Changes in groundwater, wetlands and agriculture along the All American Canal, 2007-2019

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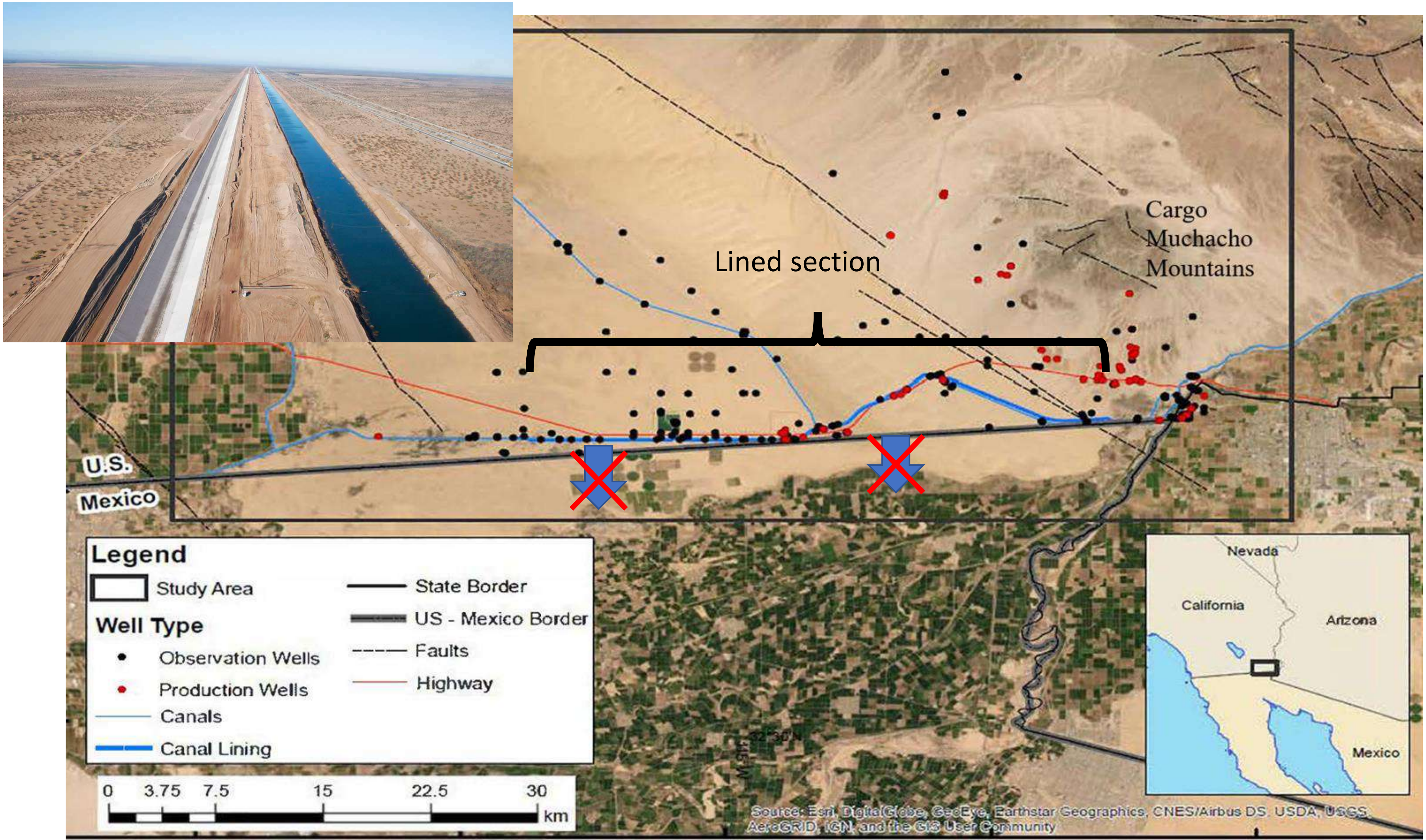
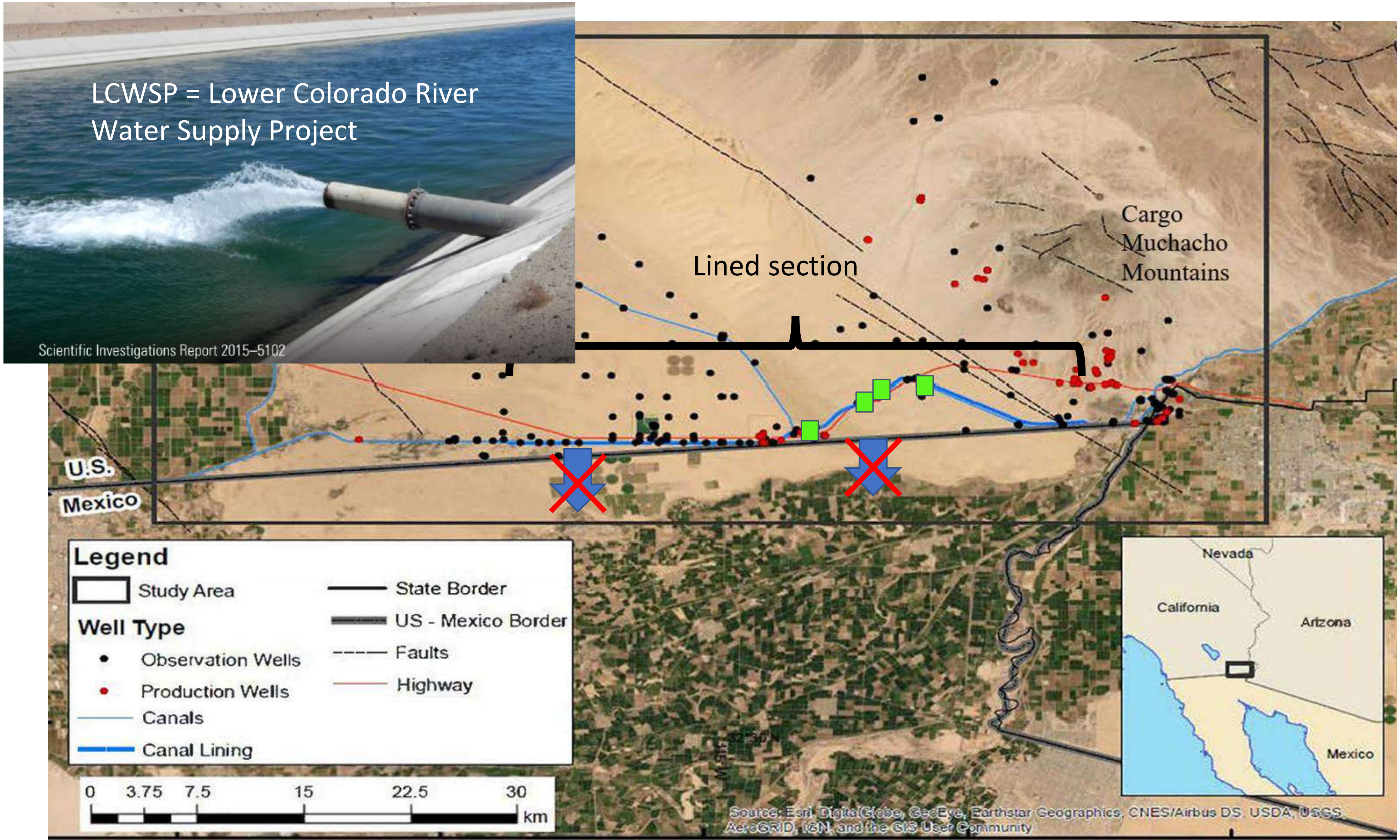
SDSU | San Diego State University

