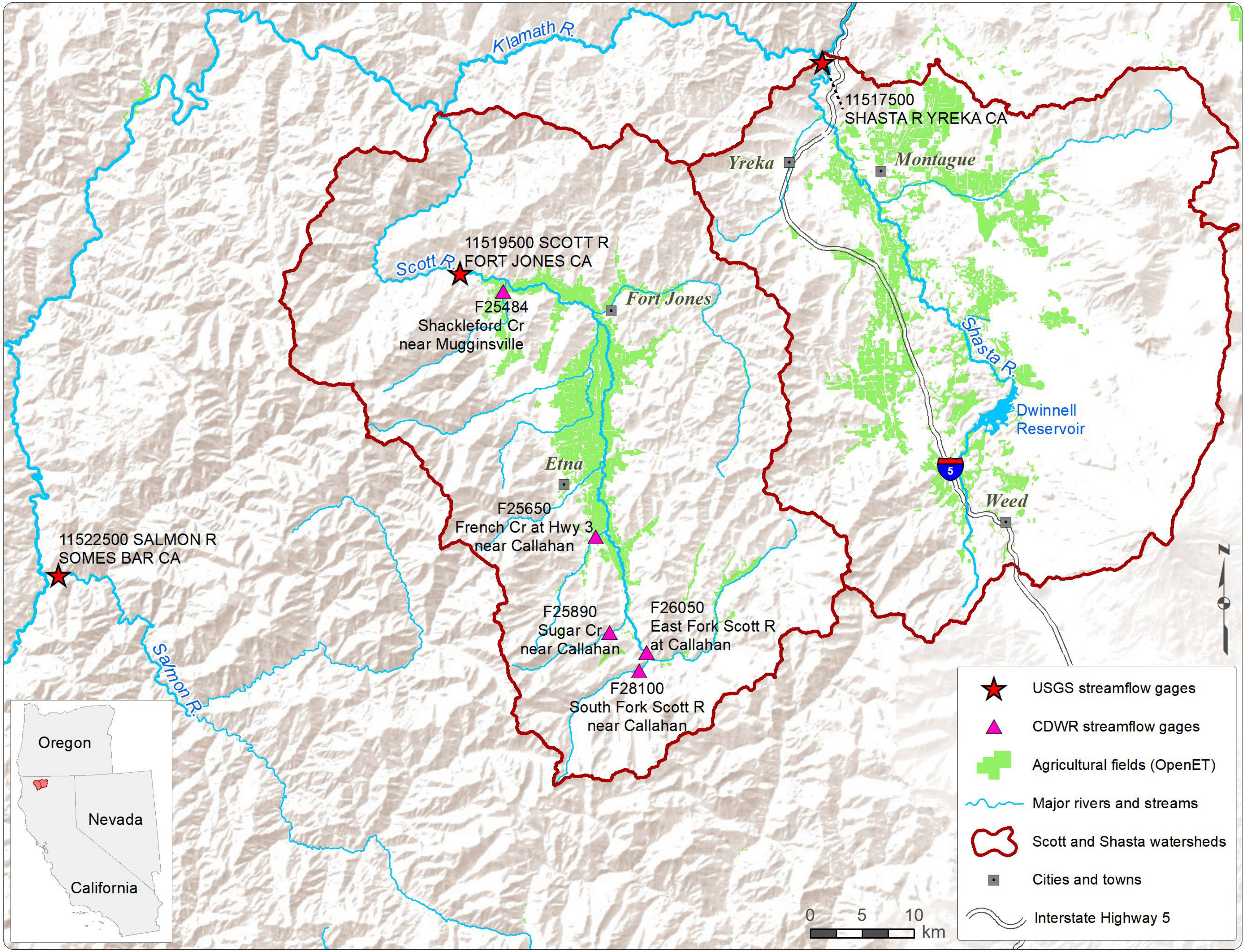
Prepared for:
Klamath Tribal Water Quality Consortium
September 11, 2023

Riverbend Sciences

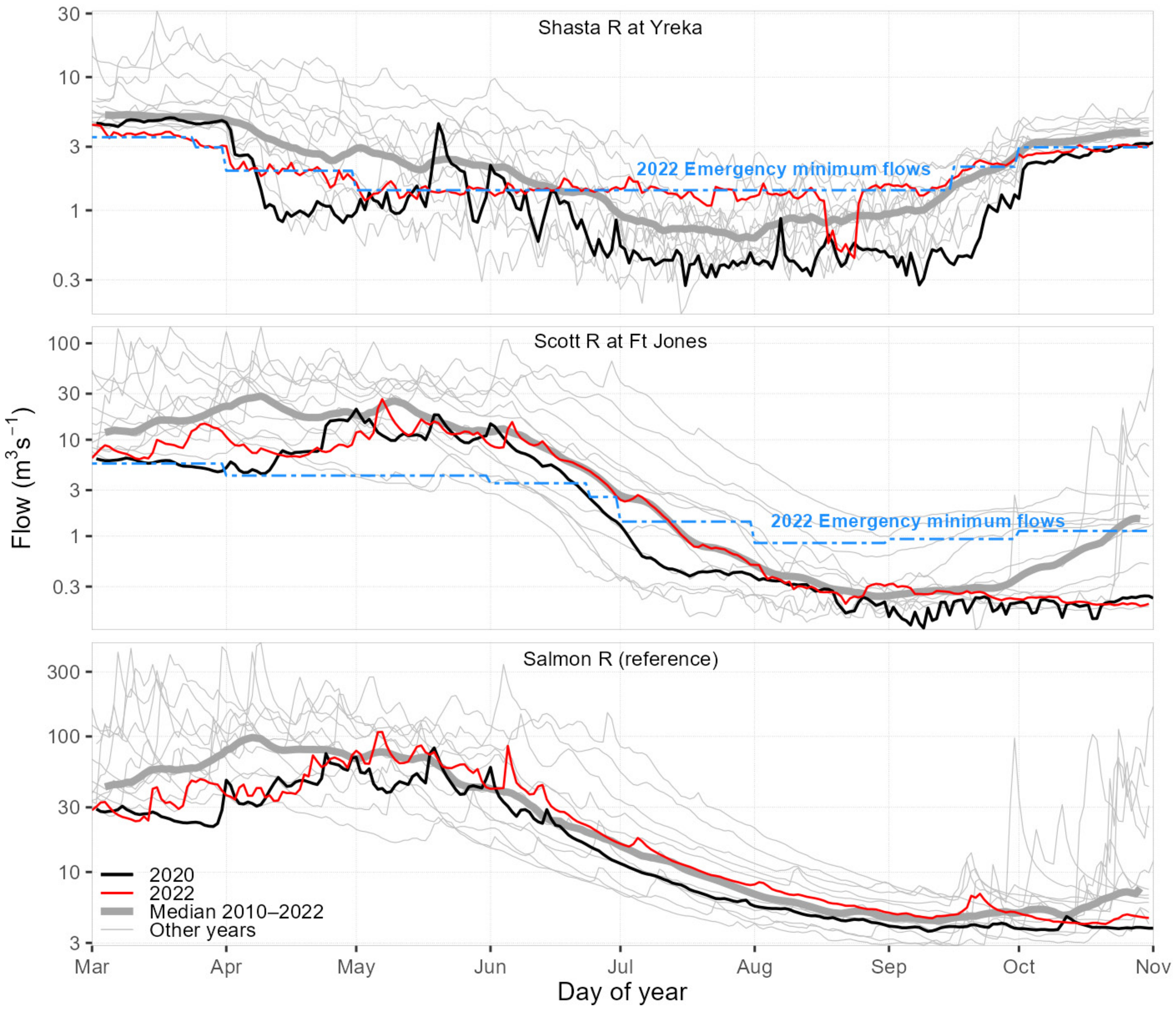
Peer-review manuscript in prep

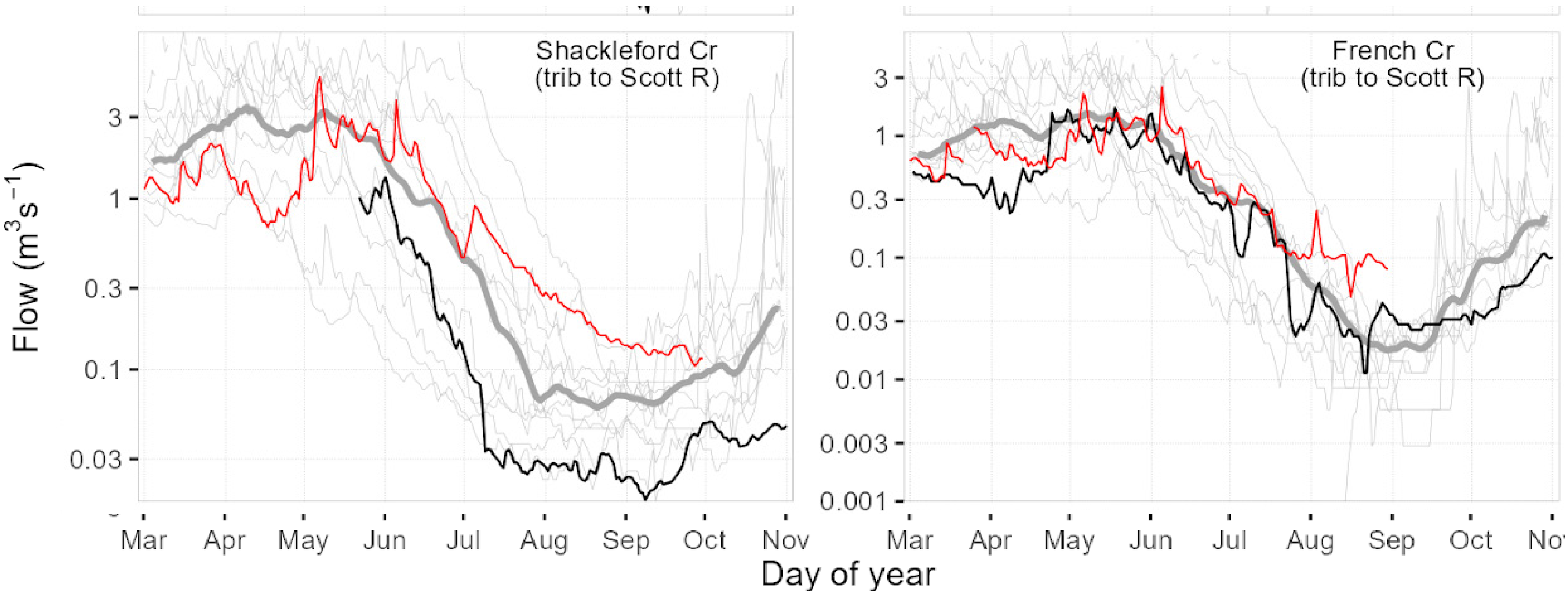
Authors:
Eli Asarian, Riverbend Sciences
Bronwen Stanford and Nicholas Murphy, The Nature Conservancy
Michael Pollock, NOAA Fisheries

RESULTS PROVISIONAL!


Klamath R.
11517500
SHASTA R YREKA CA
Yreka
Montague
11519500 SCOTT R
FORT JONES CA
Scott R.
F25484
Shackleford Cr
near Mugginsville
Fort Jones
Shasta R.
Dwinnell
Reservoir
5
Etna
Weed
F25650
French Cr at Hwy 3
near Callahan
11522500 SALMON R
SOMES BAR CA
F25890
Sugar Cr
near Callahan
F26050
East Fork Scott R
at Callahan
F28100
South Fork Scott R
near Callahan
Salmon R.
Oregon
Nevada
California
N
0 5 10
km
USGS streamflow gages
CDWR streamflow gages
Agricultural fields (OpenET)
Major rivers and streams
Scott and Shasta watersheds
Cities and towns
Interstate Highway 5

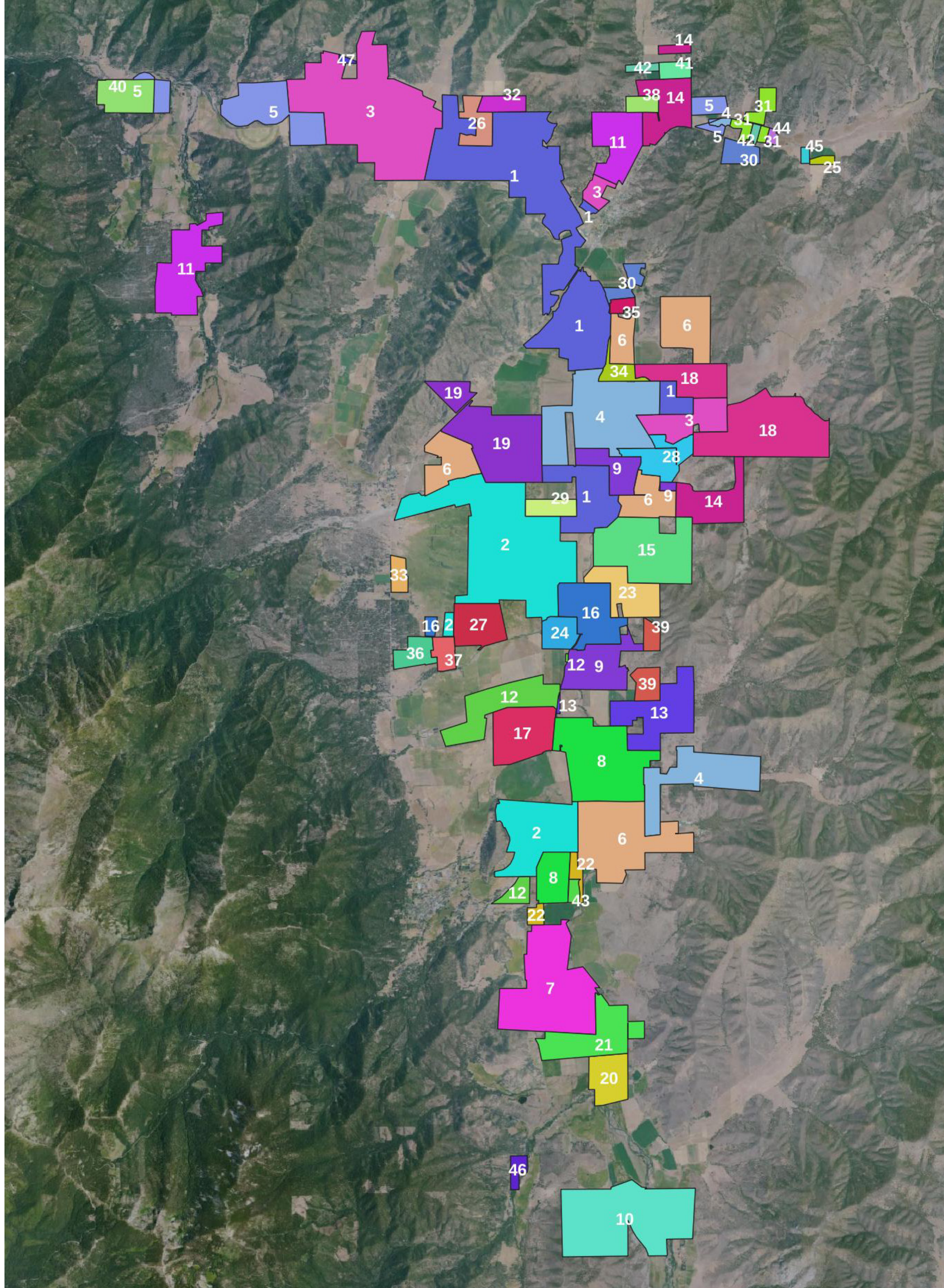
- Drought emergency
- 2021 curtailment
  - Sept 10
- 2022 Shasta curtailment
  - By priority date
- 2022 Scott curtailment
  - Surface water
    - July 1
  - Groundwater
    - July 14
    - Continued pumping with Local cooperative solutions (LCS)




Shackleford Cr
(trib to Scott R)
French Cr
(trib to Scott R)
Flow (m^{3}s^{-1})
3
1
0.3
0.1
0.03
0.01
0.003
0.001
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Day of year

2022 Local cooperative solutions (LCS)

- 47 of 50 are Scott groundwater
- Reduce 2022 pumping from 2020 (or 2021) by 30% during irrigation season:
  - Irrigation efficiency
  - Alfalfa → grain
  - Fallow fields/corners
  - Reduced cuttings
- Self-reported pumping, some oversight by RCD and/or CDFW
- ≥90 percent of groundwater acres



Remote Sensing

Remote sensing tools

(See tutorials at https://www.riverbendsci.com/projects/remote-sensing)

OPENET

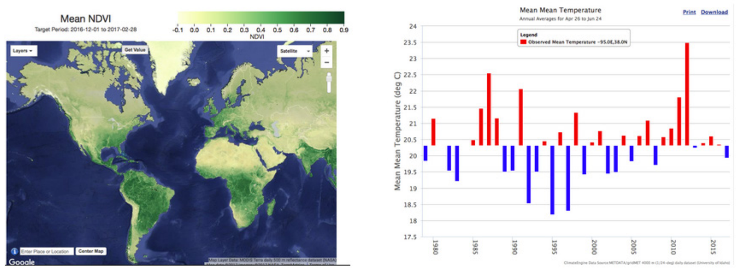
https://openetdata.org/

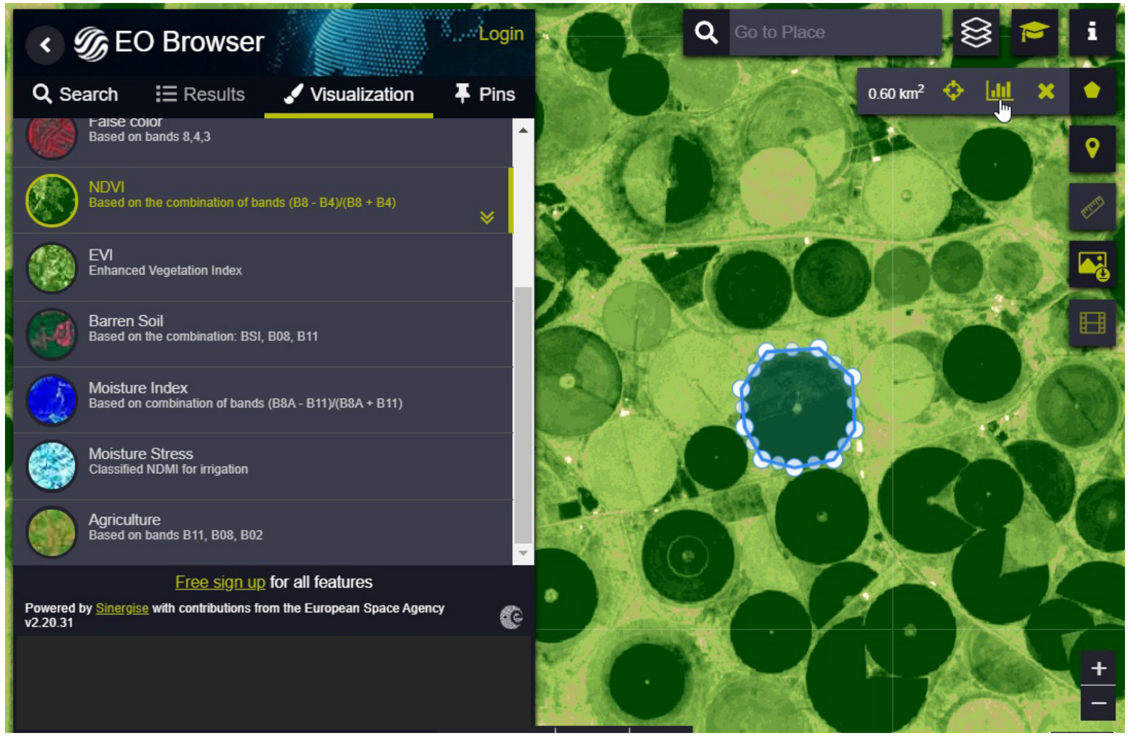
sentinelhub

https://apps.sentinel-hub.com/eo-browser

ClimateEngine.org

Cloud Computing of Climate and Remote Sensing Data






USDA
NAIP aerial
1-3 years
≤1m resolution

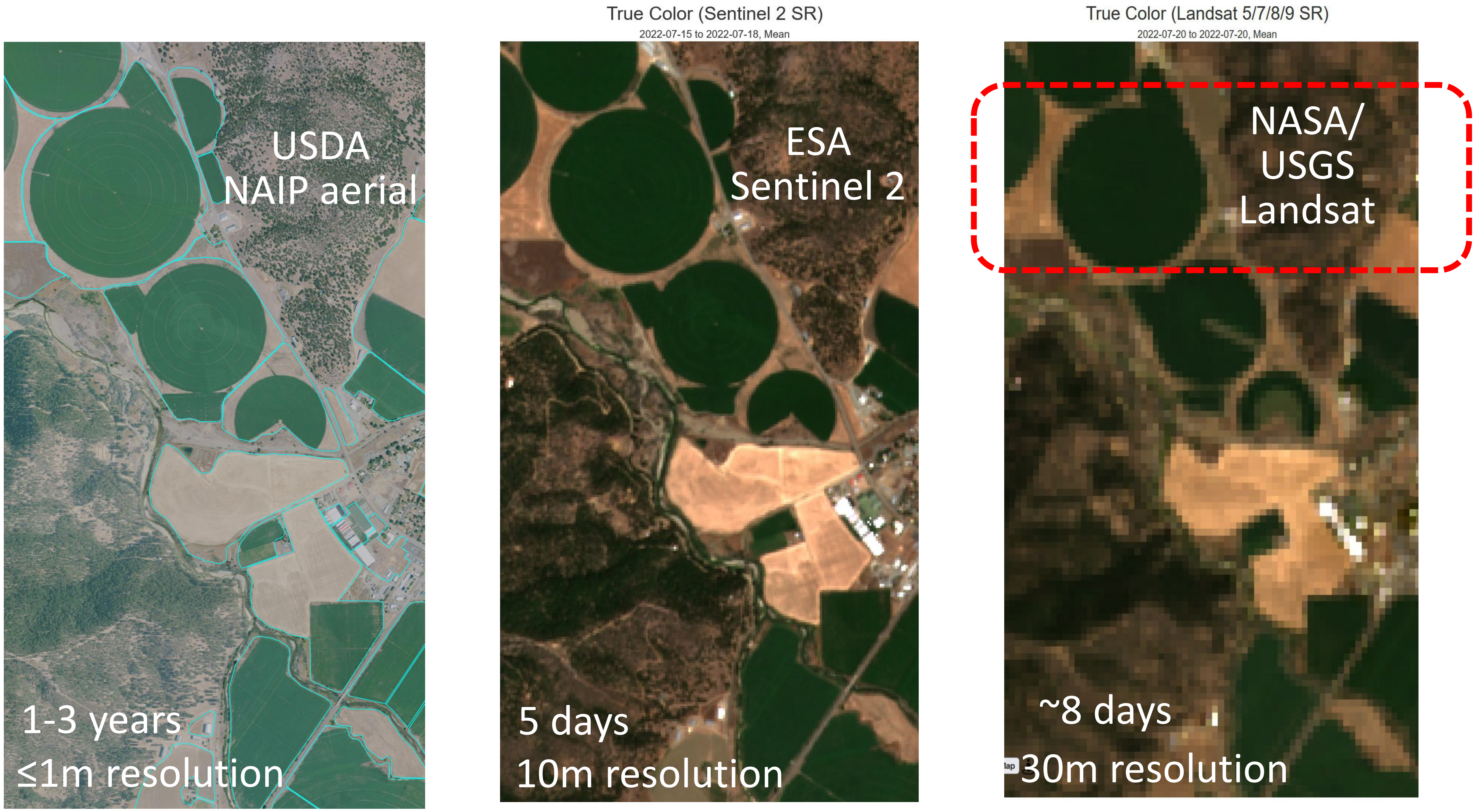
True Color (Sentinel 2 SR)
2022-07-15 to 2022-07-18, Mean

True Color (Sentinel 2 SR)

2022-07-15 to 2022-07-18, Mean

True Color (Landsat 5/7/8/9 SR)

2022-07-20 to 2022-07-20, Mean

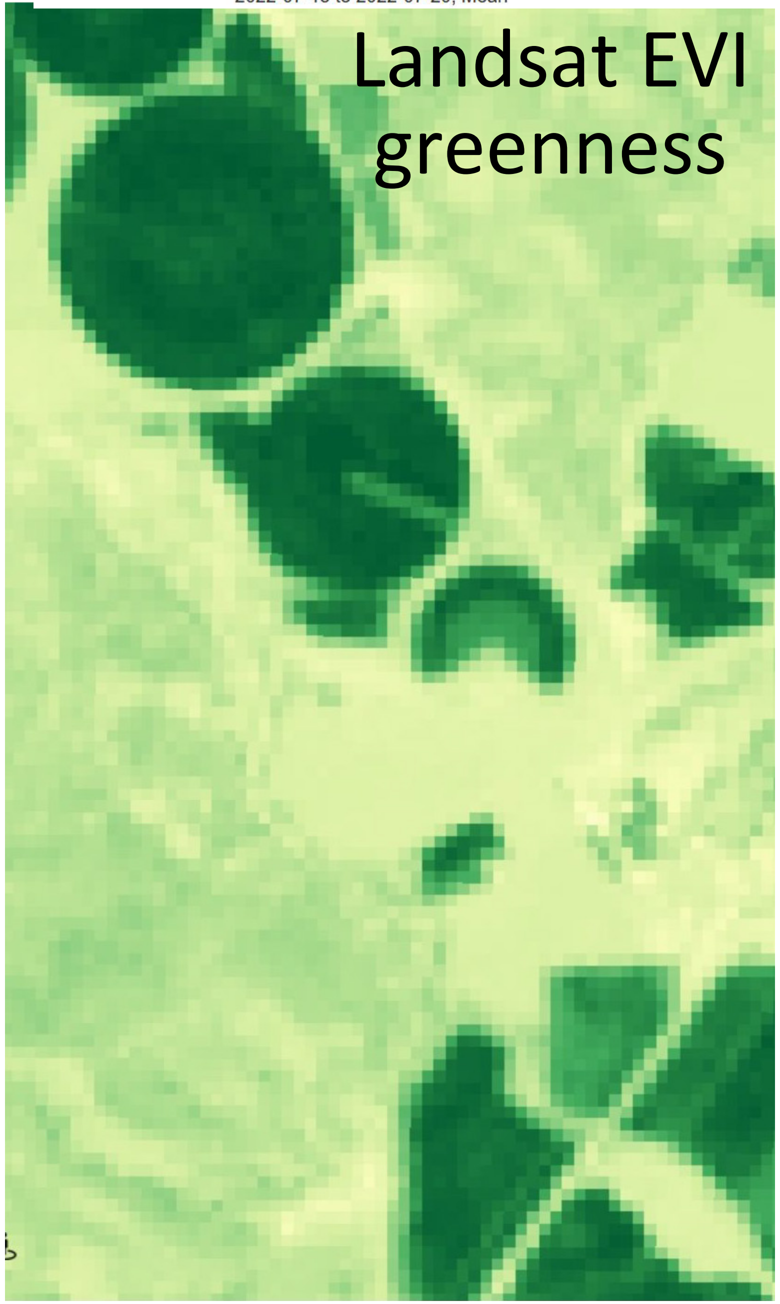

True Color (Sentinel 2 SR)
2022-07-15 to 2022-07-18, Mean
True Color (Landsat 5/7/8/9 SR)
2022-07-20 to 2022-07-20, Mean
USDA
NAIP aerial
1-3 years
≤1m resolution
ESA
Sentinel 2
5 days
10m resolution
NASA/
USGS
Landsat
~8 days
30m resolution

True Color (Landsat 5/7/8/9 SR)

2022-07-20 to 2022-07-20, Mean

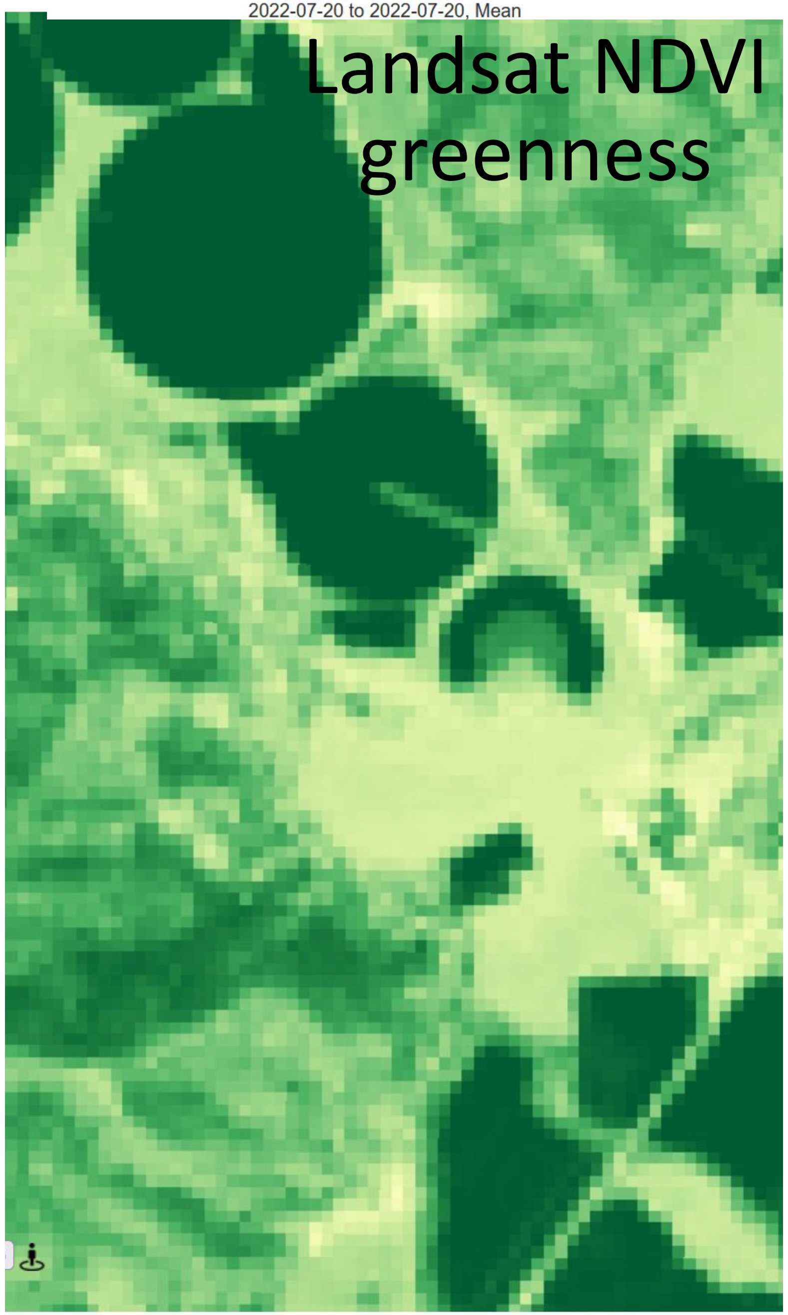
EVI (Landsat 5/7/8/9 SR)

2022-07-15 to 2022-07-20, Mean



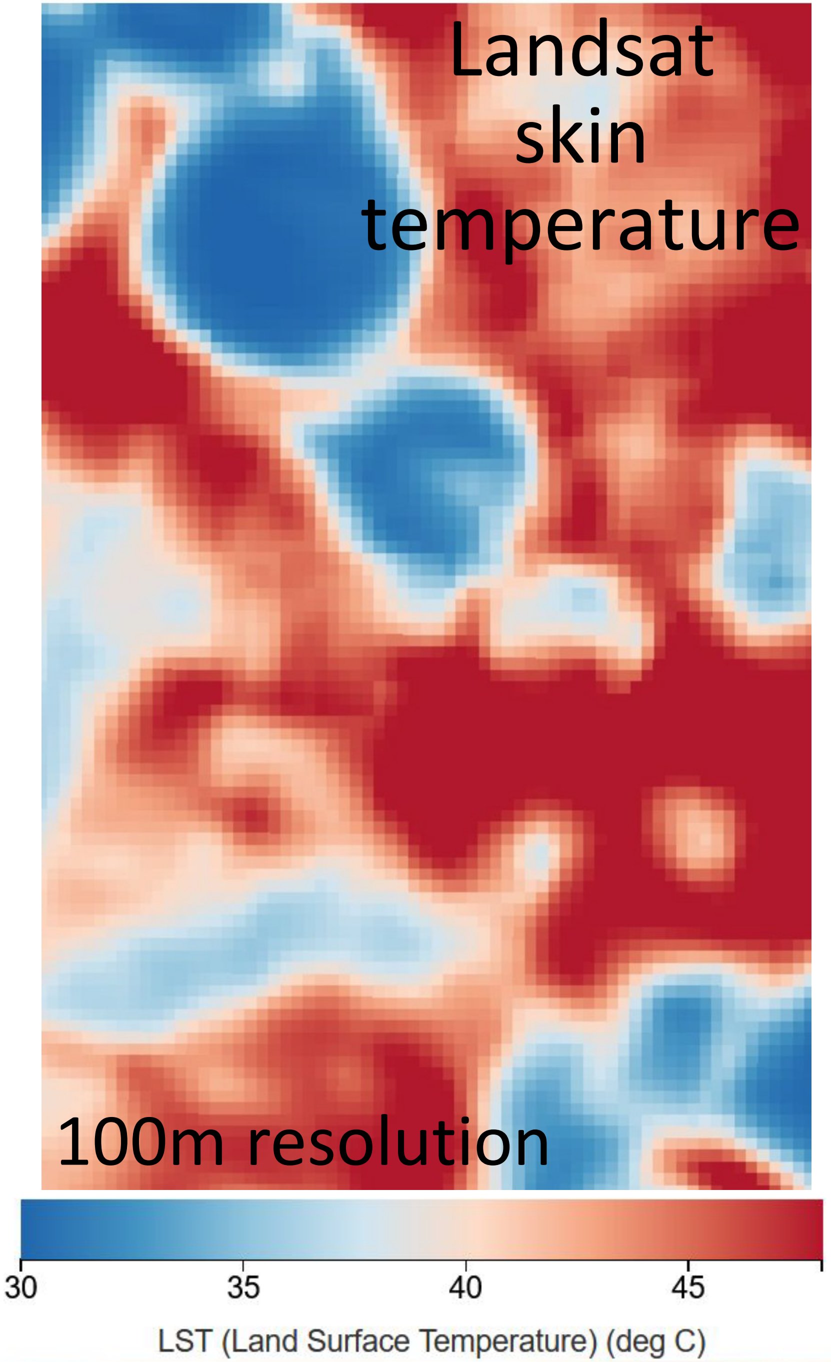
NDVI (Landsat 5/7/8/9 SR)

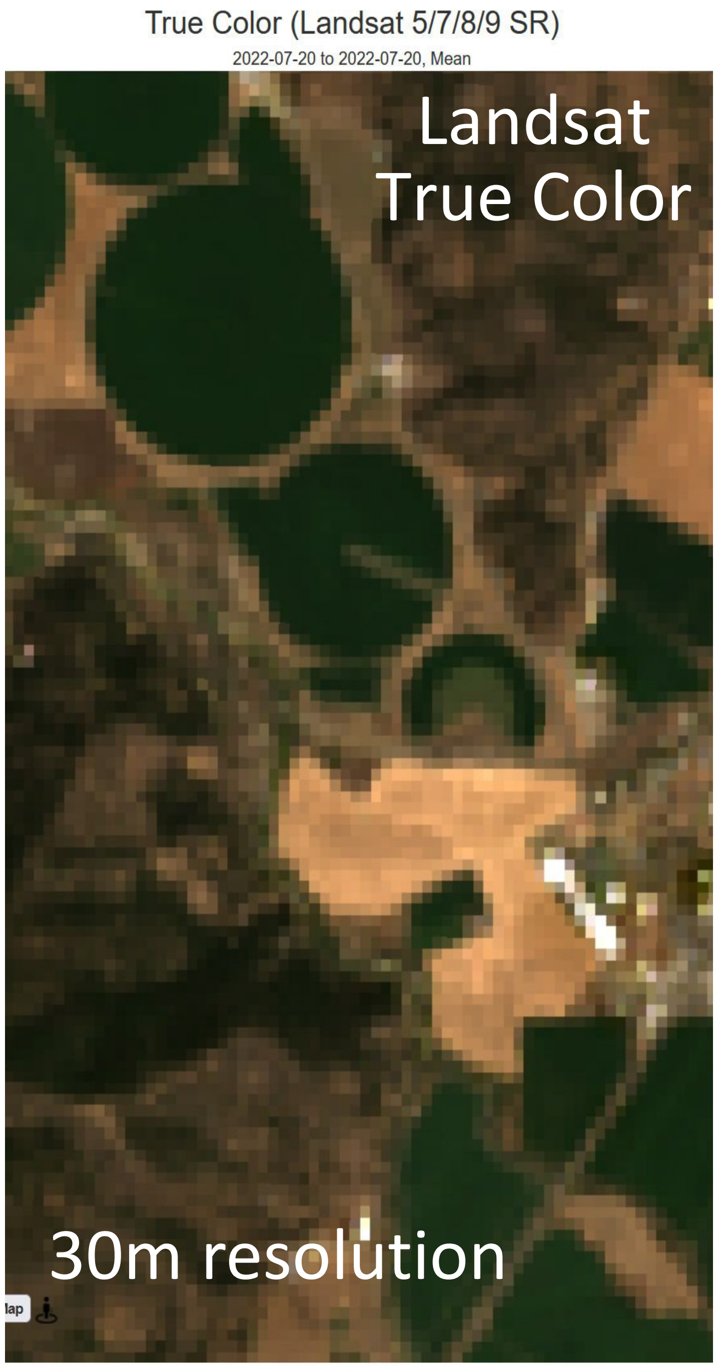
2022-07-20 to 2022-07-20, Mean



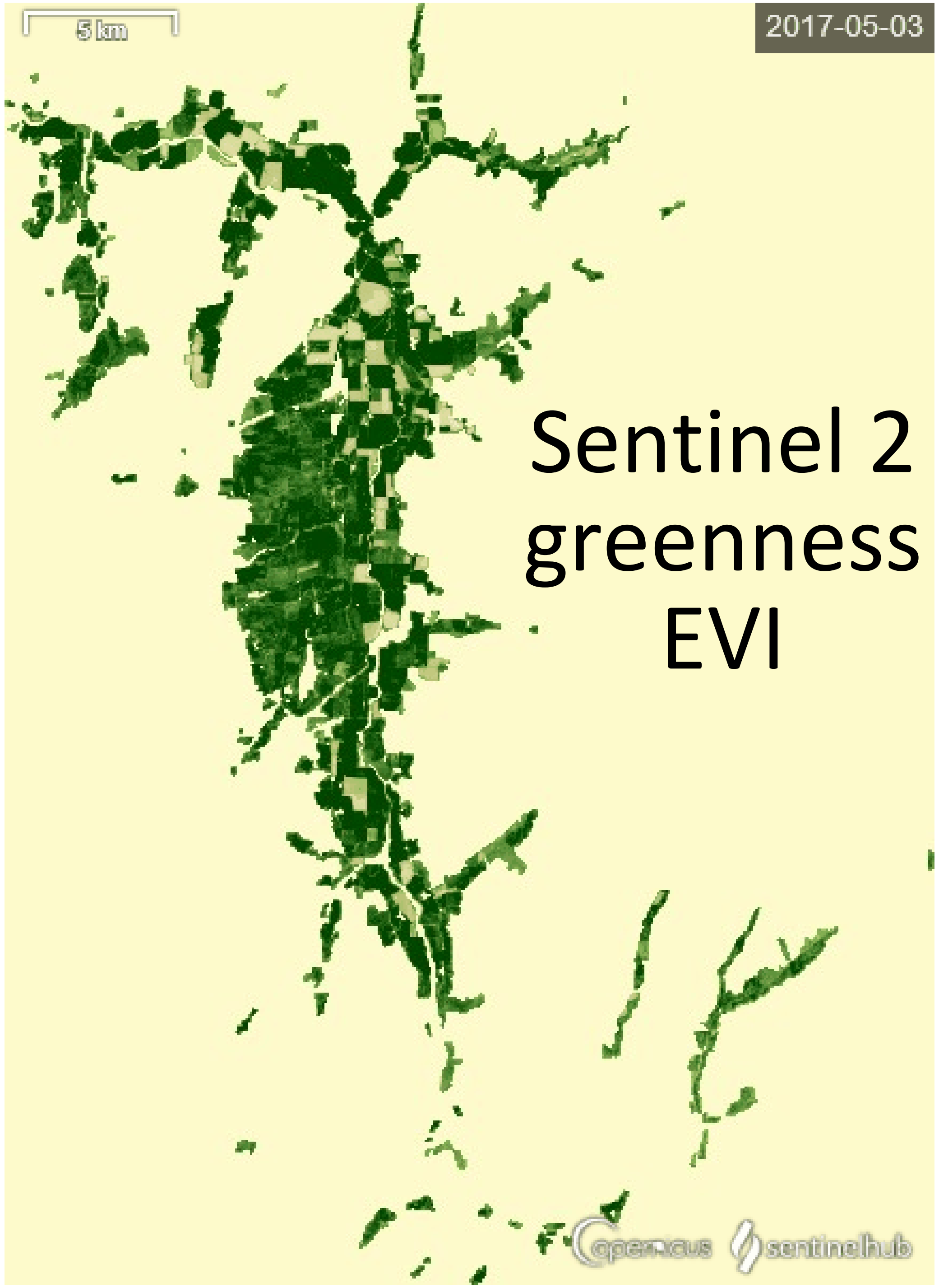
True Color (Landsat 5/7/8/9 SR)

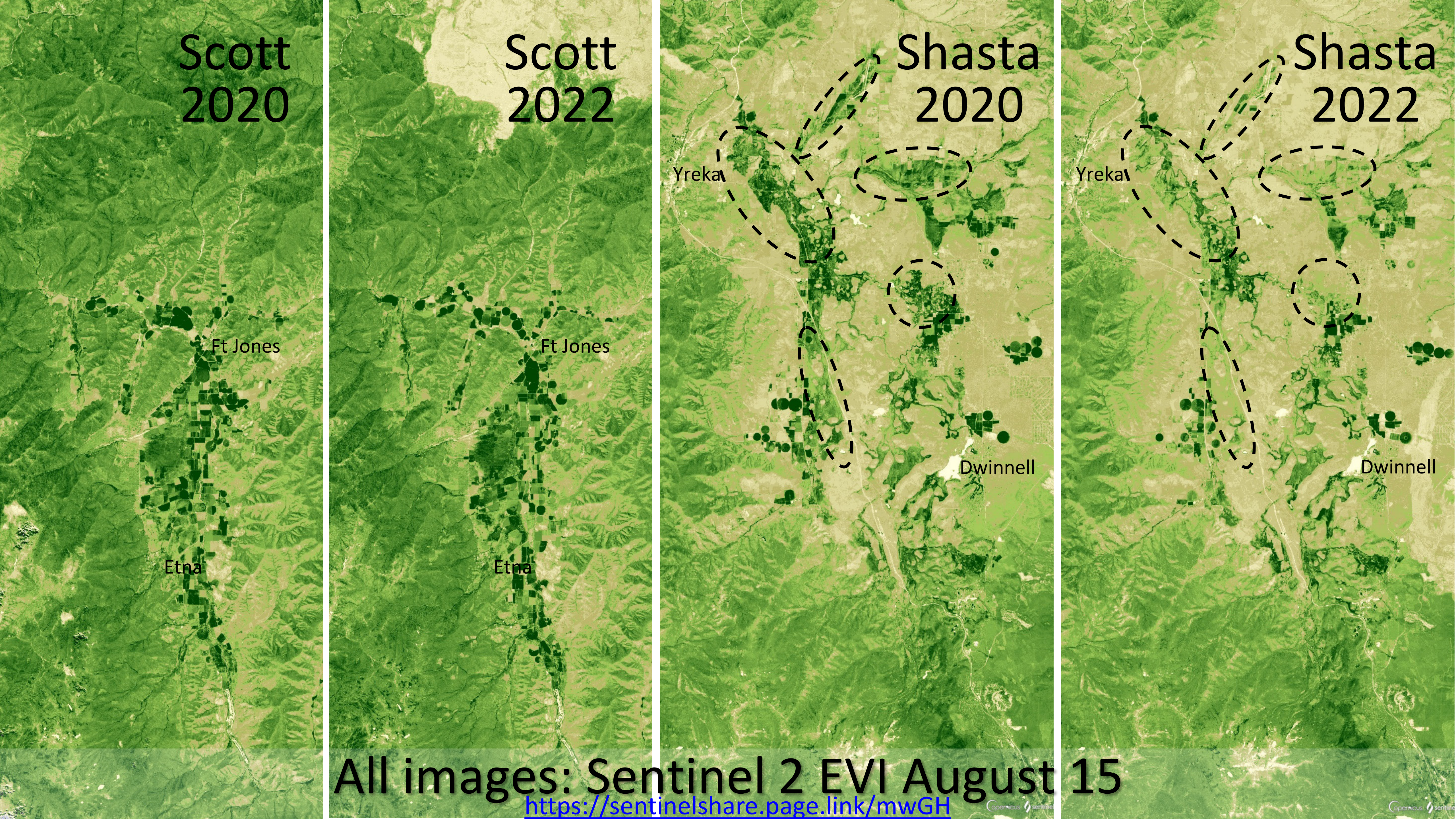
2022-07-20 to 2022-07-20, Mean


Landsat skin temperature
100m resolution
30
35
40
45
LST (Land Surface Temperature) (deg C)