Lining of the All American Canal: 37 km



Roberts 2019

Lining of the All American Canal: 37 km + 4 New production wells (2003, 2017)



Roberts 2019

Research questions

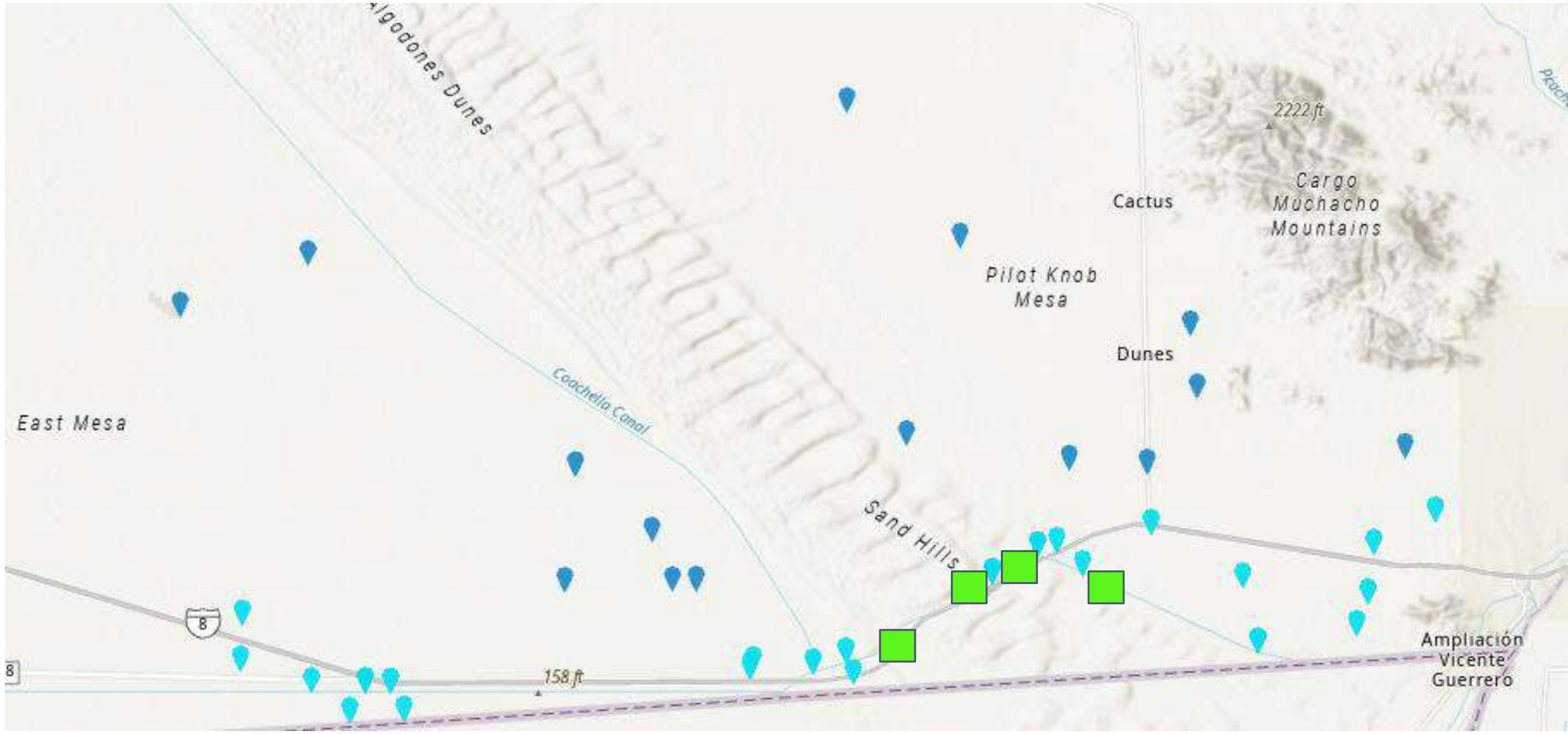
1. How have GW levels and the GW water balance in the US changed since lining + new wells? (Build on Coes et al 2015)