True Color (Landsat 5/7/8/9 SR)
2022-07-20 to 2022-07-20, Mean
Landsat True Color
30m resolution

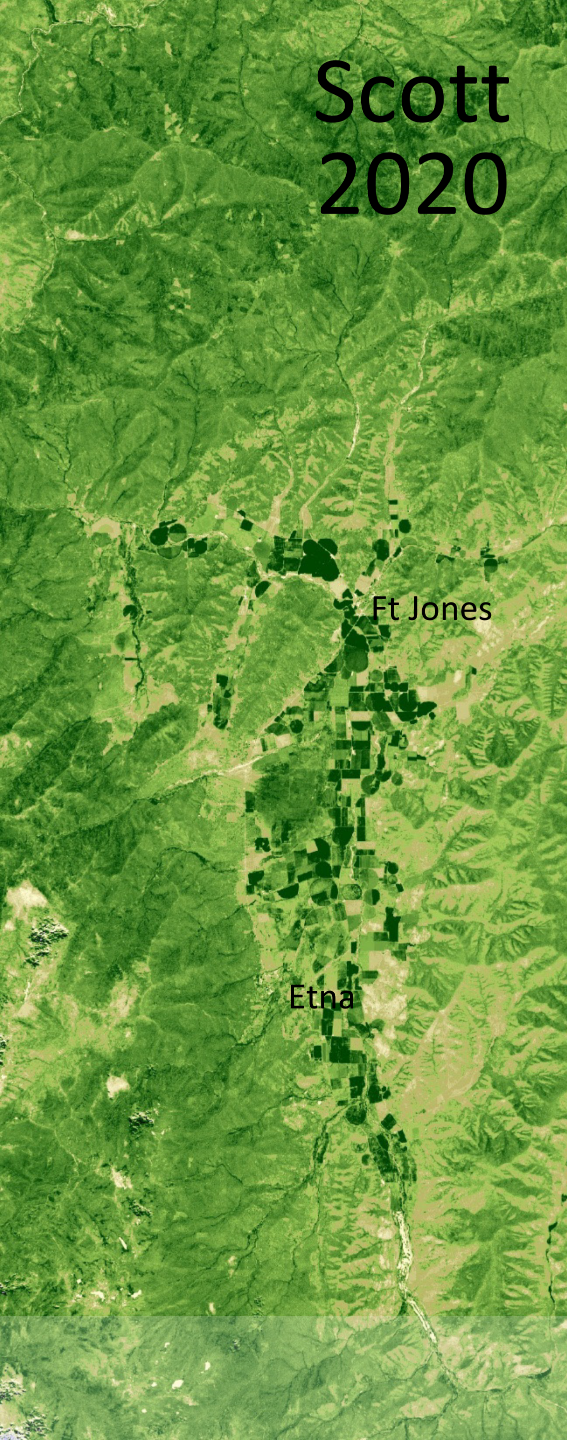

5 km
2017-05-03
Sentinel 2
true color
copernicus
sentinelhub

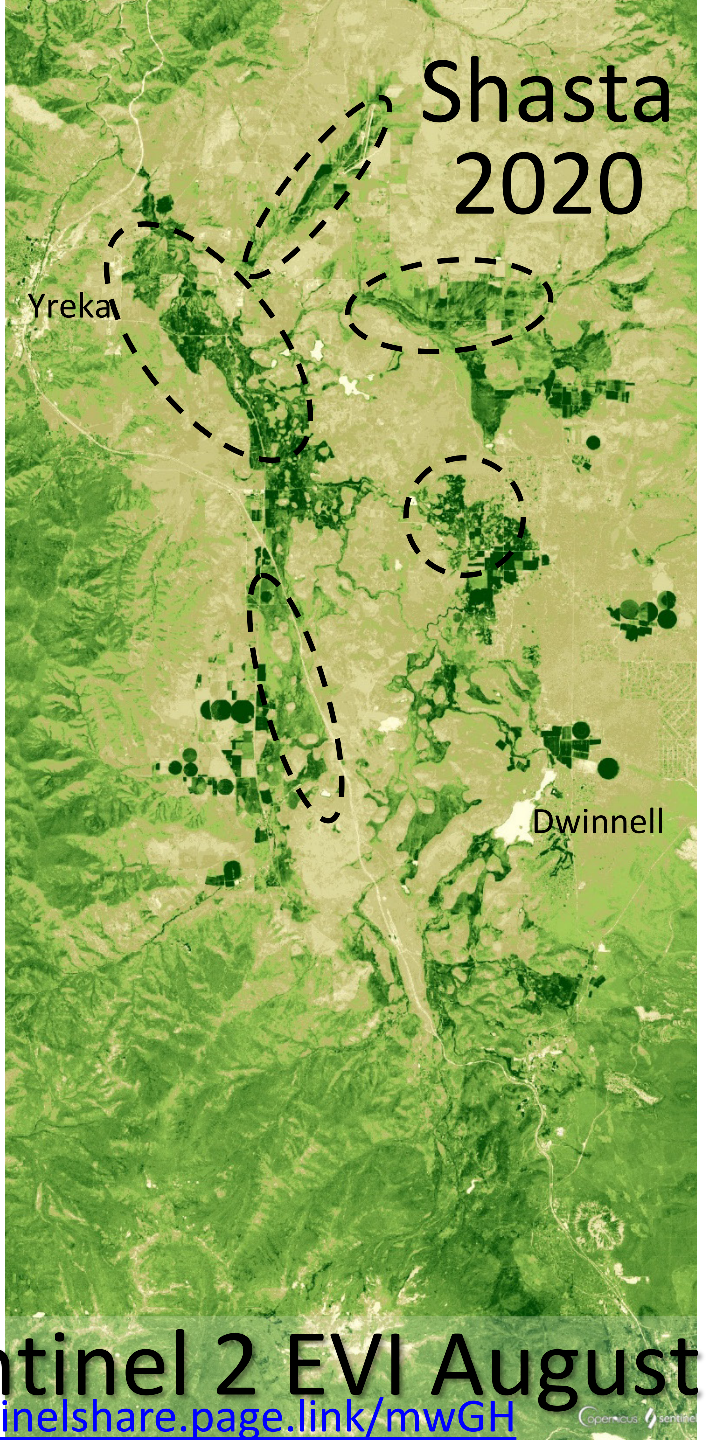

5 km
2017-05-03
Sentinel 2
greenness
EVI
copernicus
sentinelhub



All images: Sentinel 2 EVI August 15

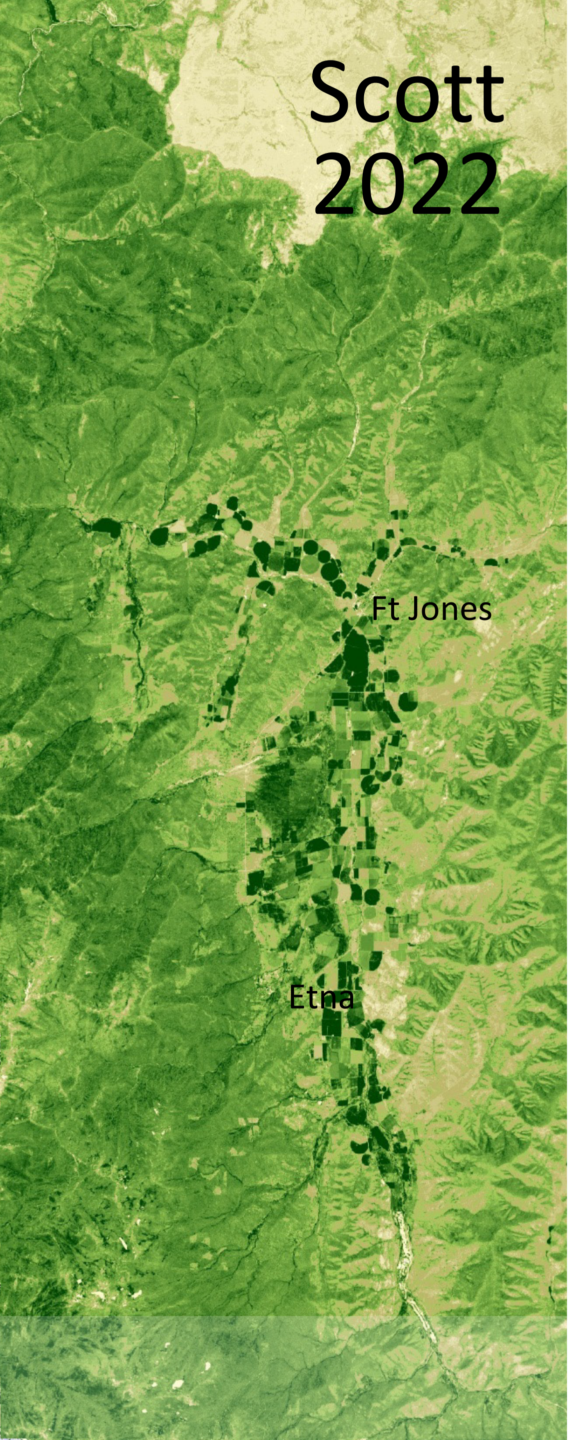
https://sentinelshare.page.link/mwGH

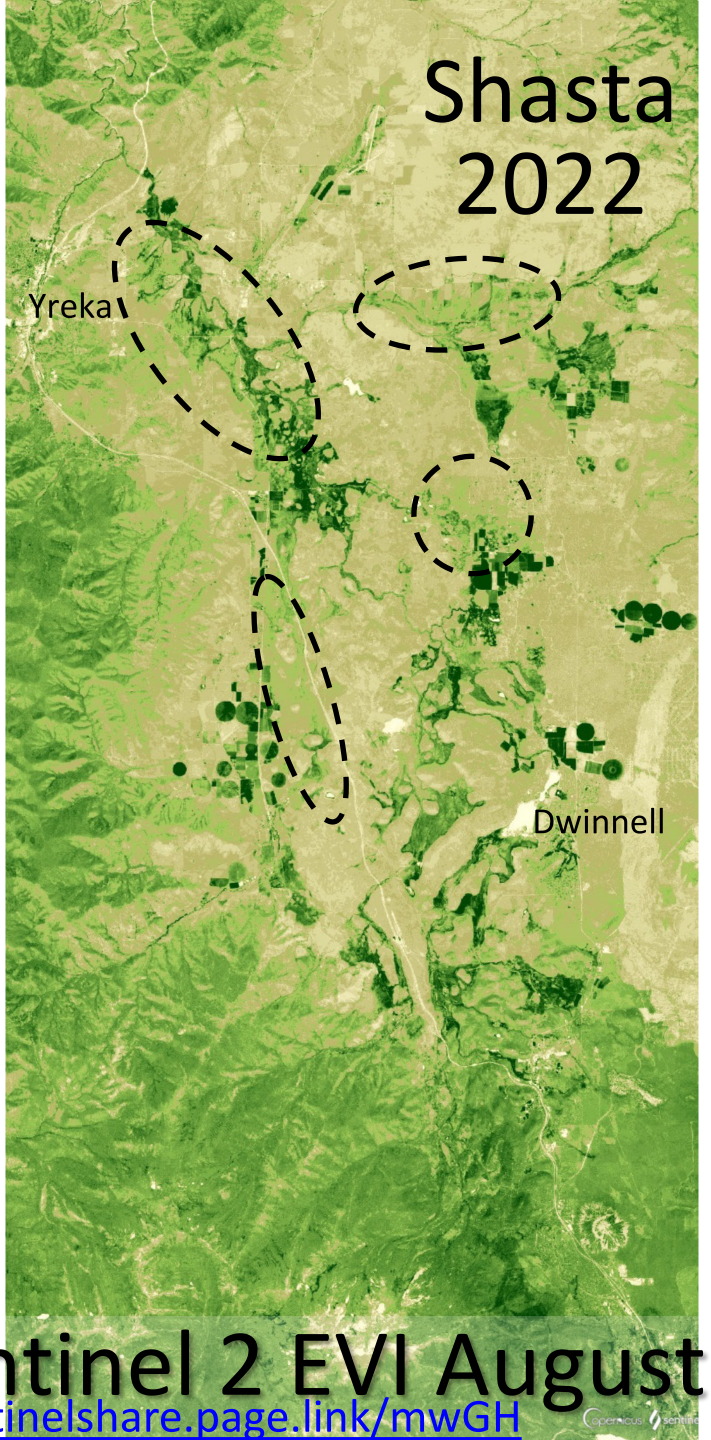




All images: Sentinel 2 EVI August 15

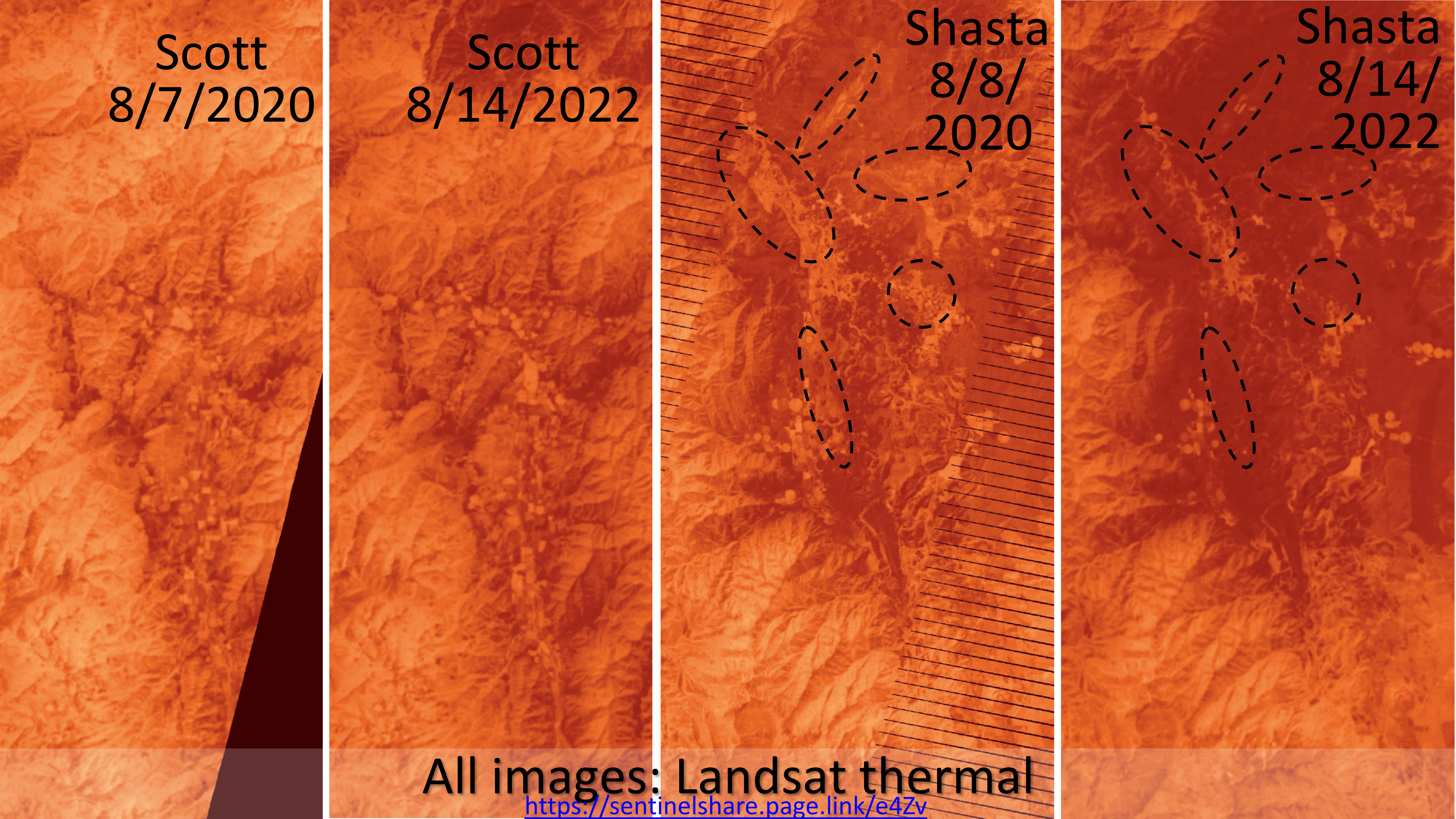
https://sentinelshare.page.link/mwGH





All images: Sentinel 2 EVI August 15

https://sentinelshare.page.link/mwGH


Scott
8/7/2020
Scott
8/14/2022
Shasta
8/8/
2020
Shasta
8/14/
2022
All images: Landsat thermal
https://sentinelshare.page.link/e4Zv

What are consumptive use (evapotranspiration) and irrigation efficiency?

How does they affect water budgets?