1. Where and how have wetlands been impacted? (Lesser et al 2019, Llanes 2019)

1. Where have farms been impacted?

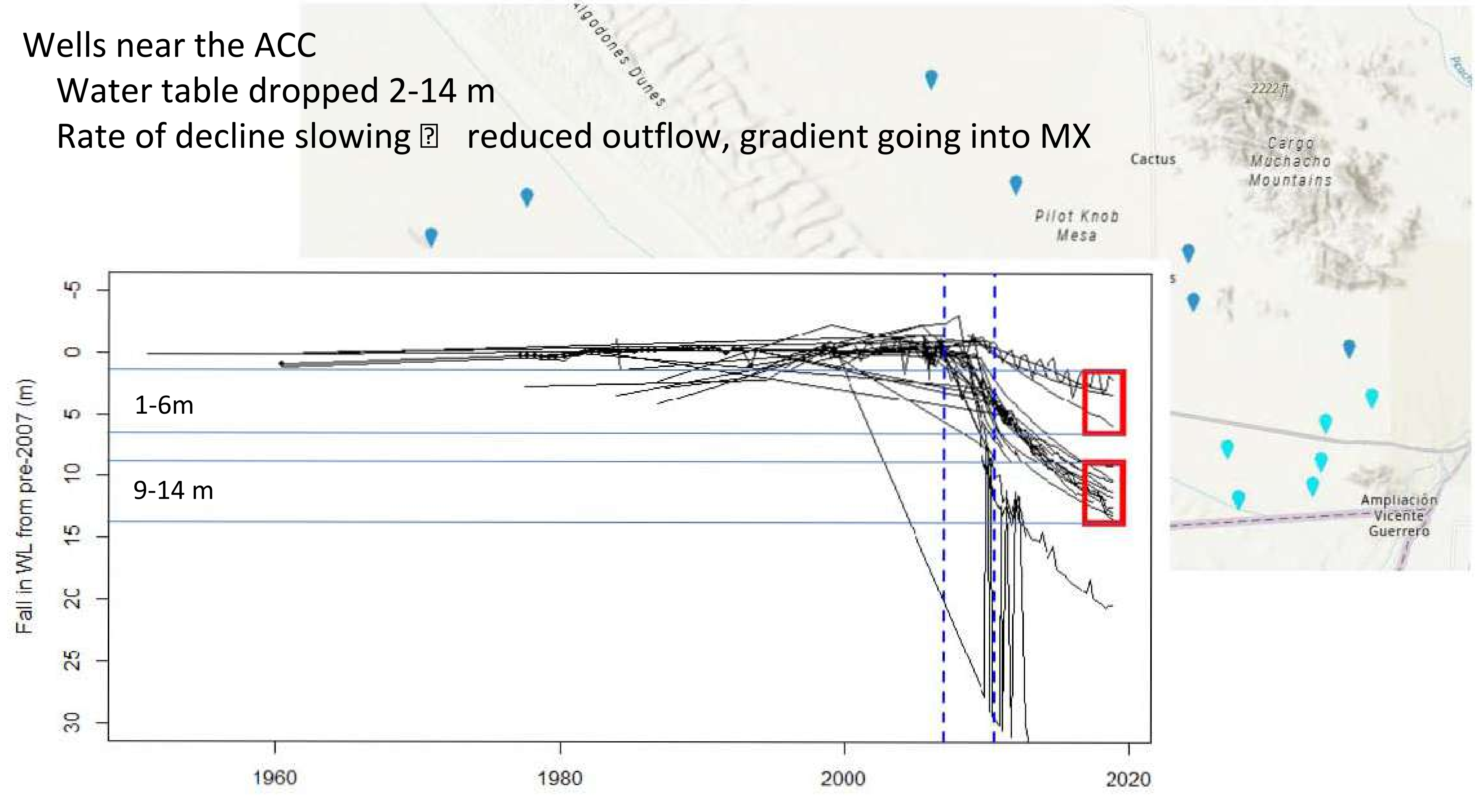
Monitoring wells with data for 2007-2010: N= 44