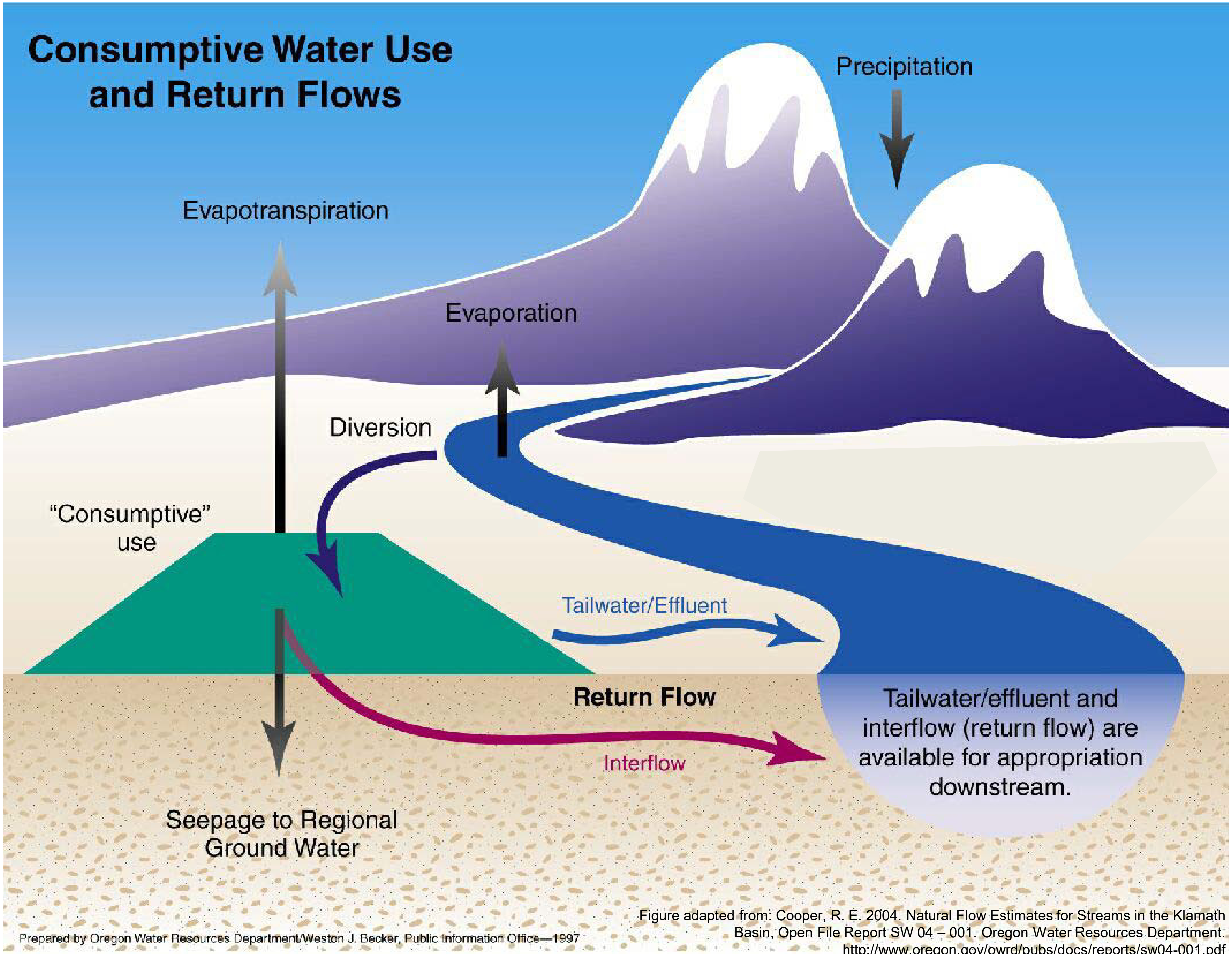
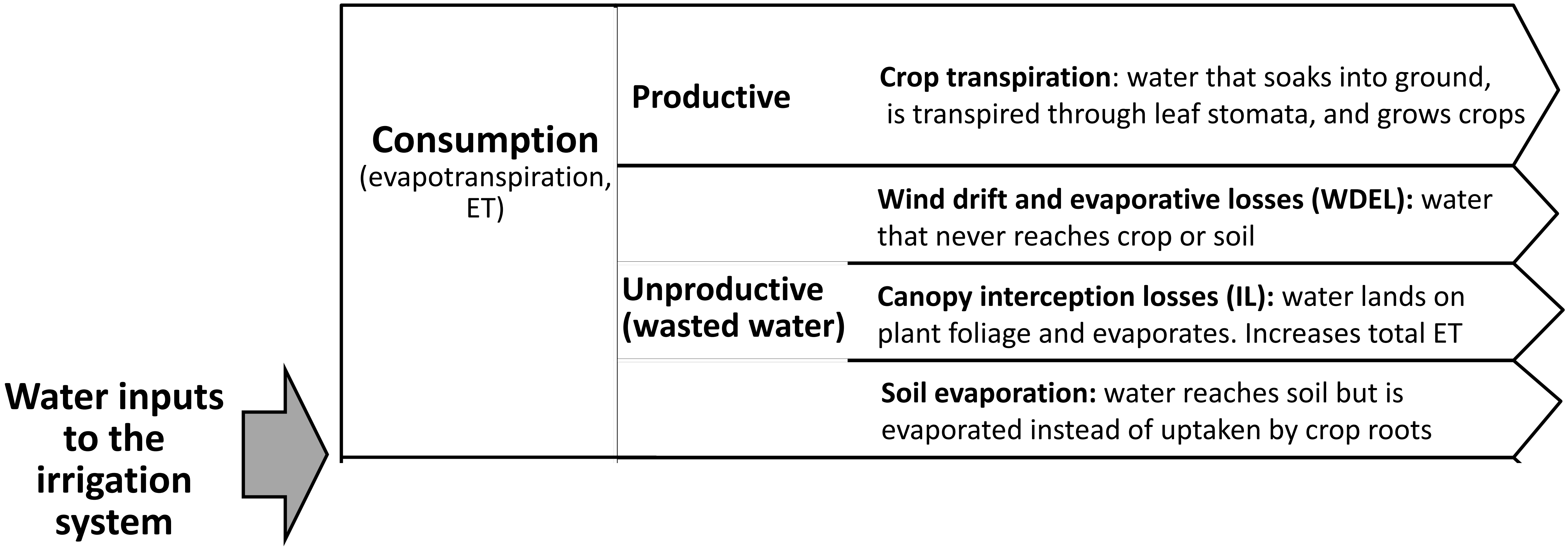
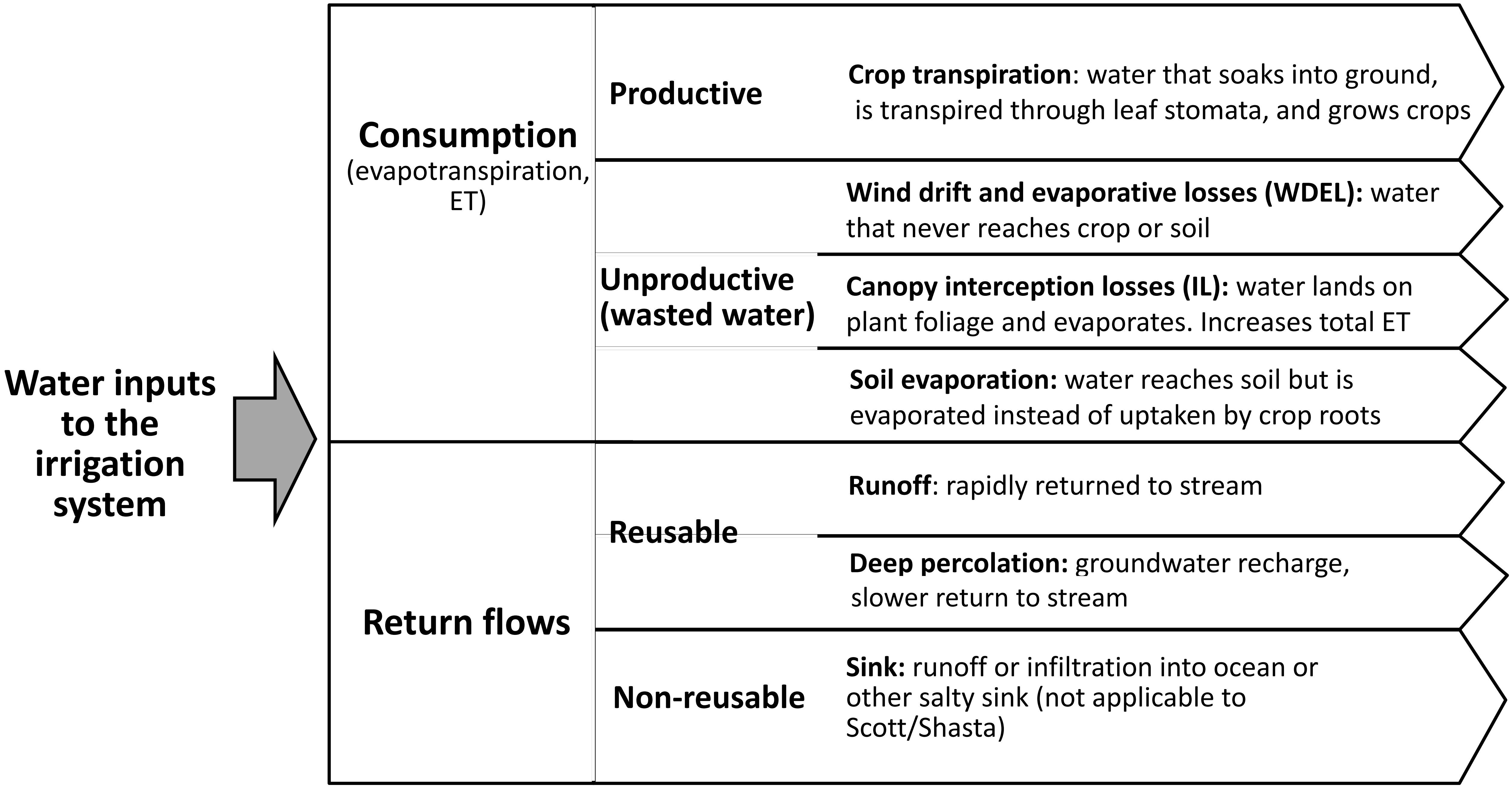


Figure adapted from: Cooper, R. E. 2004. Natural Flow Estimates for Streams in the Klamath Basin, Open File Report SW 04 – 001. Oregon Water Resources Department. http://www.oregon.gov/owrd/pubs/docs/reports/sw04-001.pdf


Water inputs to the irrigation system
Consumption
(evapotranspiration, ET)
Productive
Crop transpiration: water that soaks into ground, is transpired through leaf stomata, and grows crops
Unproductive (wasted water)
Wind drift and evaporative losses (WDEL): water that never reaches crop or soil
Canopy interception losses (IL): water lands on plant foliage and evaporates. Increases total ET
Soil evaporation: water reaches soil but is evaporated instead of uptaken by crop roots


Water inputs to the irrigation system
Consumption
(evapotranspiration, ET)
Productive
Crop transpiration: water that soaks into ground, is transpired through leaf stomata, and grows crops
Unproductive (wasted water)
Wind drift and evaporative losses (WDEL): water that never reaches crop or soil
Canopy interception losses (IL): water lands on plant foliage and evaporates. Increases total ET
Soil evaporation: water reaches soil but is evaporated instead of uptaken by crop roots
Return flows
Reusable
Runoff: rapidly returned to stream
Deep percolation: groundwater recharge, slower return to stream
Non-reusable
Sink: runoff or infiltration into ocean or other salty sink (not applicable to Scott/Shasta)

The More You Expose, the More You Lose: Limiting Center Pivot Irrigation Water Losses

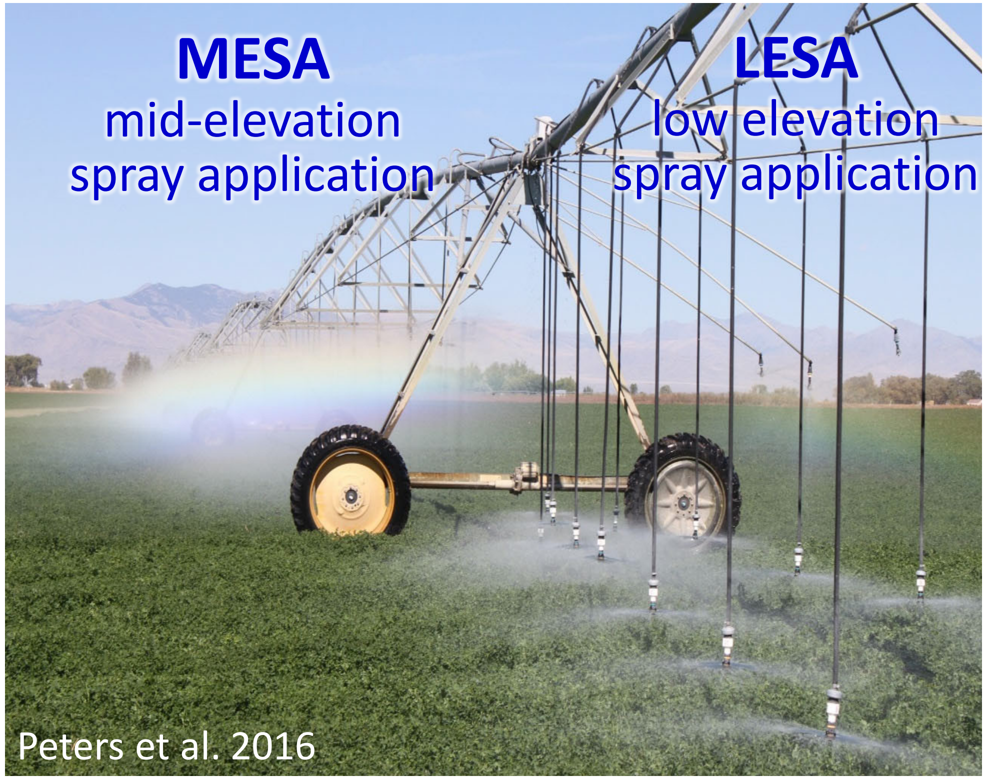
Sarwar and Peters

~5-20%?

More consumptive use → **Less consumptive use**

High-pressure impact sprinkler

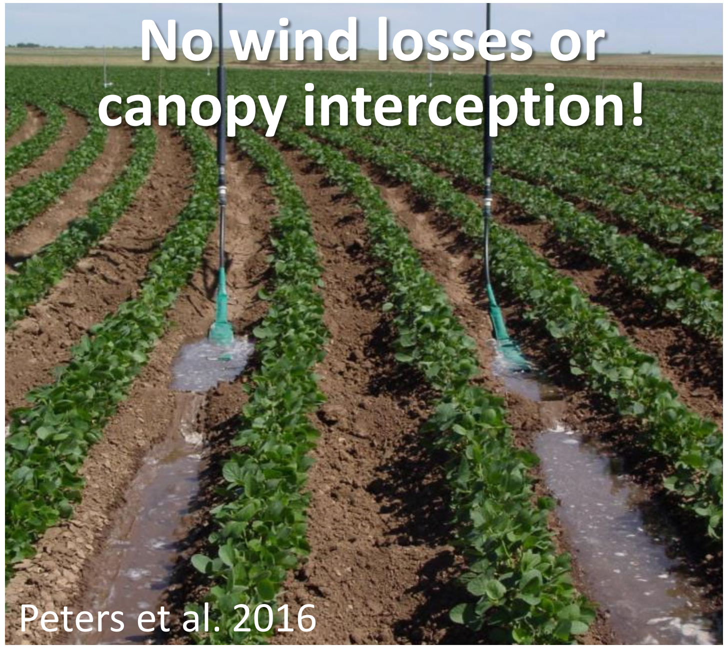

Hill 2020



Peters et al. 2016

LEPA

Low energy precision application



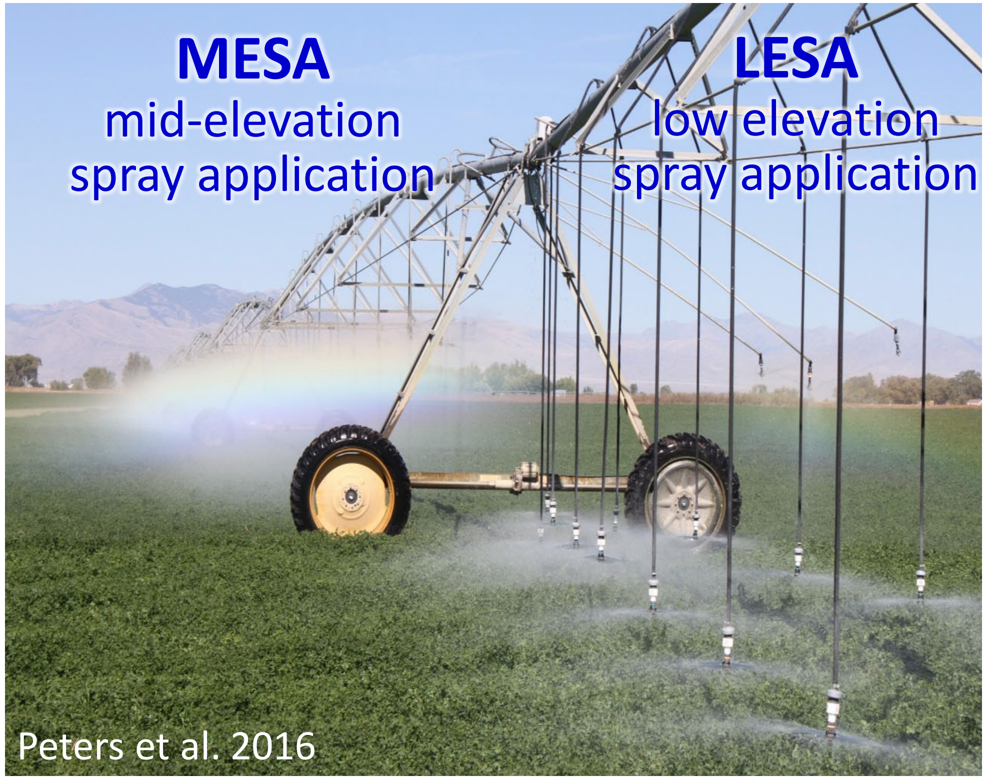
Peters et al. 2016

- Move sprinklers as close to the ground as possible
- Decrease pressure
- Increase nozzle sizes
- Large droplets, but don’t compromise water distribution uniformity and runoff

~5-20%?

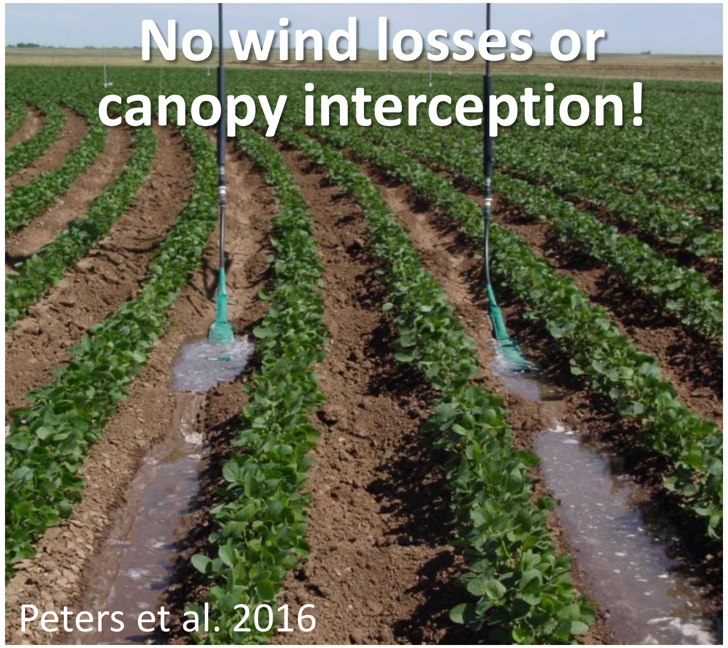
More consumptive use → **Less consumptive use**

High-pressure impact sprinkler



LEPA

Low energy precision application

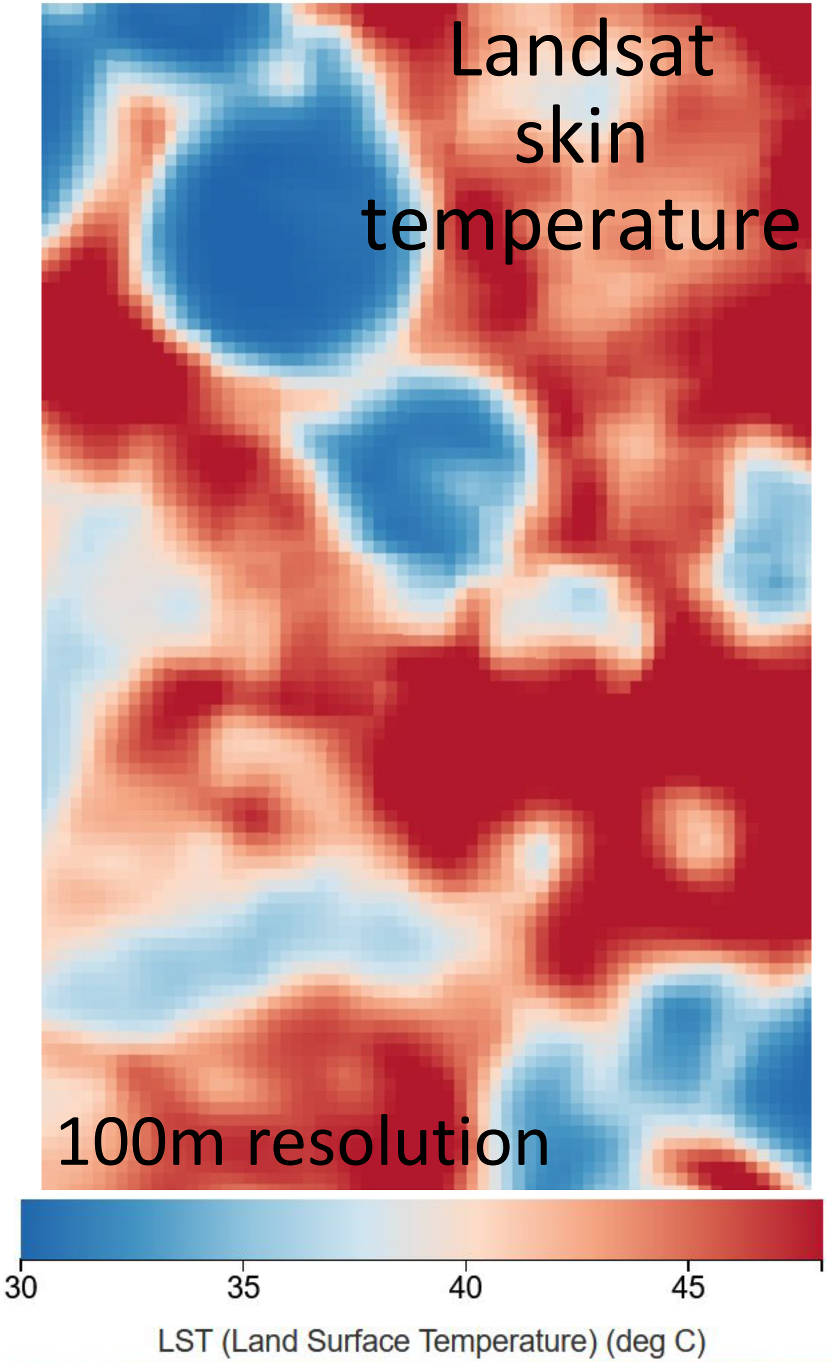


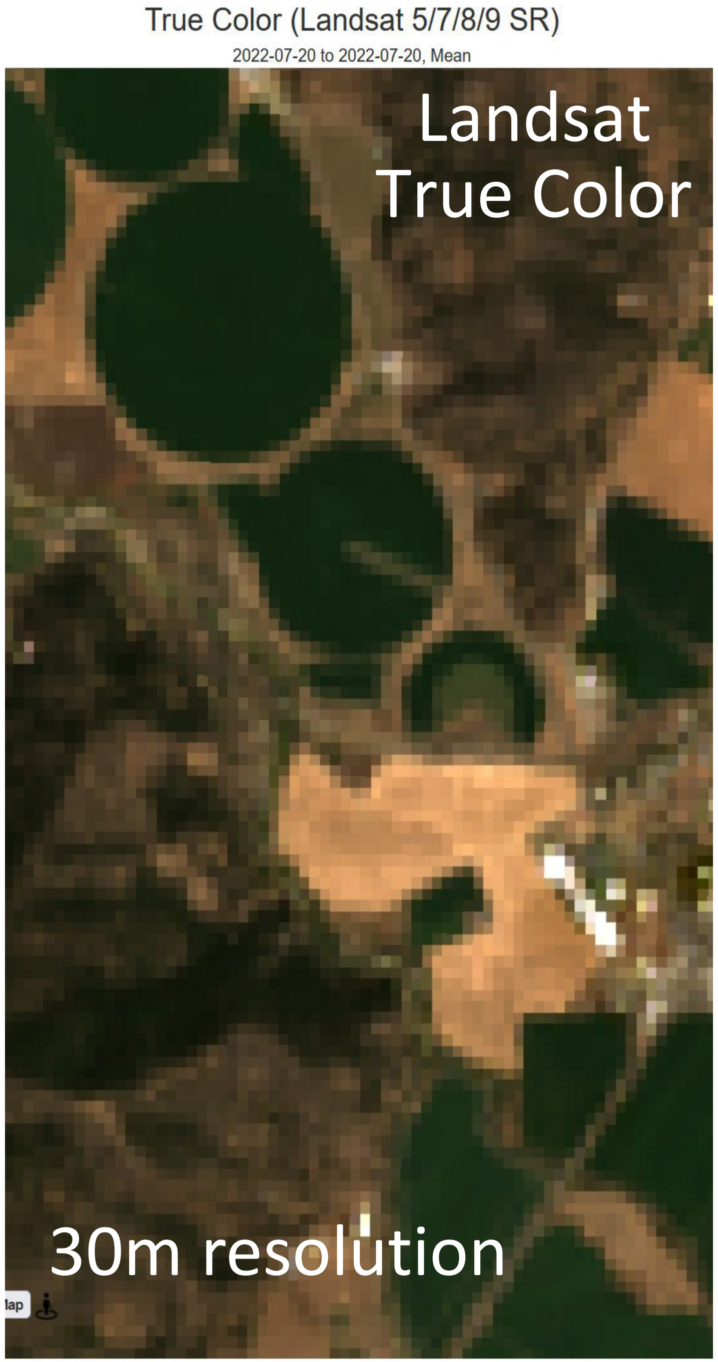
Estimating "actual evapotranspiration" (ETa)