and near AAC: N=29

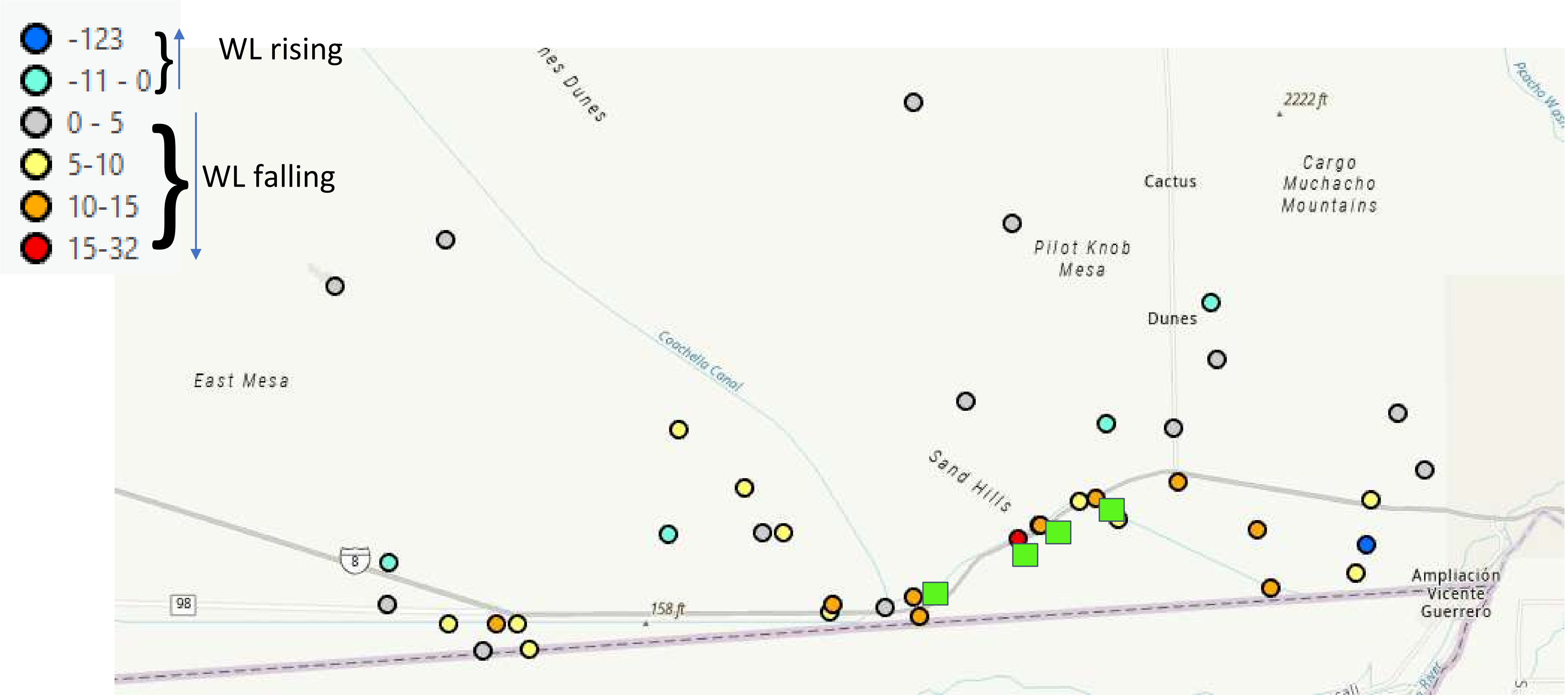


Wells near the ACC

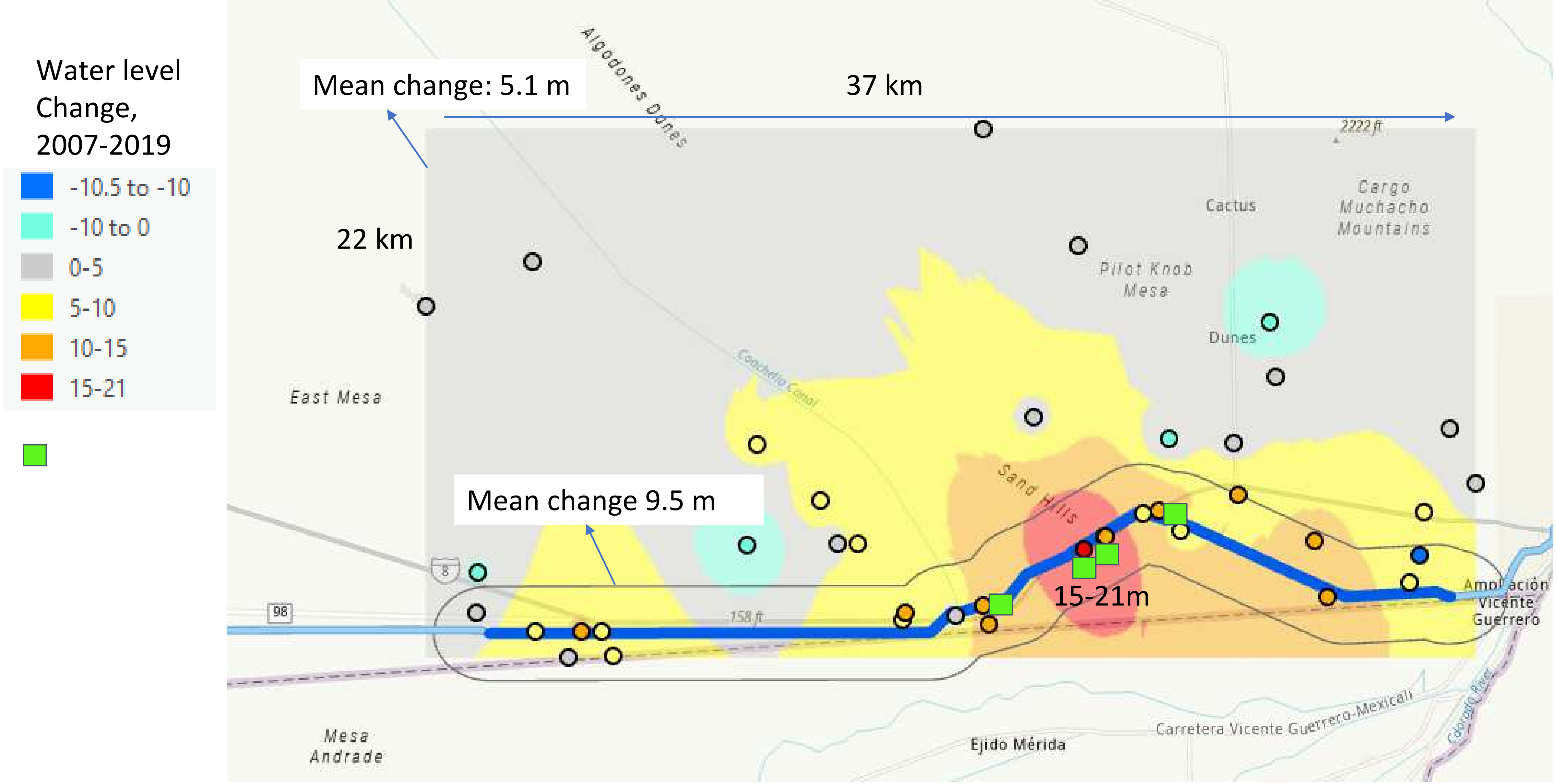
- Water table dropped 2-14 m
- Rate of decline slowing reduced outflow, gradient going into MX



Change in water level from pre-2007 to 2019



Interpolated map….largest changes in static water levels near AAC, production wells



How has GW balance changed?

Change in storage ΔS

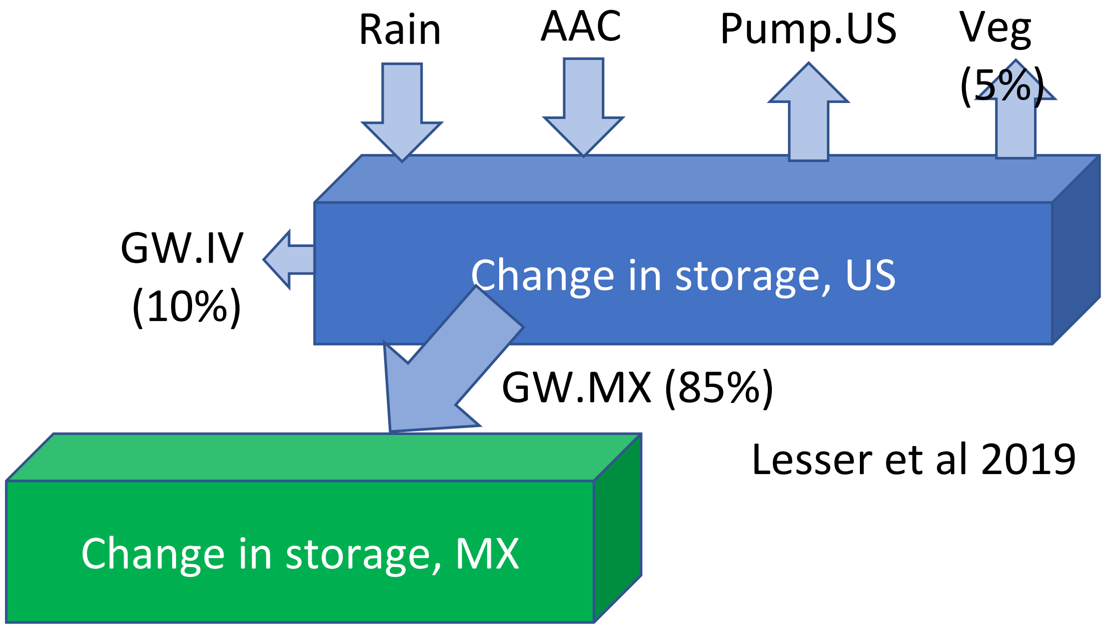
$$\Delta S = A \times \Delta z \times Sy$$