Field measurements (hard)

Assuming fully-watered field: calculate reference evapotranspiration (ET_0 or ET_r, aka "evaporative demand") from weather data, then multiply by crop coefficient

Remote sensing


Landsat skin temperature
100m resolution
30
35
40
45
LST (Land Surface Temperature) (deg C)


True Color (Landsat 5/7/8/9 SR)
2022-07-20 to 2022-07-20, Mean
Landsat True Color
30m resolution

OPENET

https://openetdata.org/

EDF ENVIRONMENTAL DEFENSE FUND Finding the ways that work

Google Earth Engine

NASA

DRI

USGS

UNIVERSITY *of* NEBRASKA–LINCOLN

HabitatSeven

USDA ars

University of Idaho

UNIVERSITY OF MARYLAND 1856

WISCONSIN UNIVERSITY OF WISCONSIN–MADISON

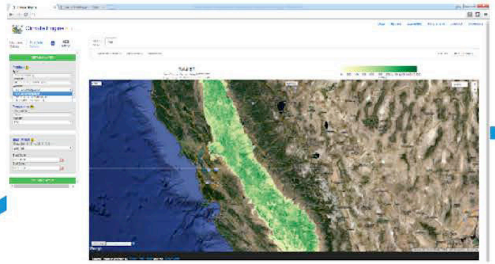
California State University MONTEREY BAY

UFRGS UNIVERSIDADE FEDERAL DO RIO GRANDE DO SUL

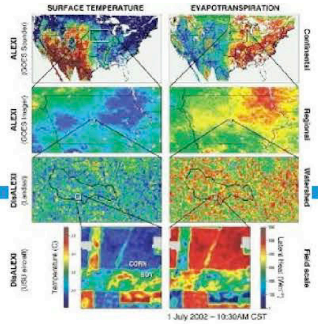
OPENET

https://openetdata.org/

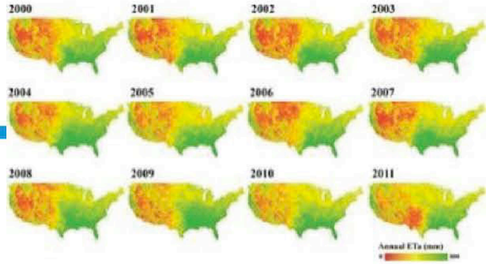
Ensemble average of 6 models



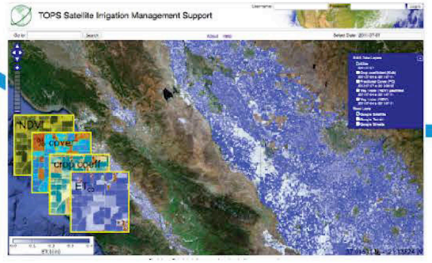
EE METRIC
University of Nebraska, University of Idaho



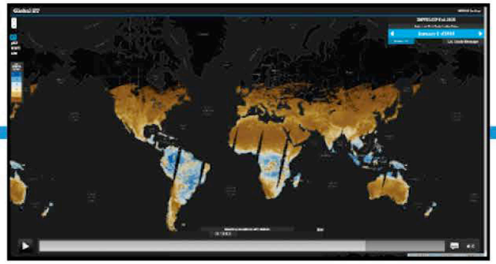
ALEXI/DisALEXI
USDA, NASA, University of Maryland, University of Wisconsin



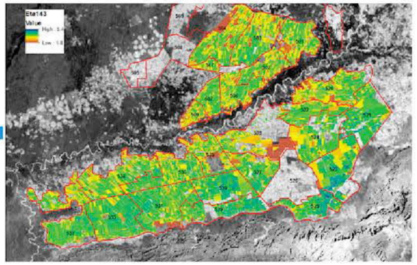
SSEBop
USGS



SIMS
NASA, CSUMB, Stanford University

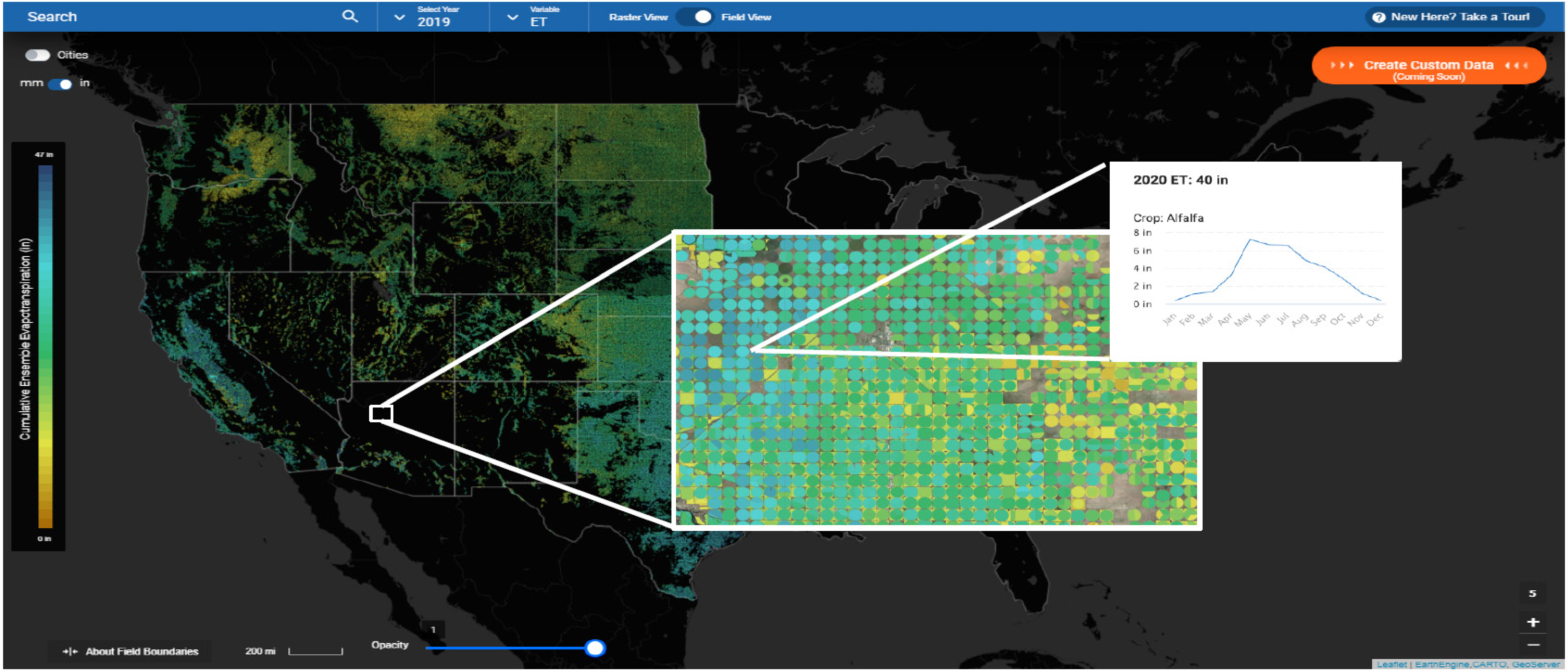


PT-JPL
NASA



SEBAL

OPENET



Time series for Scott/Shasta fields provided by OpenET's Will Carrara

OPENET methods

Gridded weather data:
(mostly spatial CIMIS)

reference ET
(assumes fully watered crop)

OPENET methods

Satellites (mostly Landsat):
mostly skin temperature
(& greenness)

% of reference ET
(including gap-filling)

Gridded weather data:
(mostly spatial CIMIS)

reference ET
(assumes fully watered crop)

OPENET methods

Satellites (mostly Landsat):
mostly skin temperature
(& greenness)

Gridded weather data:
(mostly spatial CIMIS)

% of reference ET
(including gap-filling)

reference ET
(assumes fully watered crop)

ET_a for each
30-meter pixel

OPENET methods

Satellites (mostly Landsat): mostly skin temperature (& greenness)

Gridded weather data: (mostly spatial CIMIS)

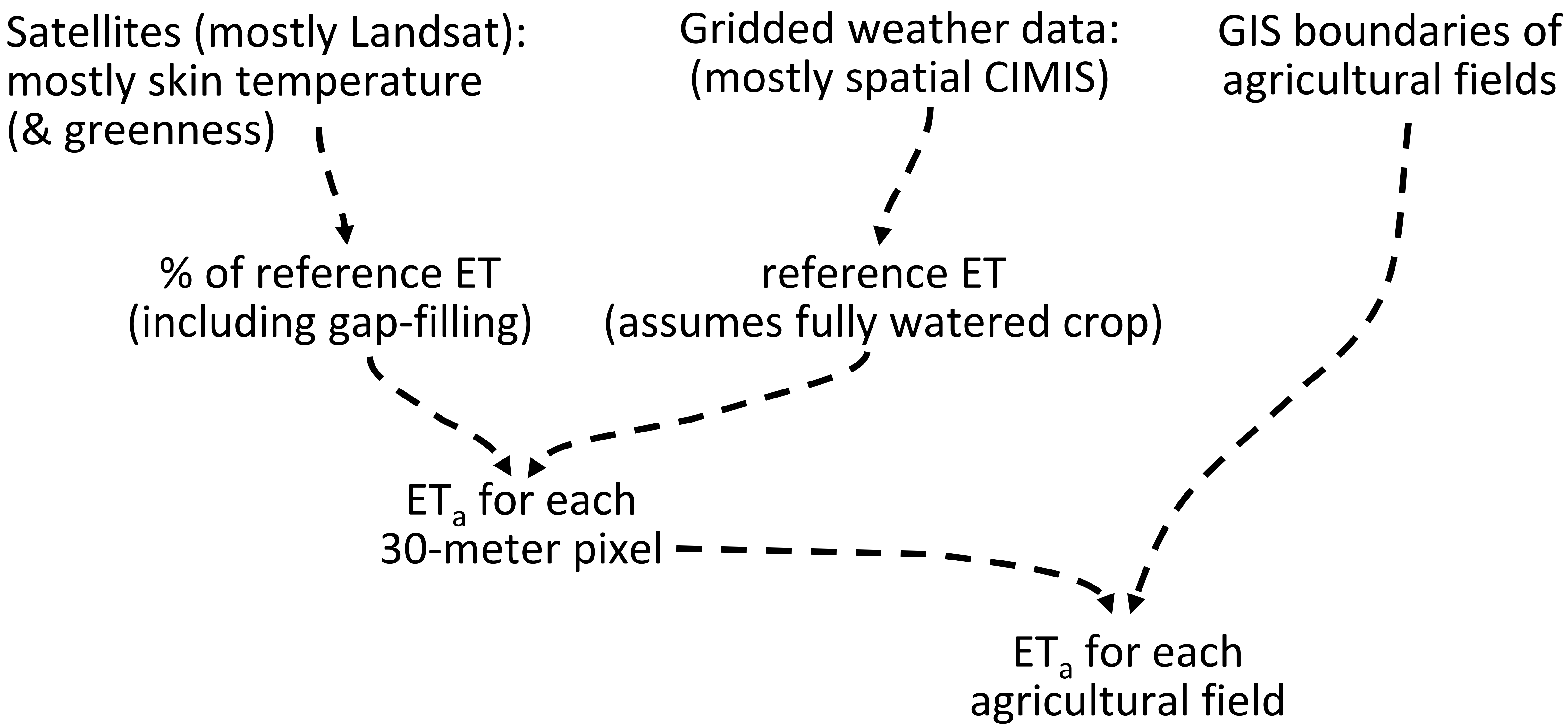
GIS boundaries of agricultural fields

% of reference ET (including gap-filling)

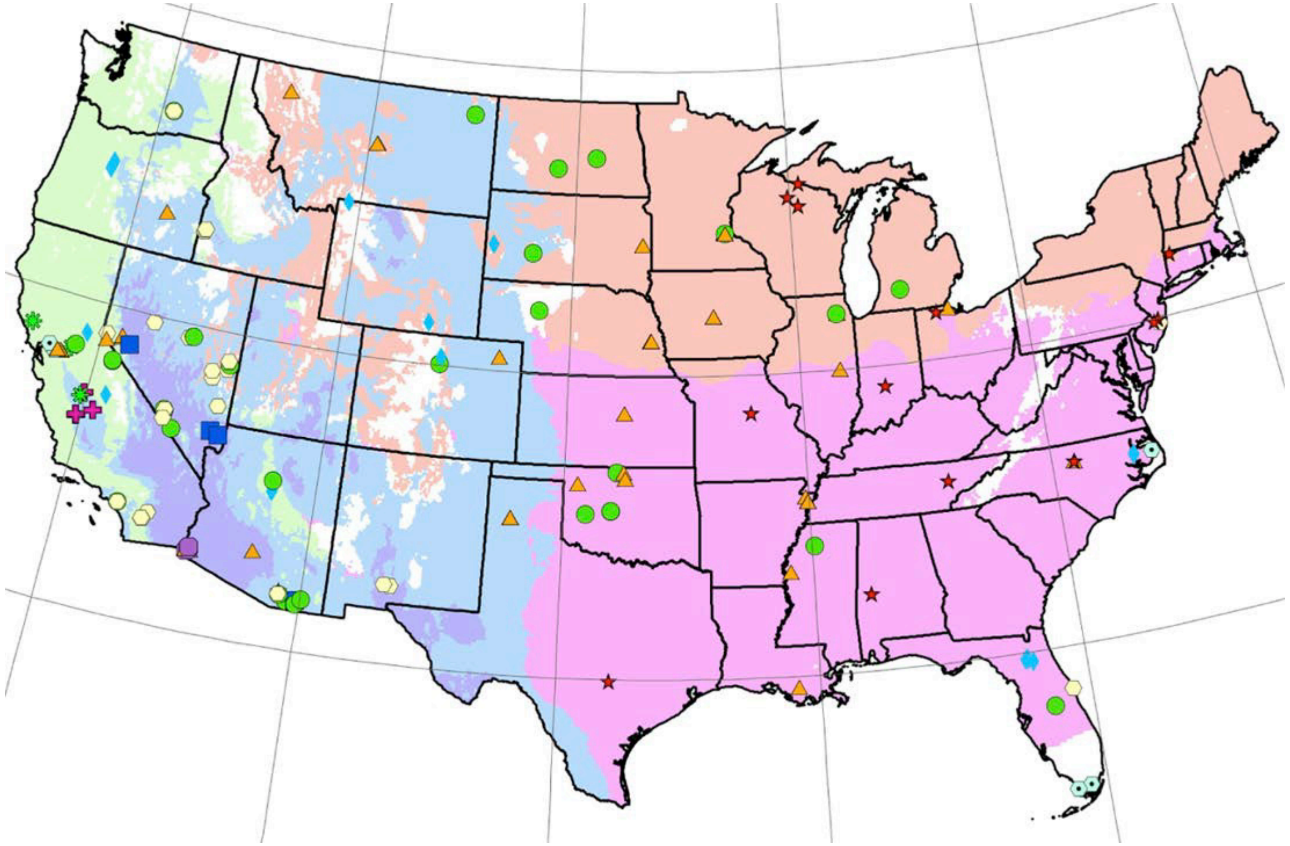
reference ET (assumes fully watered crop)

ET_a for each 30-meter pixel

OPENET methods

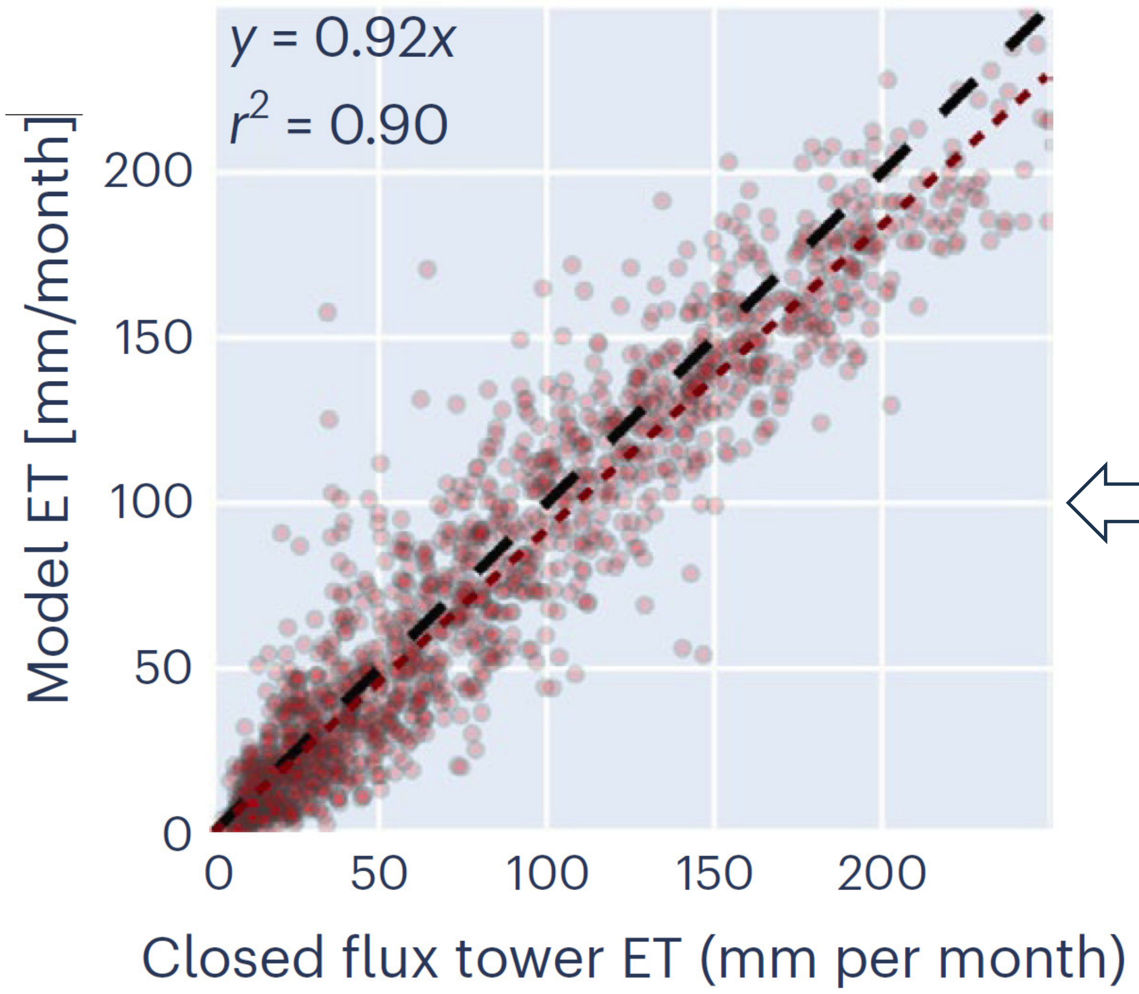


OPENET ETa validation



Volk et al. 2024: https://doi.org/10.1038/s44221-023-00181-7

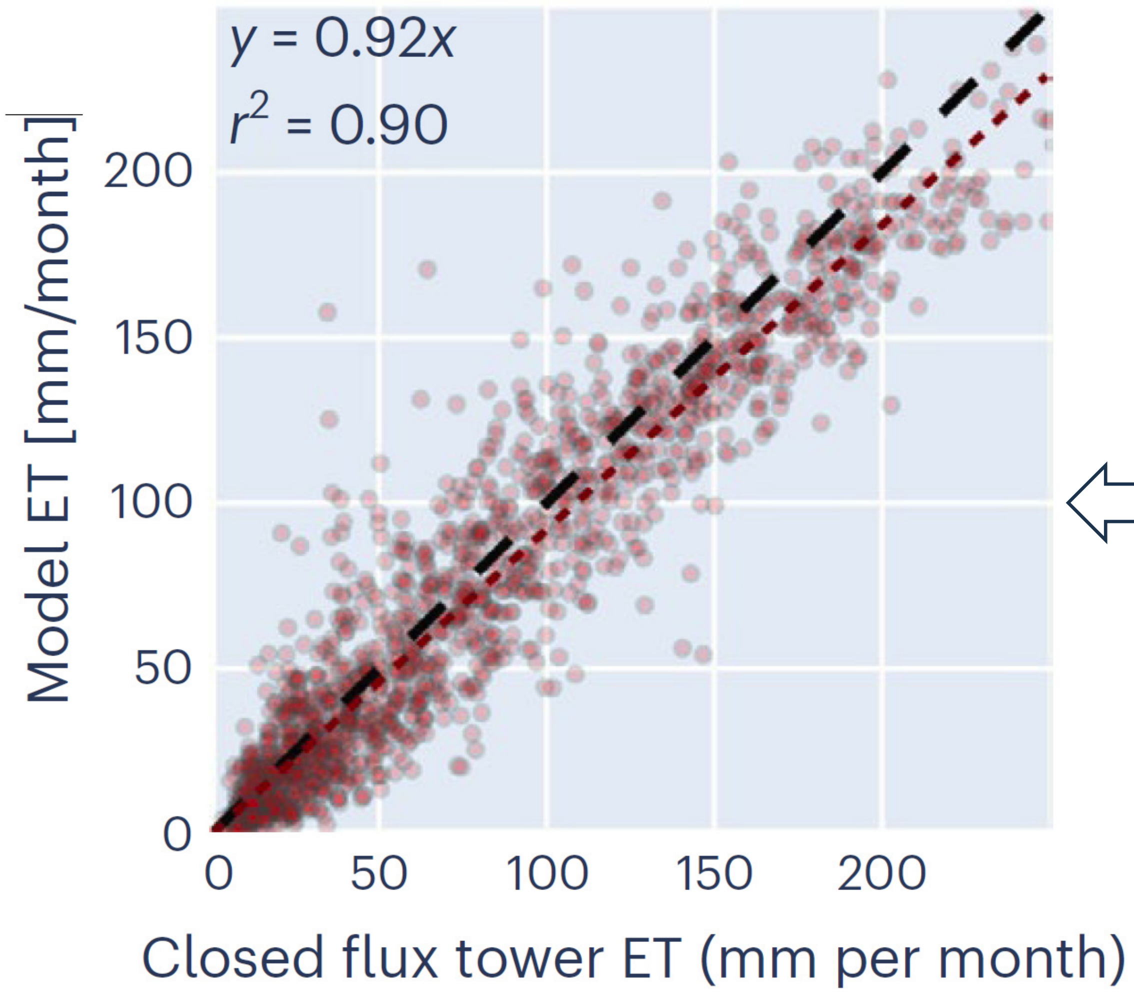
OPENET ETa validation: 53 cropland sites



Time period	Average error (MAE)
Monthly	17%

Volk et al. 2024: https://doi.org/10.1038/s44221-023-00181-7

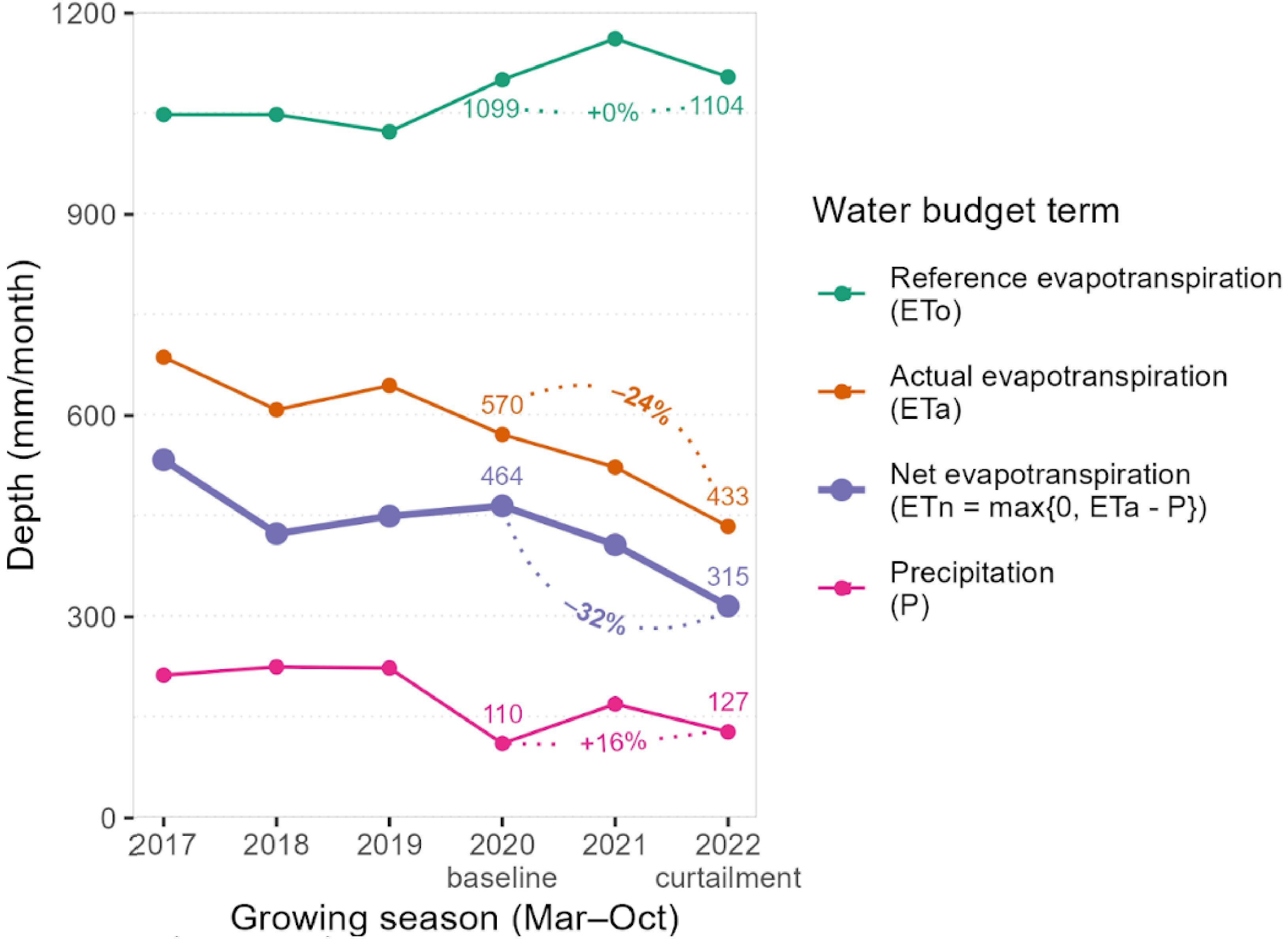
ETa validation: 53 cropland sites



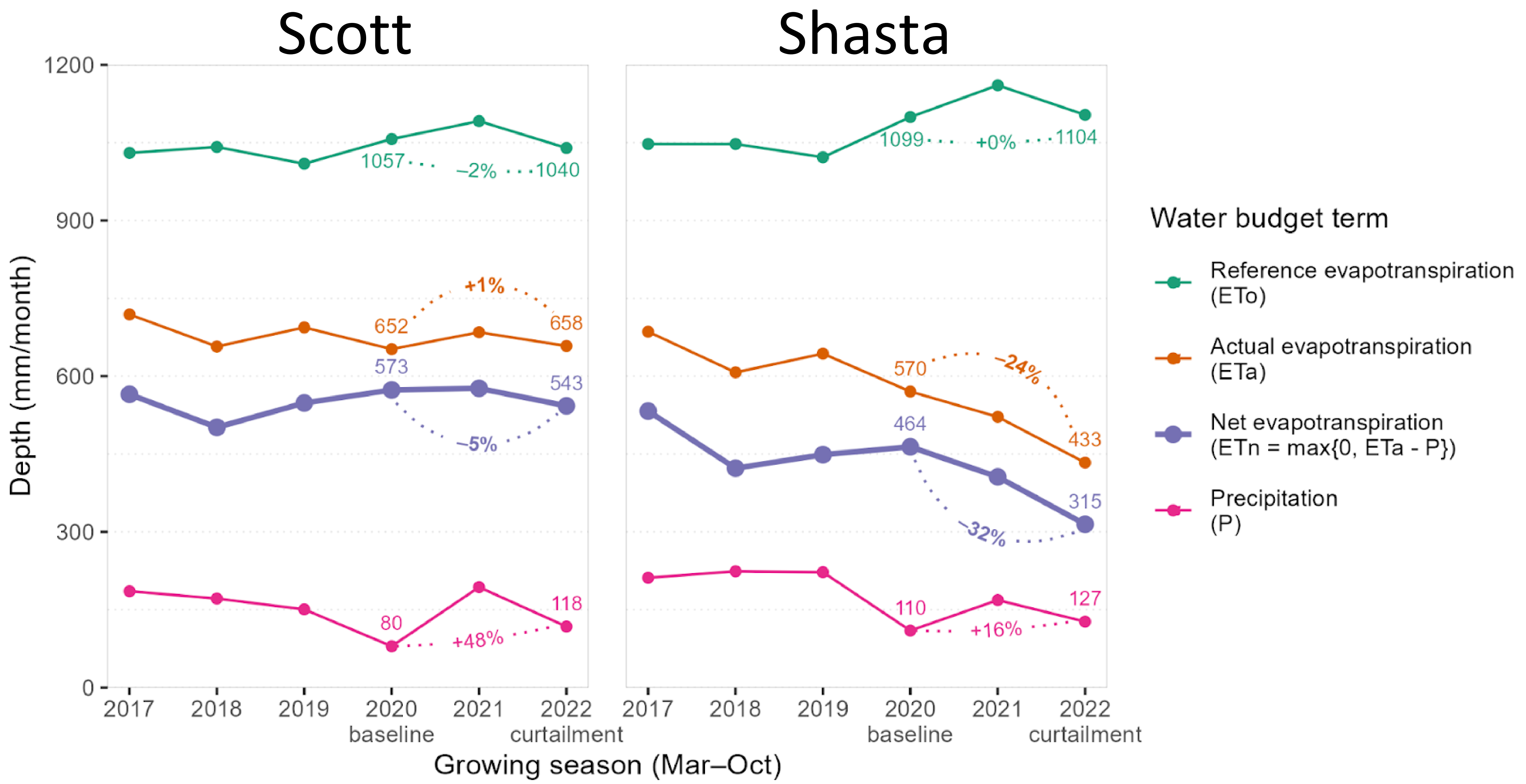
Time period	Average error (MAE)
Monthly	17%
Growing season	13%

Volk et al. 2024: https://doi.org/10.1038/s44221-023-00181-7

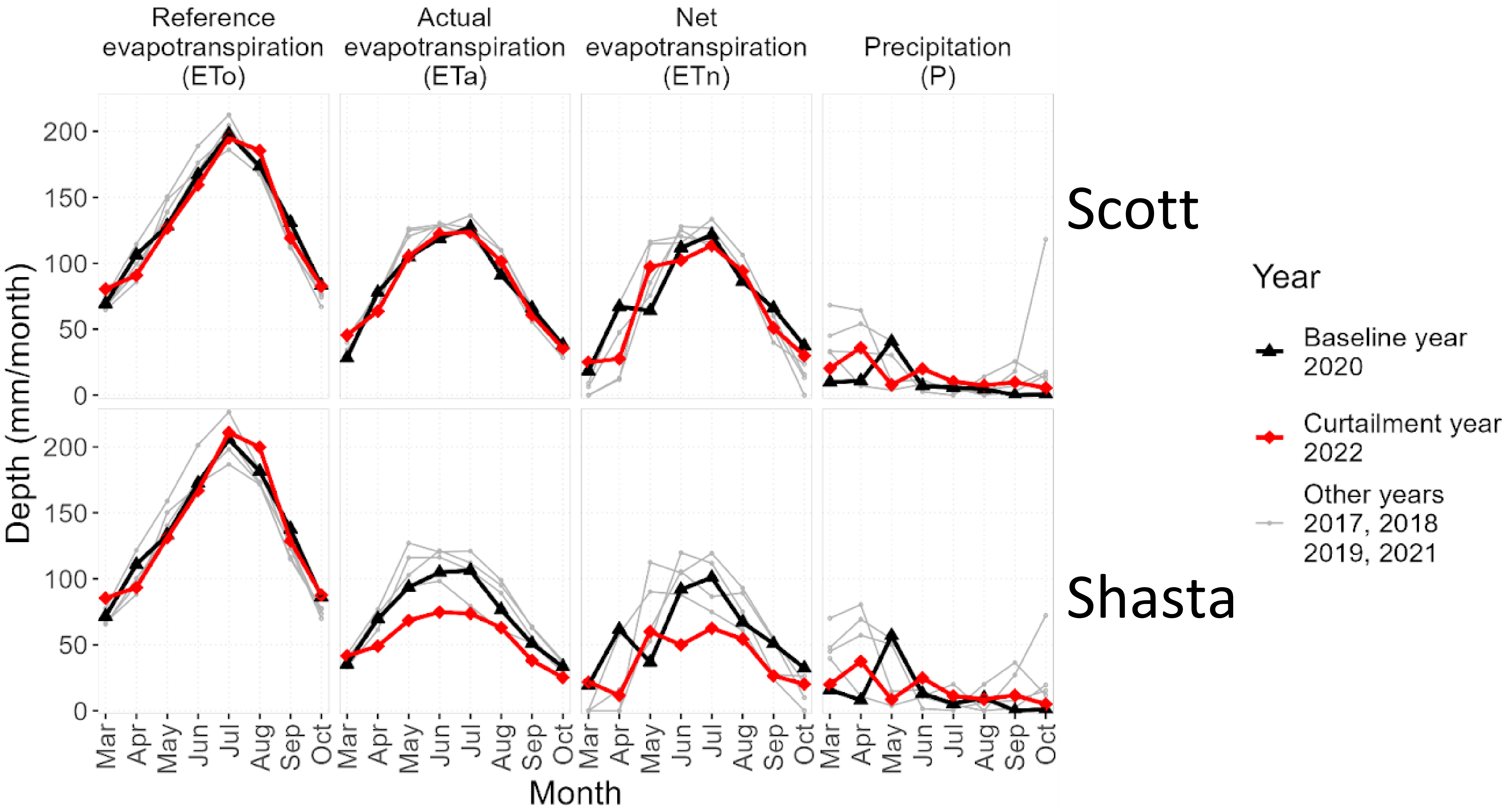
Shasta



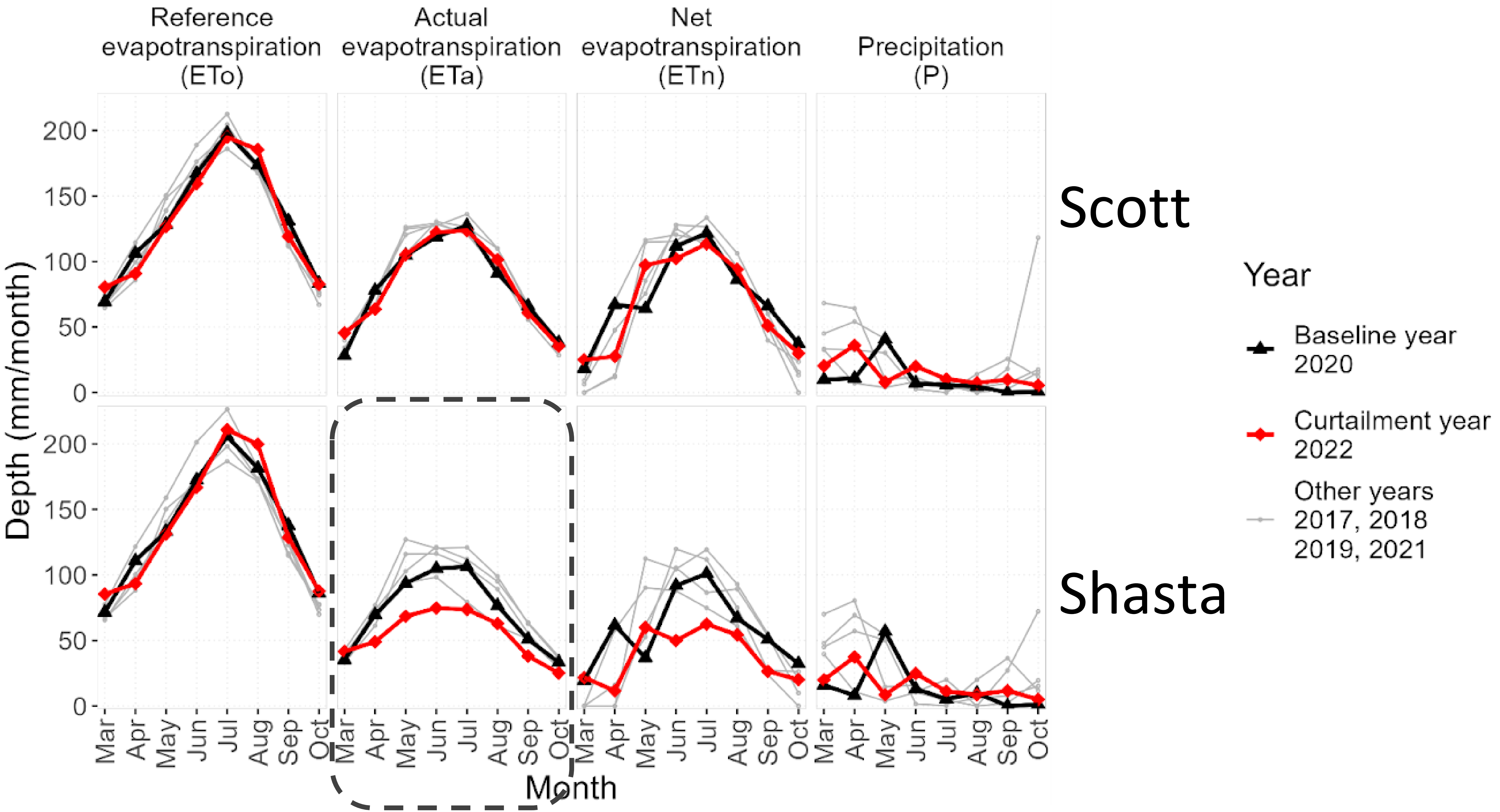
1200
900
600
300
0
Depth (mm/month)
1099
+0%
1104
570
−24%
433
464
315
−32%
110
+16%
127
2017
2018
2019
2020
baseline
2021
2022
curtailment
Growing season (Mar–Oct)
Water budget term
Reference evapotranspiration (ETo)
Actual evapotranspiration (ETa)
Net evapotranspiration (ETn = max{0, ETa - P})
Precipitation (P)

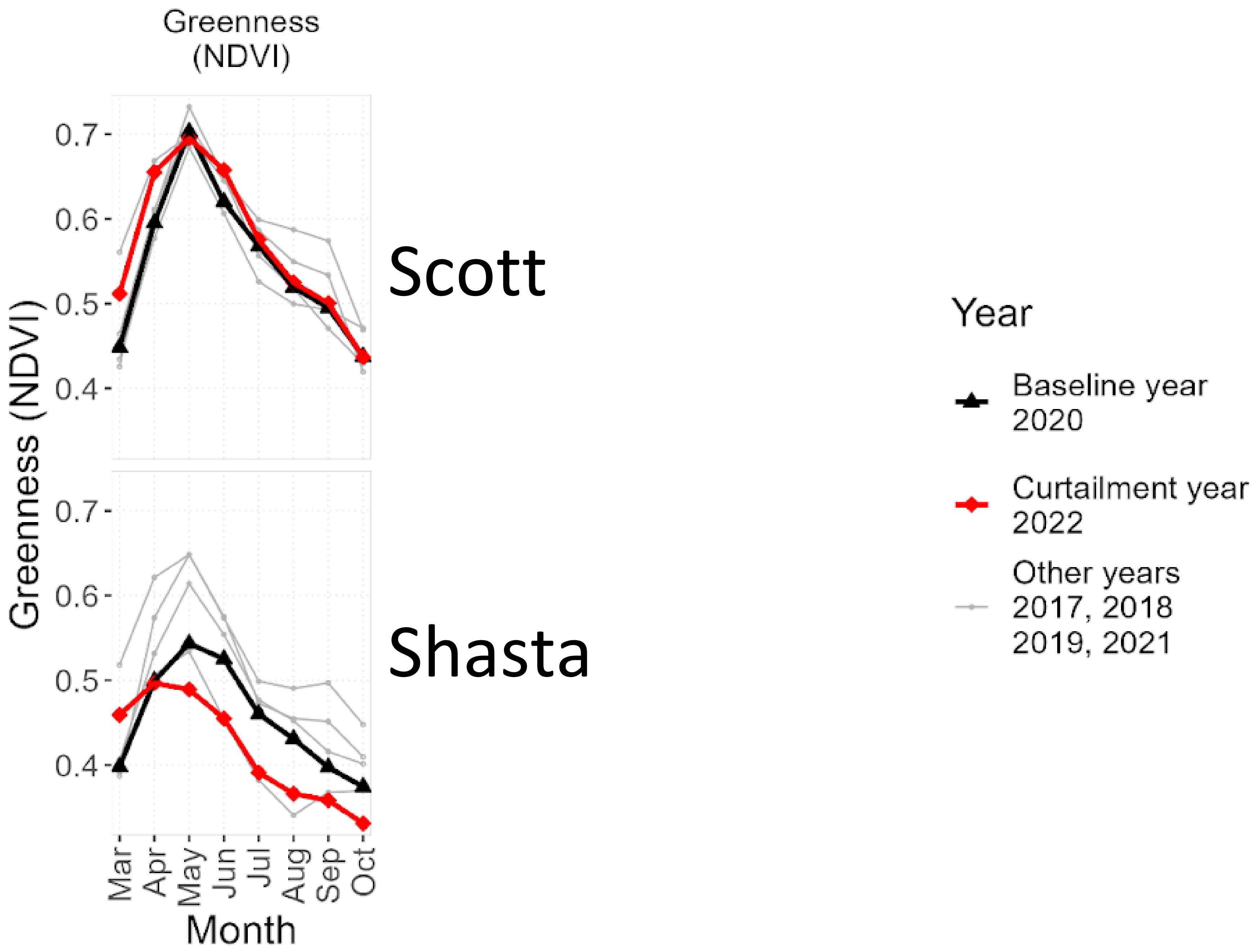


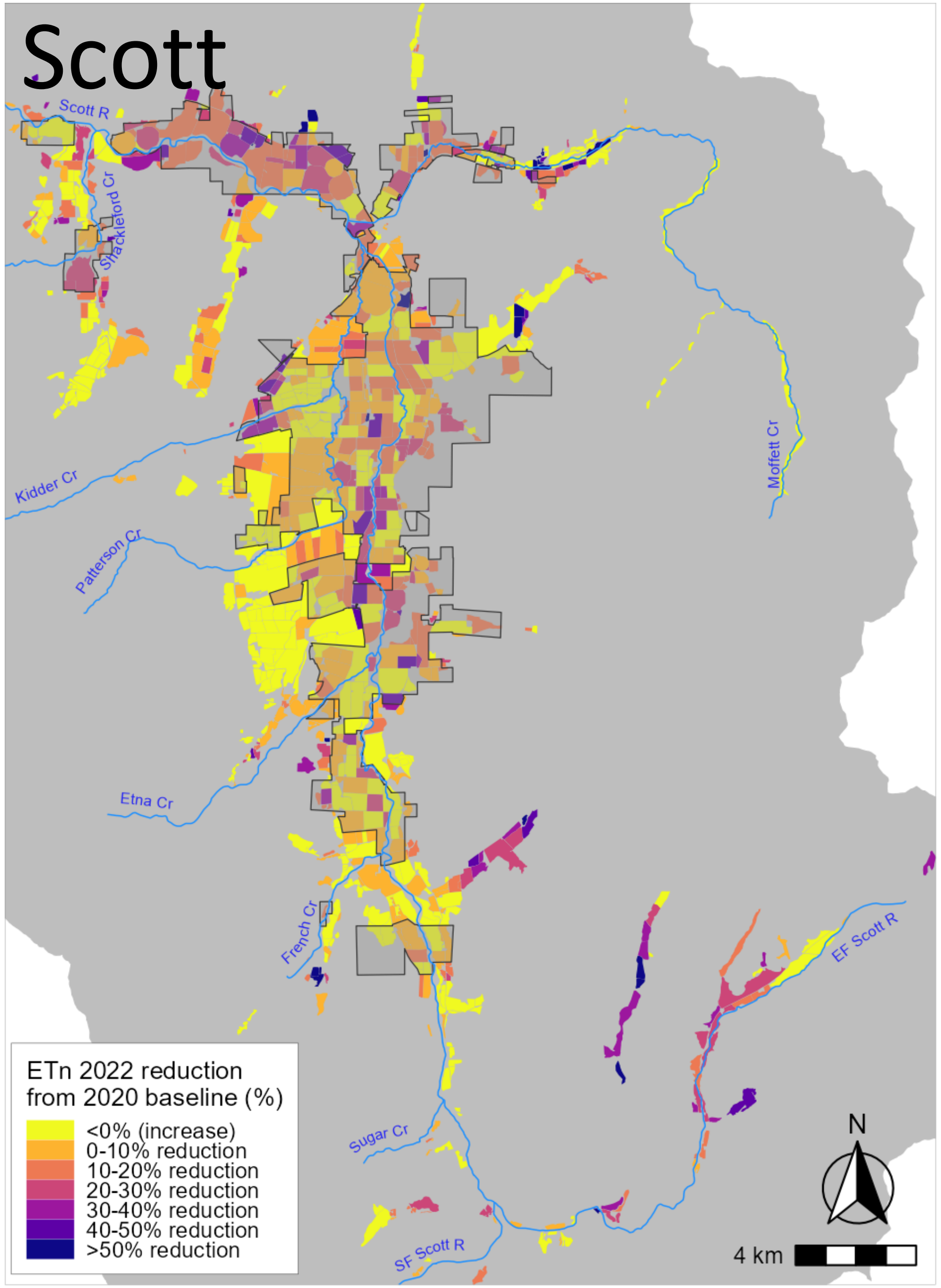
Scott
Shasta
Depth (mm/month)
1200
900
600
300
0
1057
−2%
1040
+1%
652
658
573
543
−5%
80
+48%
118
1099
+0%
1104
570
−24%
433
464
315
−32%
110
+16%
127
2017
2018
2019
2020
baseline
2021
2022
curtailment
Growing season (Mar–Oct)
Water budget term
Reference evapotranspiration (ETo)
Actual evapotranspiration (ETa)
Net evapotranspiration (ETn = max{0, ETa - P})
Precipitation (P)