A = area

Δz = mean WL change

Sy = specific yield

~ 0.2 (Llanes, 2019)



Lesser et al 2019

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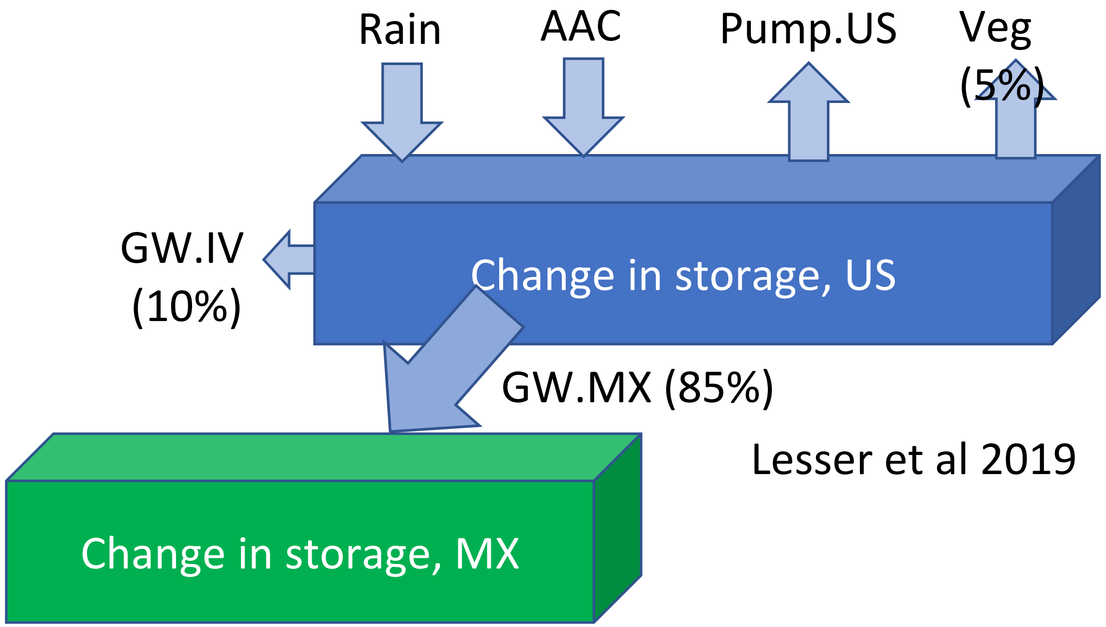
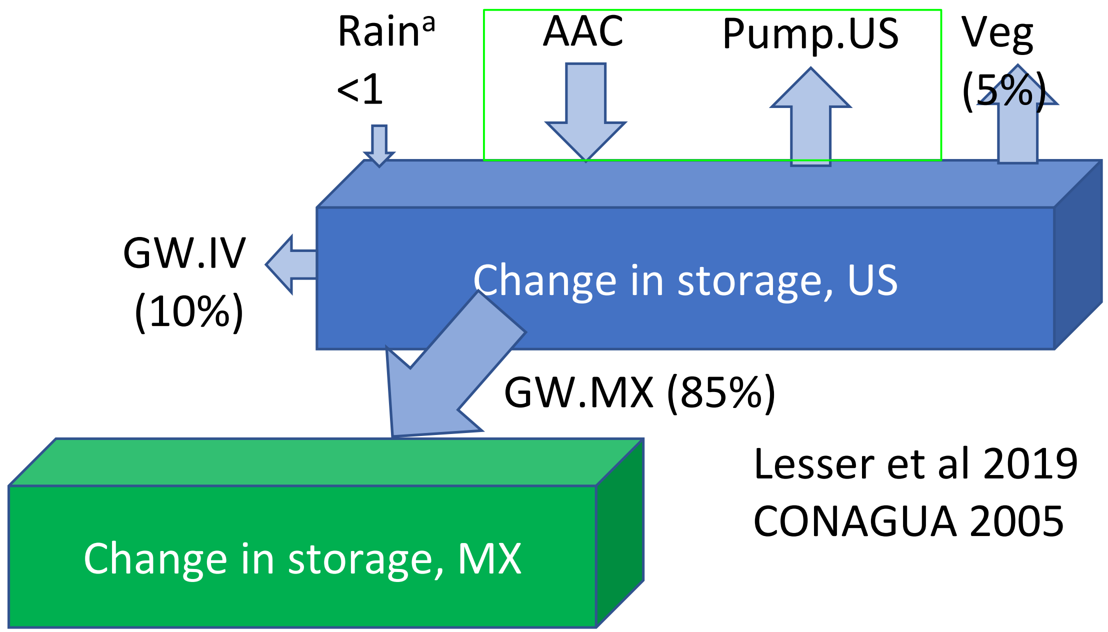


Lesser et al 2019

	Area (km2)	Δz (m)	ΔS (MCM)	ΔS (MCM) / yr 2007-2019
Large study area	833	5	833	64
AAC 2km buffer	148	9.5	281	22

How has GW balance changed?
Change in storage ΔS

ΔS = AAC
- (PUMP.US + GW.MX + GW.IV + VEG)



	INPUT	PUMP.US		INPUT + PUMP.US	ΔS	GW.MX
	AAC seep[b]	Pumping other[c]	LCWSP pumping			
Pre-lining						
Post-lining						
Change						

a. Montg. Watson, 1995
b. 67,700 AF/y = 84 MCM (USGS 2012); 94,206 AF/y = 116 MCM/y, Tompson 2008); CONAGUA (2020), minus E4 = 130 MCM
c. Tompson ea 2008, Coes ea 2015
d. USBR, 2005; USBR 1990