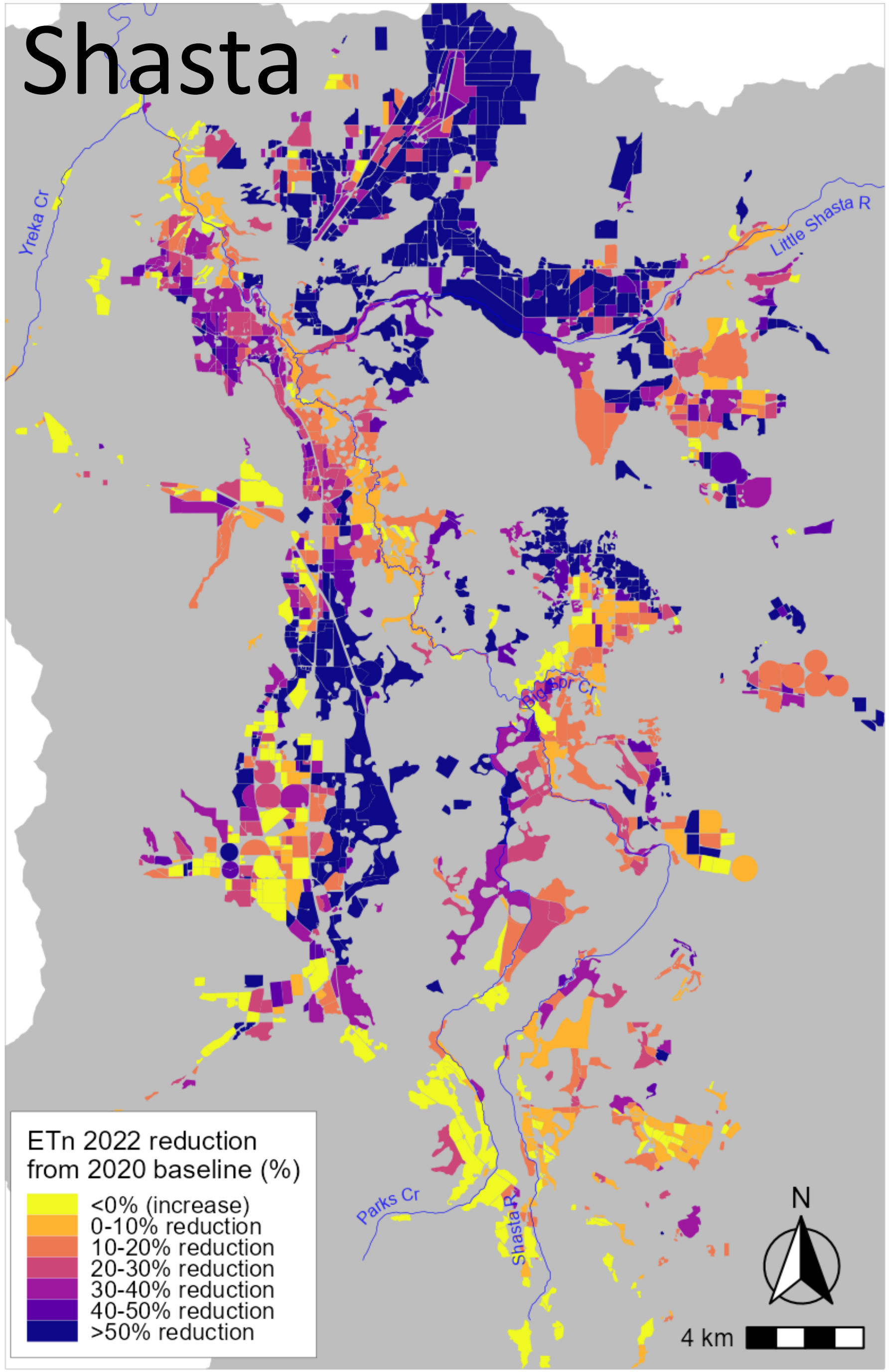


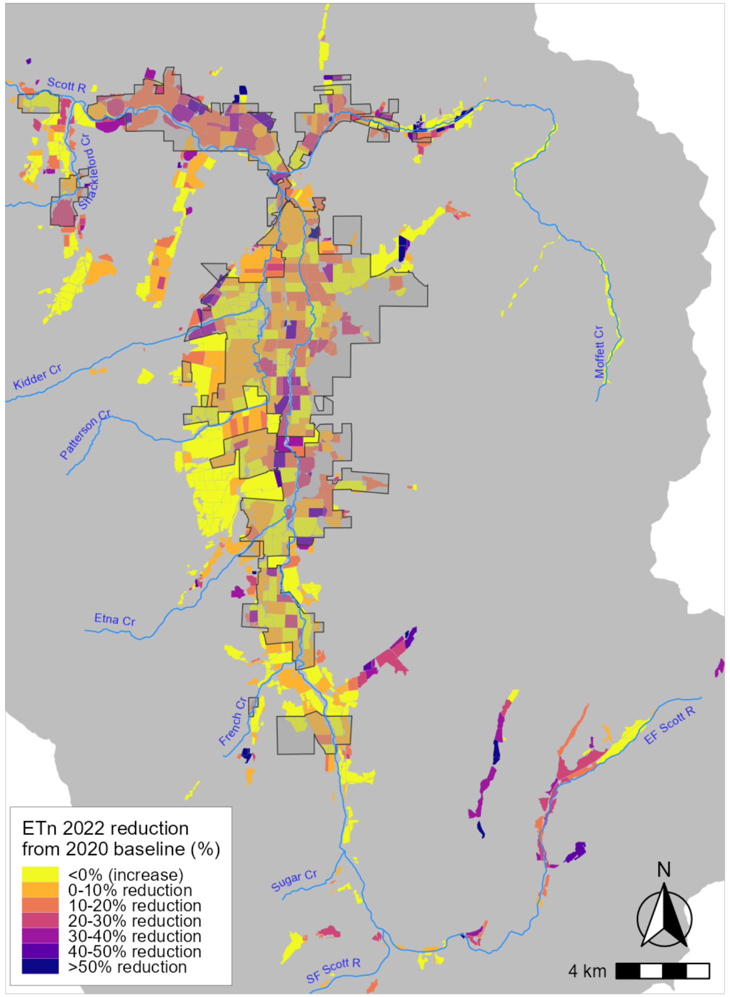
Reference evapotranspiration (ETo)
Actual evapotranspiration (ETa)
Net evapotranspiration (ETn)
Precipitation (P)
Scott
Shasta
Depth (mm/month)
Month
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
0
50
100
150
200
Year
Baseline year 2020
Curtailment year 2022
Other years 2017, 2018 2019, 2021

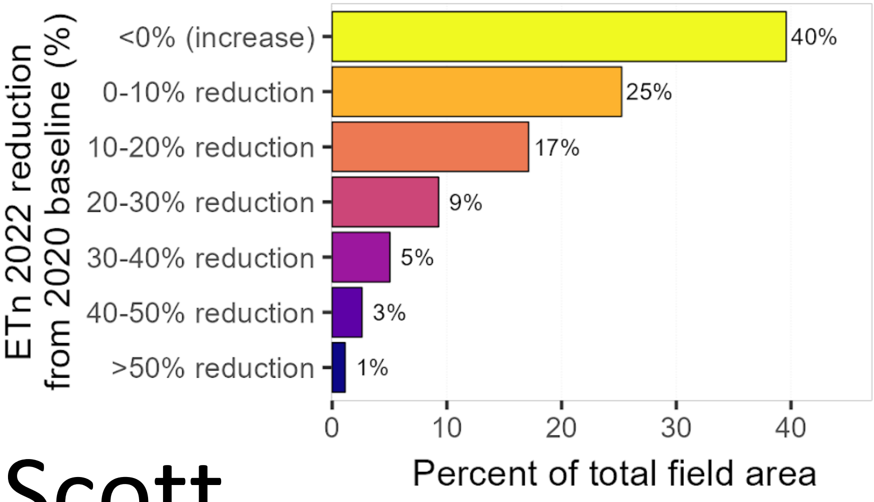

Reference evapotranspiration (ETo)
Actual evapotranspiration (ETa)
Net evapotranspiration (ETn)
Precipitation (P)
Depth (mm/month)
0
50
100
150
200
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Month
Scott
Shasta
Year
Baseline year 2020
Curtailment year 2022
Other years 2017, 2018 2019, 2021


Greenness
(NDVI)
Greenness (NDVI)
0.4
0.5
0.6
0.7
Scott
Shasta
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Month
Year
Baseline year
2020
Curtailment year
2022
Other years
2017, 2018
2019, 2021


Scott
Scott R
Shackleford Cr
Kidder Cr
Patterson Cr
Etna Cr
French Cr
Moffett Cr
Sugar Cr
SF Scott R
EF Scott R
ETn 2022 reduction from 2020 baseline (%)
<0% (increase)
0-10% reduction
10-20% reduction
20-30% reduction
30-40% reduction
40-50% reduction
>50% reduction
N
4 km

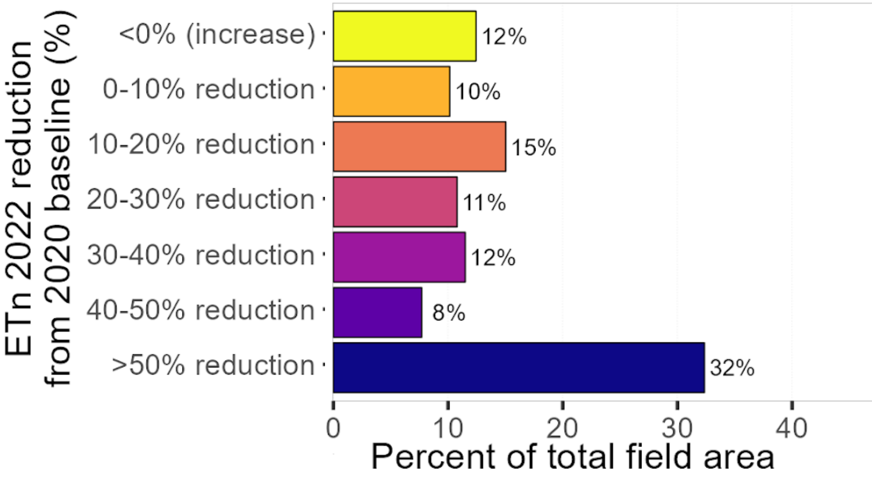

Shasta
Yreka Cr
Little Shasta R
Parks Cr
Shasta R
ETn 2022 reduction from 2020 baseline (%)
<0% (increase)
0-10% reduction
10-20% reduction
20-30% reduction
30-40% reduction
40-50% reduction
>50% reduction
N
4 km

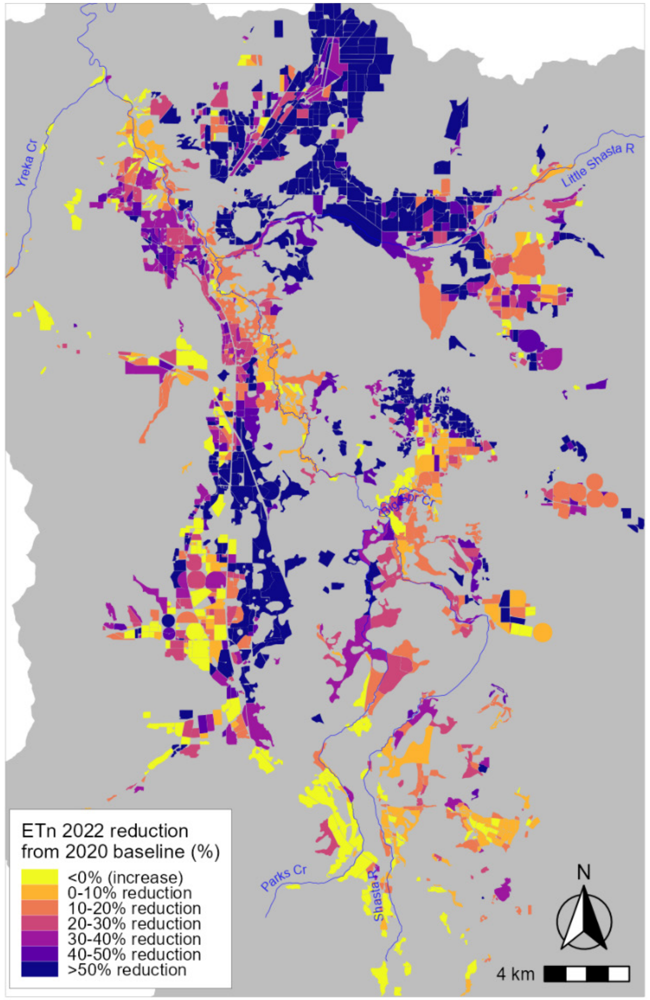


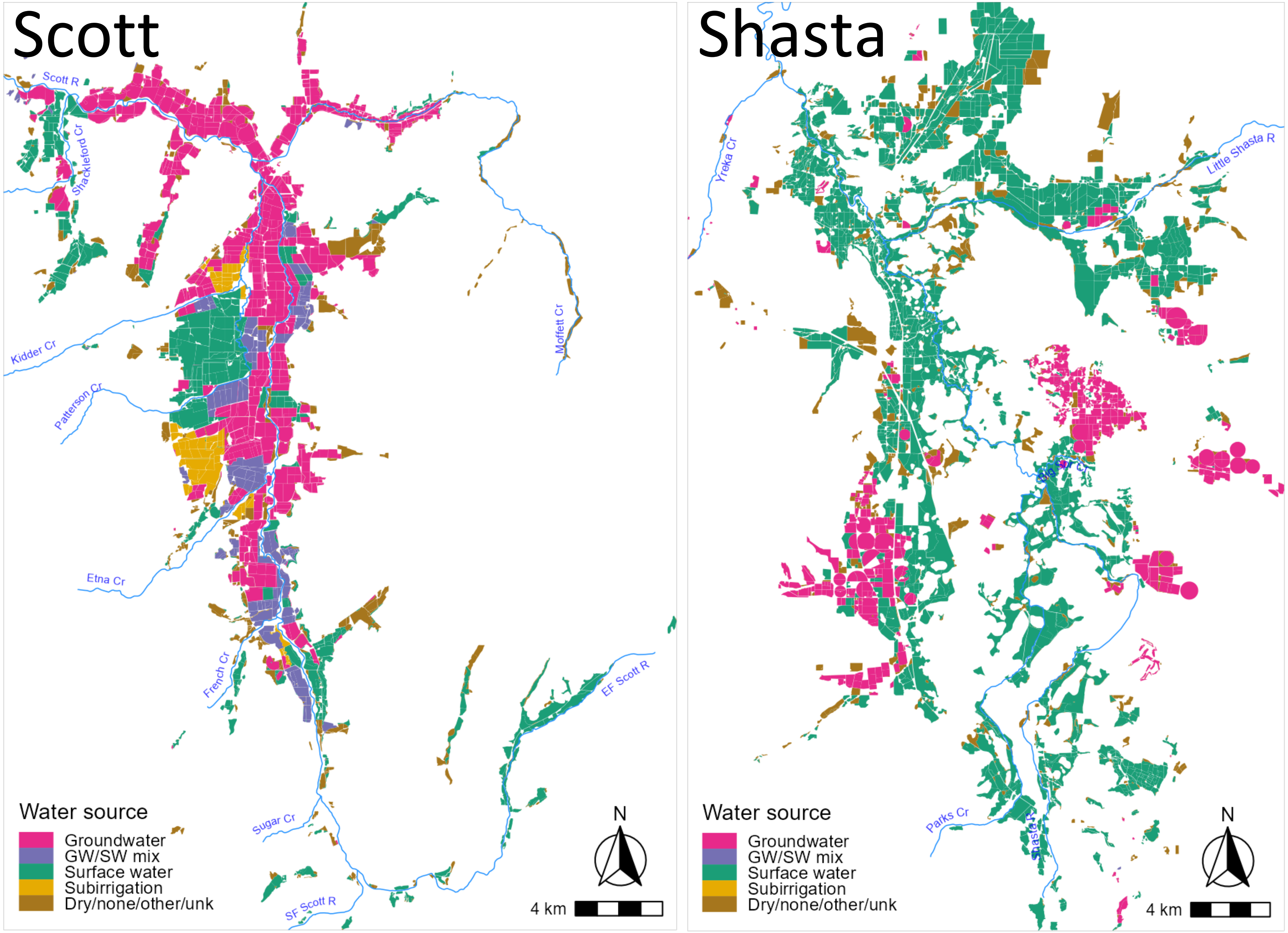


Scott

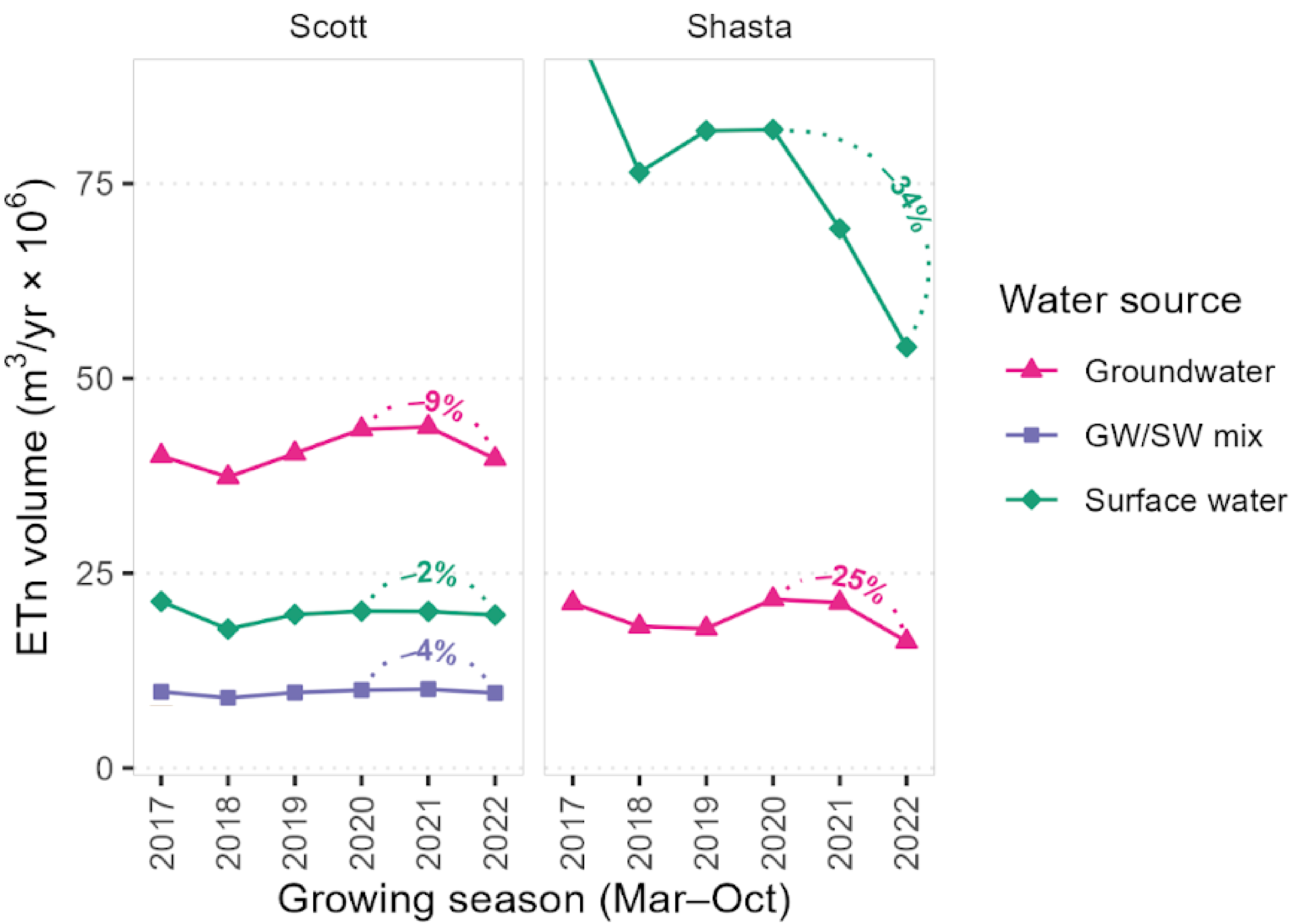
Shasta





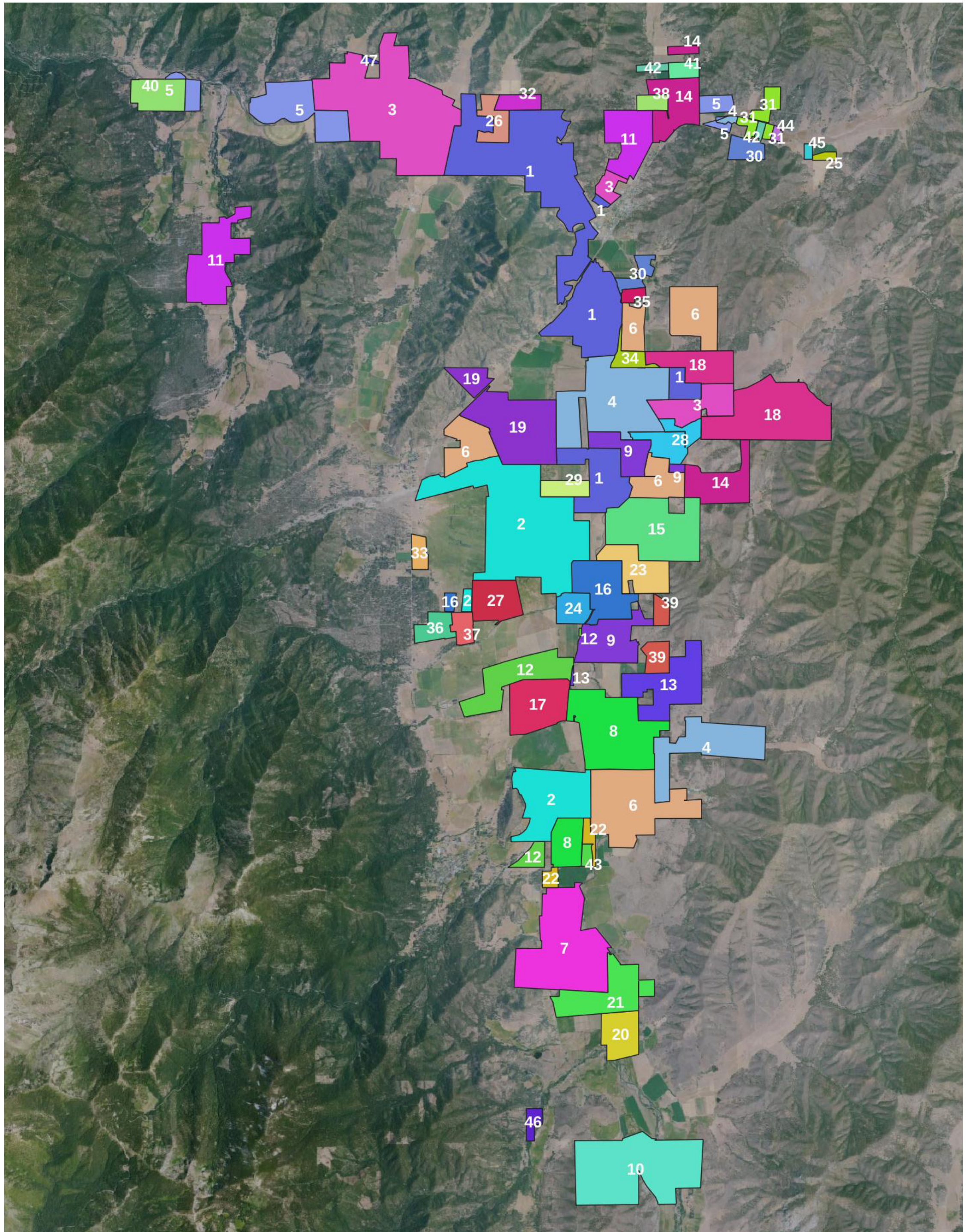


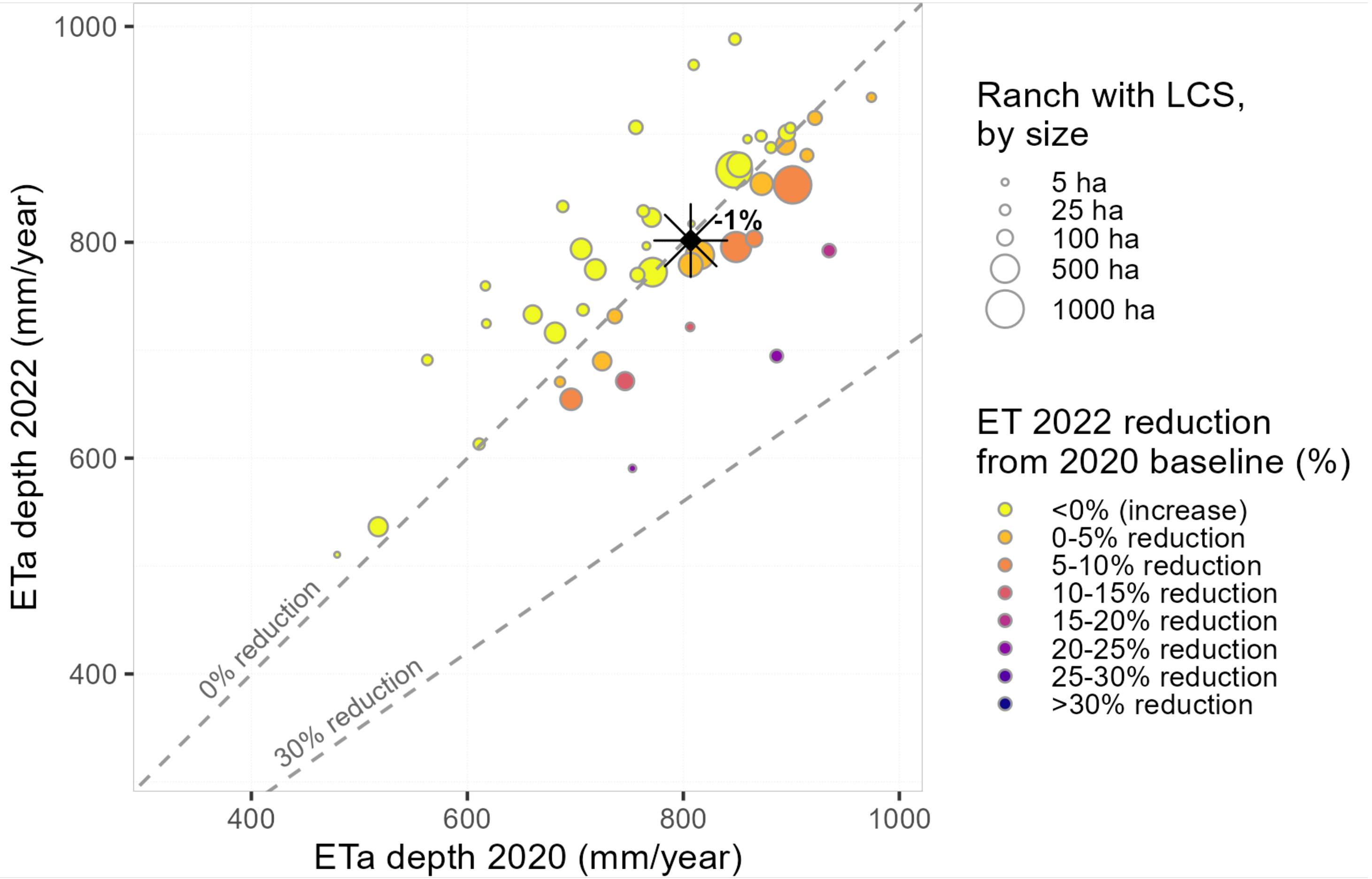
Irrigation sources:
Groundwater
Surface water



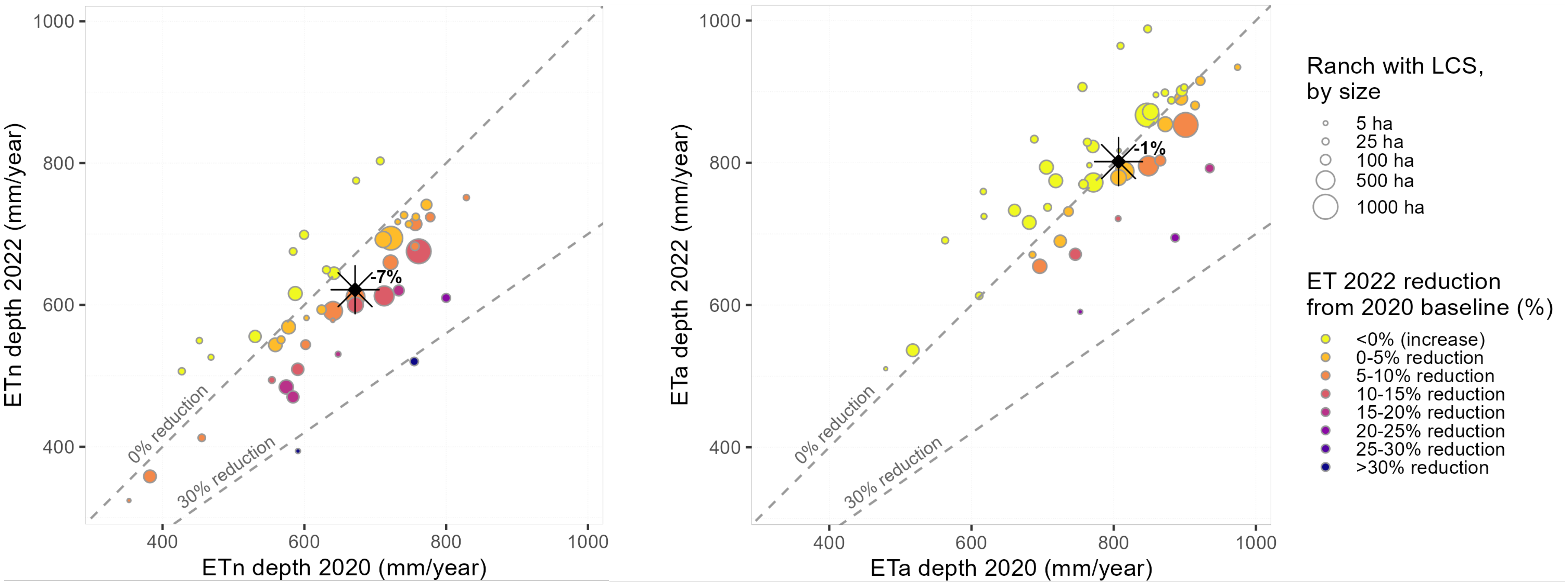
Scott
Shasta
ETn volume (m3/yr × 106)
75
50
25
0
−9%
−2%
−4%
−34%
−25%
2017
2018
2019
2020
2021
2022
Growing season (Mar–Oct)
Water source
Groundwater
GW/SW mix
Surface water

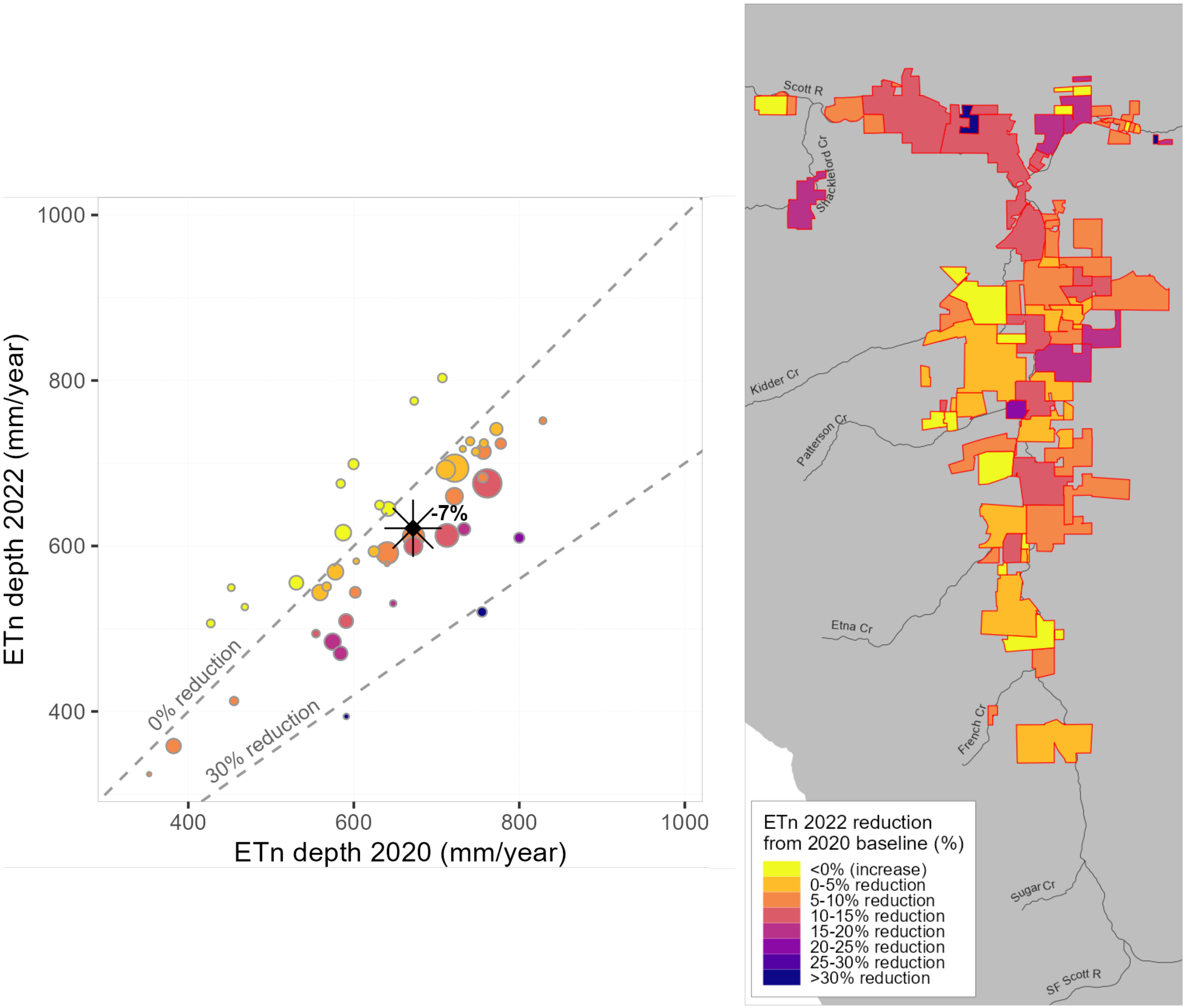
2022 Scott Local cooperative solutions (LCS)





ETa depth 2022 (mm/year)
1000
800
600
400
ETa depth 2020 (mm/year)
400
600
800
1000
-1%
0% reduction
30% reduction
Ranch with LCS, by size
5 ha
25 ha
100 ha
500 ha
1000 ha
ET 2022 reduction from 2020 baseline (%)
<0% (increase)
0-5% reduction
5-10% reduction
10-15% reduction
15-20% reduction
20-25% reduction
25-30% reduction
>30% reduction


ETn depth 2022 (mm/year)
ETn depth 2020 (mm/year)
0% reduction
30% reduction
-7%
ETa depth 2022 (mm/year)
ETa depth 2020 (mm/year)
-1%
Ranch with LCS, by size
5 ha
25 ha
100 ha
500 ha
1000 ha
ET 2022 reduction from 2020 baseline (%)
<0% (increase)
0-5% reduction
5-10% reduction
10-15% reduction
15-20% reduction
20-25% reduction
25-30% reduction
>30% reduction


ETn depth 2022 (mm/year)
1000
800
600
400
-7%
0% reduction
30% reduction
400
600
800
1000
ETn depth 2020 (mm/year)
Scott R
Shackleford Cr
Kidder Cr
Patterson Cr
Etna Cr
French Cr
Sugar Cr
SF Scott R
ETn 2022 reduction
from 2020 baseline (%)
<0% (increase)
0-5% reduction
5-10% reduction
10-15% reduction
15-20% reduction
20-25% reduction
25-30% reduction
>30% reduction

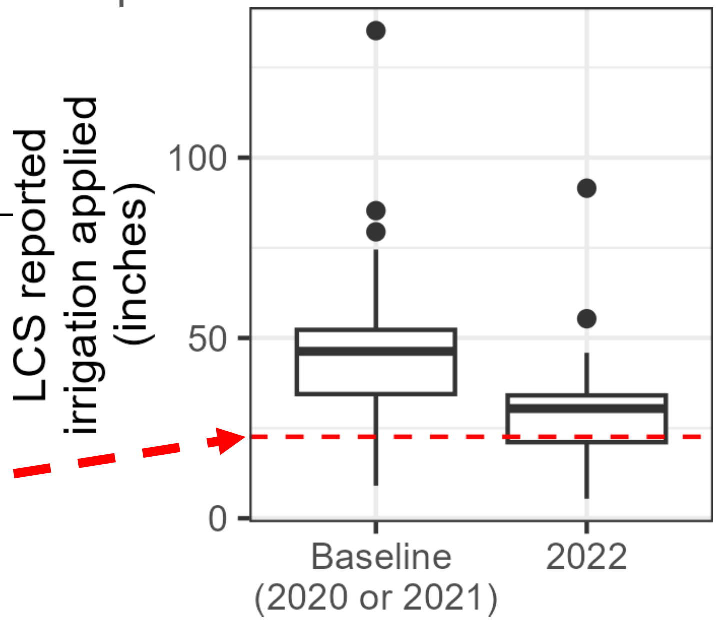
Inflated Baselines

Source	Irrigation (inches)			
	All	Alfalfa	Pasture	Grain
SVIHM Foglia et al. (2013)	30.3	33.1	29.7	14.1
SVIHM Foglia et al. (2018)	22.6	21.5	26.0	10.3

Inflated Baselines

Source	Irrigation (inches)			
	All	Alfalfa	Pasture	Grain
SVIHM Foglia et al. (2013)	30.3	33.1	29.7	14.1
SVIHM Foglia et al. (2018)	22.6	21.5	26.0	10.3
LCS baseline 2020 or 2021	44.1			
LCS reporting 2022	29.2			

6 of 46 LCS reported baseline ≤ 22.6

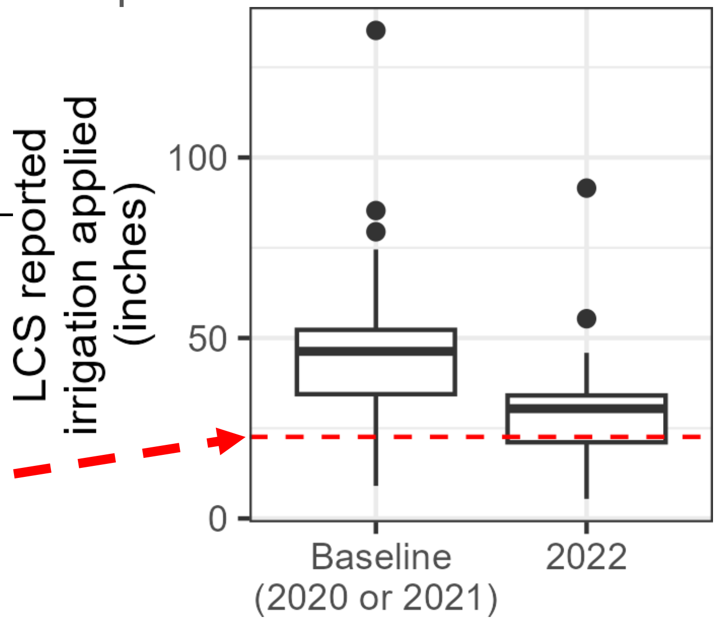


Inflated Baselines

Source	Irrigation (inches)			
	All	Alfalfa	Pasture	Grain
SVIHM Foglia et al. (2013)	30.3	33.1	29.7	14.1
SVIHM Foglia et al. (2018)	22.6	21.5	26.0	10.3
LCS baseline 2020 or 2021	44.1			
LCS reporting 2022	29.2			

Too low?

Too high?



6 of 46 LCS reported baseline ≤ 22.6

Conclusions

- 2022 curtailments
  - Shasta: reduction in ETa and ETn
  - Scott: no ETa reduction, but precip reduced ETn
- Irrigation systems
  - Shasta mostly water-mastered surface water
  - Scott mostly groundwater
- Local Cooperative Solutions (LCS) ineffective at reducing pumping
  - Inflated baselines
  - No metering
  - Little independent verification

Need for further data and analysis

- Which more accurately represents applied irrigation:
  - Scott groundwater model or LCS reports?
- Field-specific GIS of LCS practices needed to evaluate:
  - Which LCS practices effectively reduced ET?
  - Compliance rates for (some) practices