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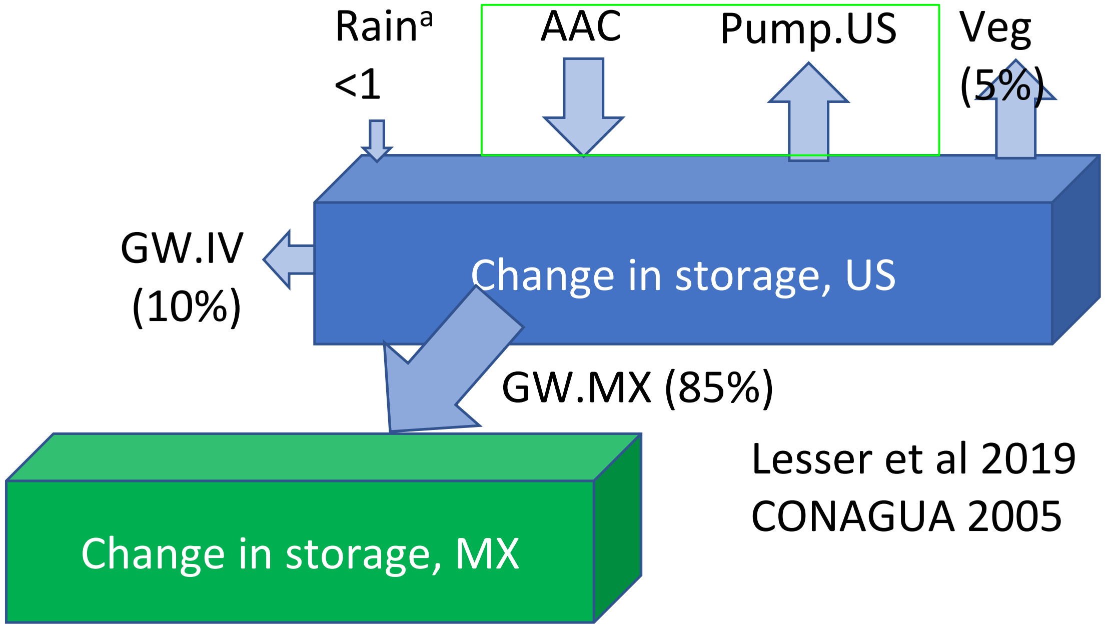
Change in storage ΔS



Lesser et al 2019
CONAGUA 2005

ΔS = AAC - (PUMP.US + GW.MX + GW.IV + VEG)

Solve for change:

ΔGW.MX = 0.85(-$\Delta(\Delta S)$ + ΔAAC - ΔPUMP.US)

	INPUT	PUMP.US		INPUT + PUMP.US	ΔS	GW.MX
	AAC seep[b]	Pumping other[c]	LCWSP pumping			
Pre-lining		?			0	
Post-lining		?			22, 64	
Change		~0			-22, -64	

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b. 67,700 AF/y = 84 MCM (USGS 2012); 94,206 AF/y = 116 MCM/y, Tompson 2008); CONAGUA (2020), minus E4 = 130 MCM
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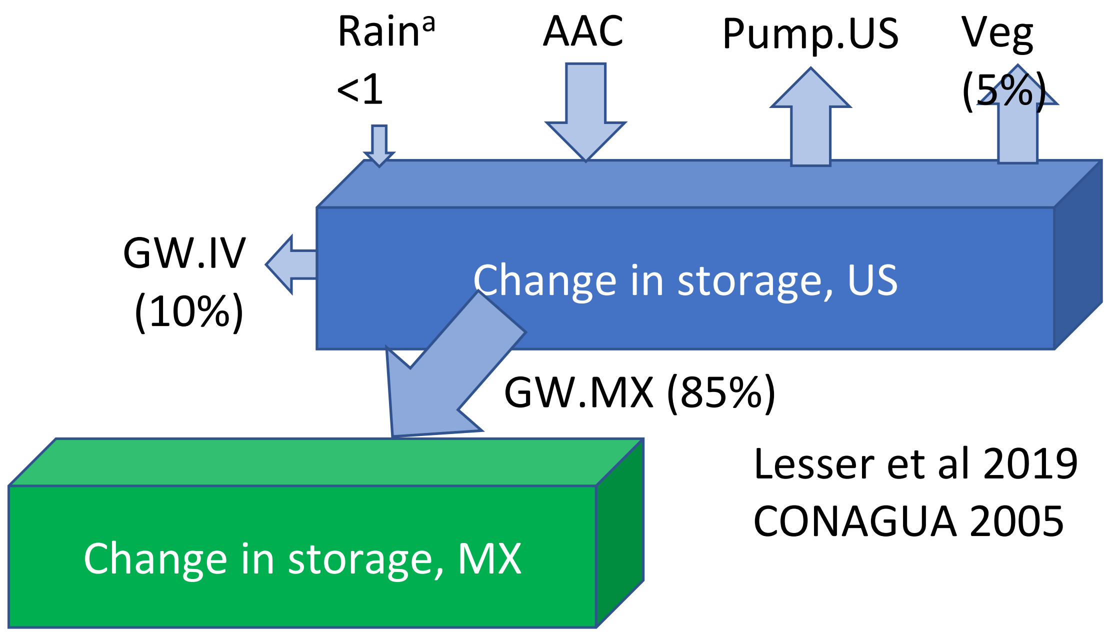
How has GW balance changed?

Change in storage ΔS

$\Delta S = AAC$

$- (PUMP.US + GW.MX + GW.IV + VEG)$



Lesser et al 2019
CONAGUA 2005

Solve for change:

$\Delta GW.MX$

$= 0.85(-\Delta(\Delta S) + \Delta AAC - \Delta PUMP.US)$

	INPUT	PUMP.US		INPUT + PUMP.US	ΔS	GW.MX
	AAC seep[b]	Pumping other[c]	LCWSP pumping			
Pre-lining	84, 116, 130	?			0	
Post-lining	0	?			22, 64	
Change	-84, -116, -130	~0			-22, -64	

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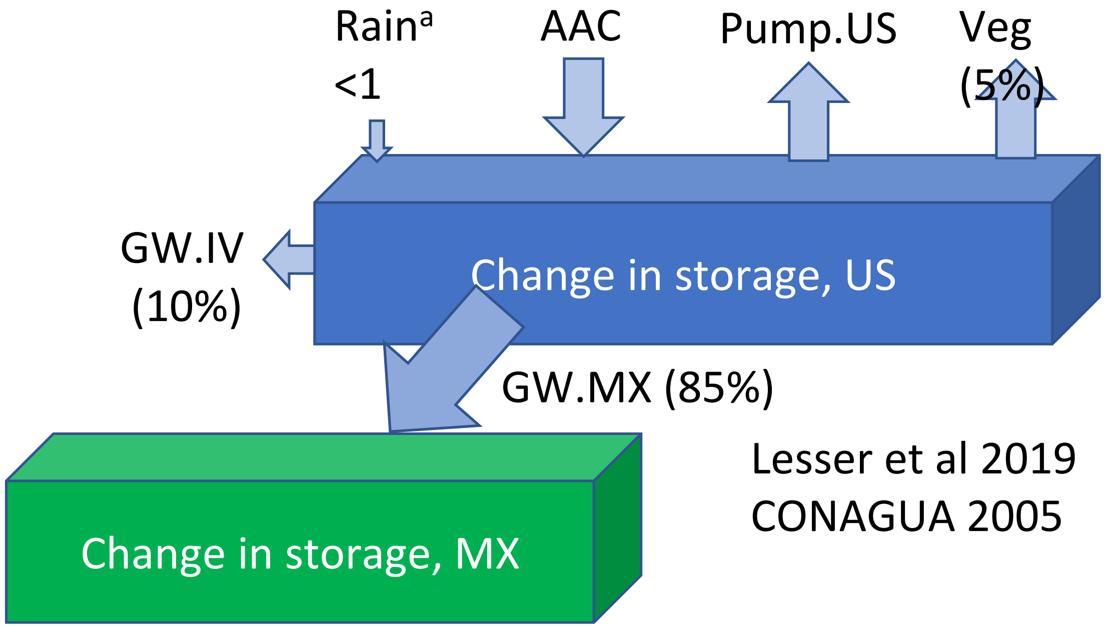
How has GW balance changed?

Change in storage ΔS

$$\Delta S = AAC - (PUMP.US + GW.MX + GW.IV + VEG)$$

Solve for change:

$$\Delta GW.MX = 0.85(-\Delta(\Delta S) + \Delta AAC - \Delta PUMP.US)$$



Lesser et al 2019
CONAGUA 2005

	INPUT	PUMP.US		INPUT + PUMP.US	ΔS	GW.MX
	AAC seep[b]	Pumping other[c]	LCWSP pumping			
Pre-lining	84, 116, 130	?	0	…	0	
Post-lining	0	?	-6 to -12	…	22, 64	
Change	-84, -116, -130	~0	-6 to -12	-90 to -142	-22, -64	

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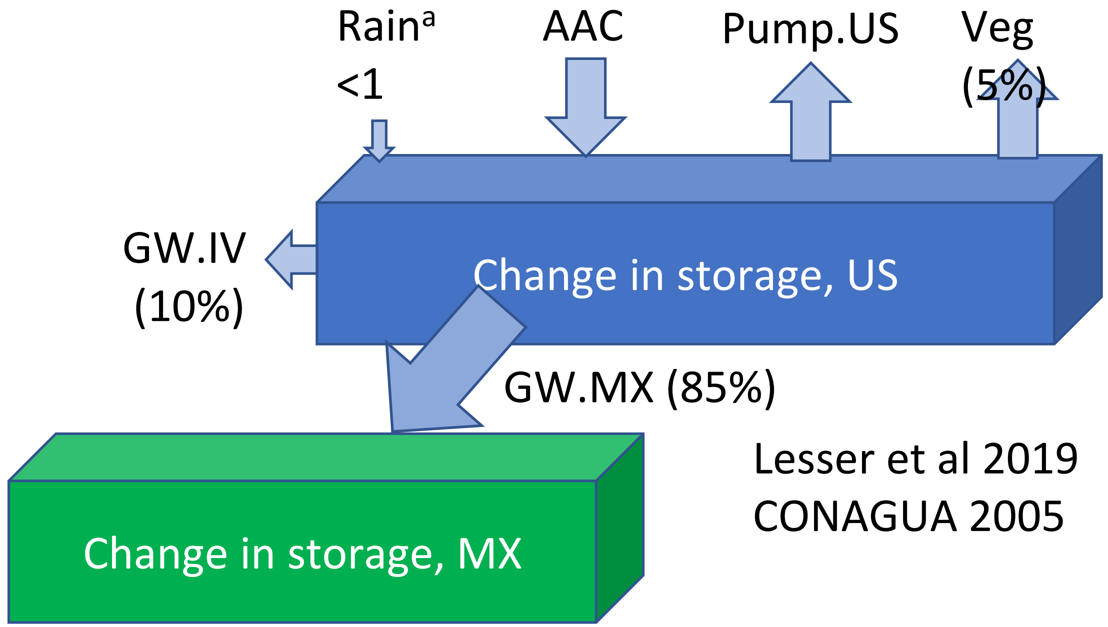

Lesser et al 2019
CONAGUA 2005

	INPUT	PUMP.US		INPUT + PUMP.US	ΔS	GW.MX
	AAC seep[b]	Pumping other[c]	LCWSP pumping			
Pre-lining	84, 116, 130	?	0	…	0	72[d], 130[b]
Post-lining	0	?	-6 to -12	…	22, 64	0, 103
Change	-84, -116, -130	~0	-6 to -12	-90 to -142	-22, -64	-27, -102

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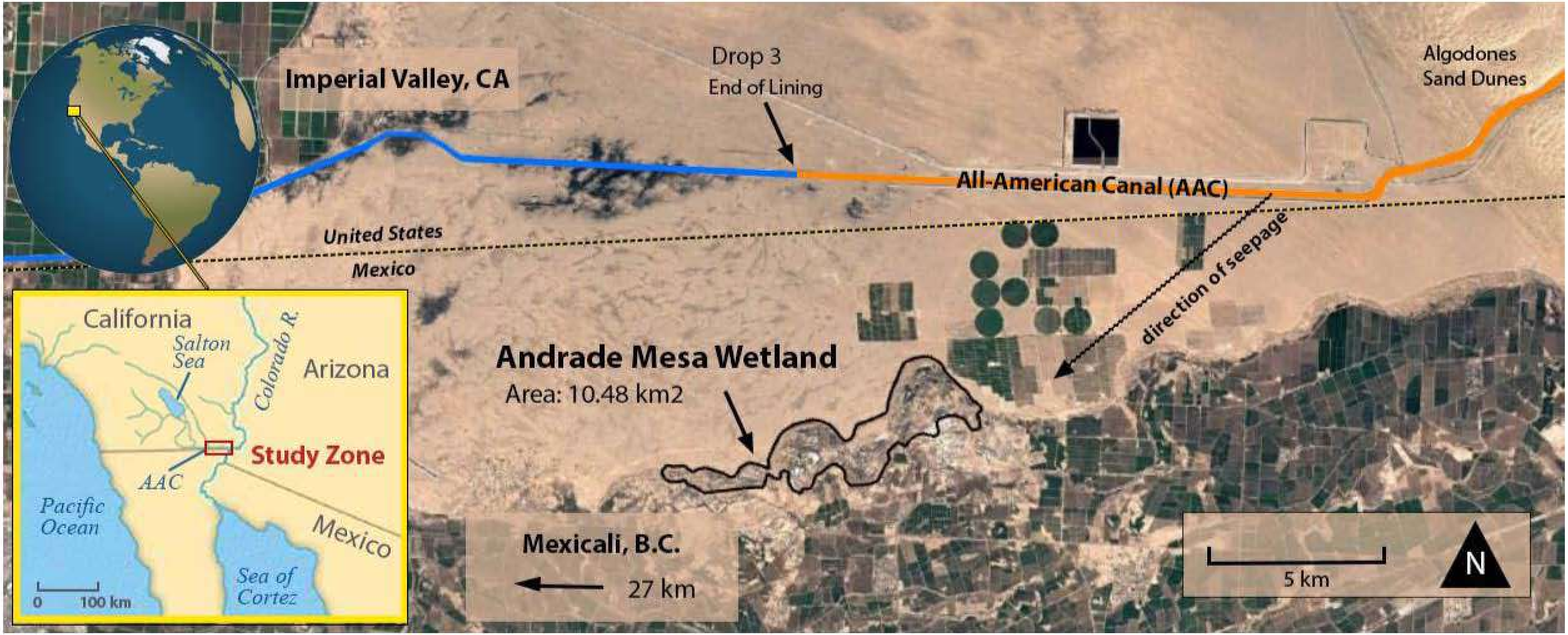
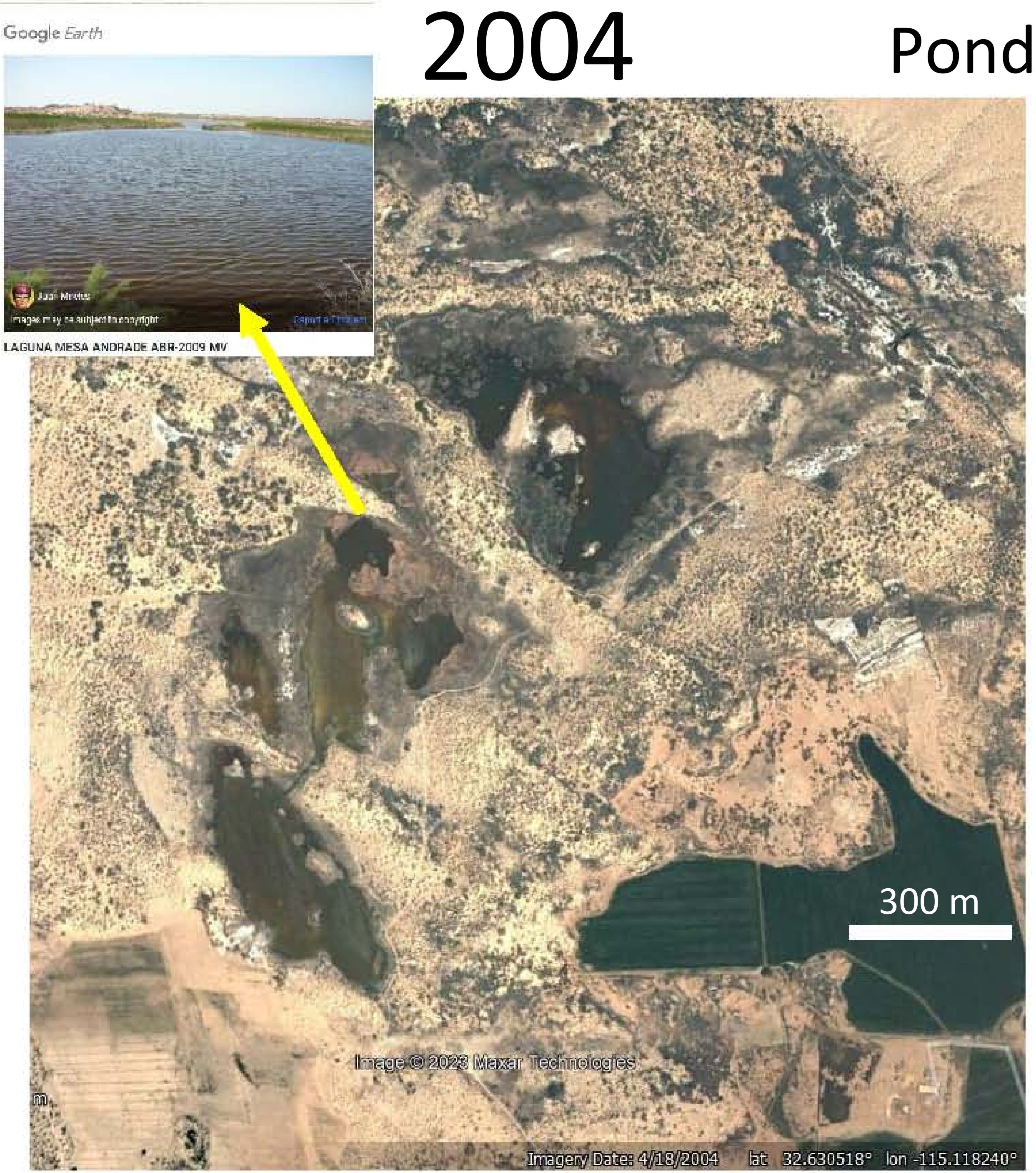
2. Where and how have wetlands been impacted?



Mattson, MS Thesis, SDSU, 2023

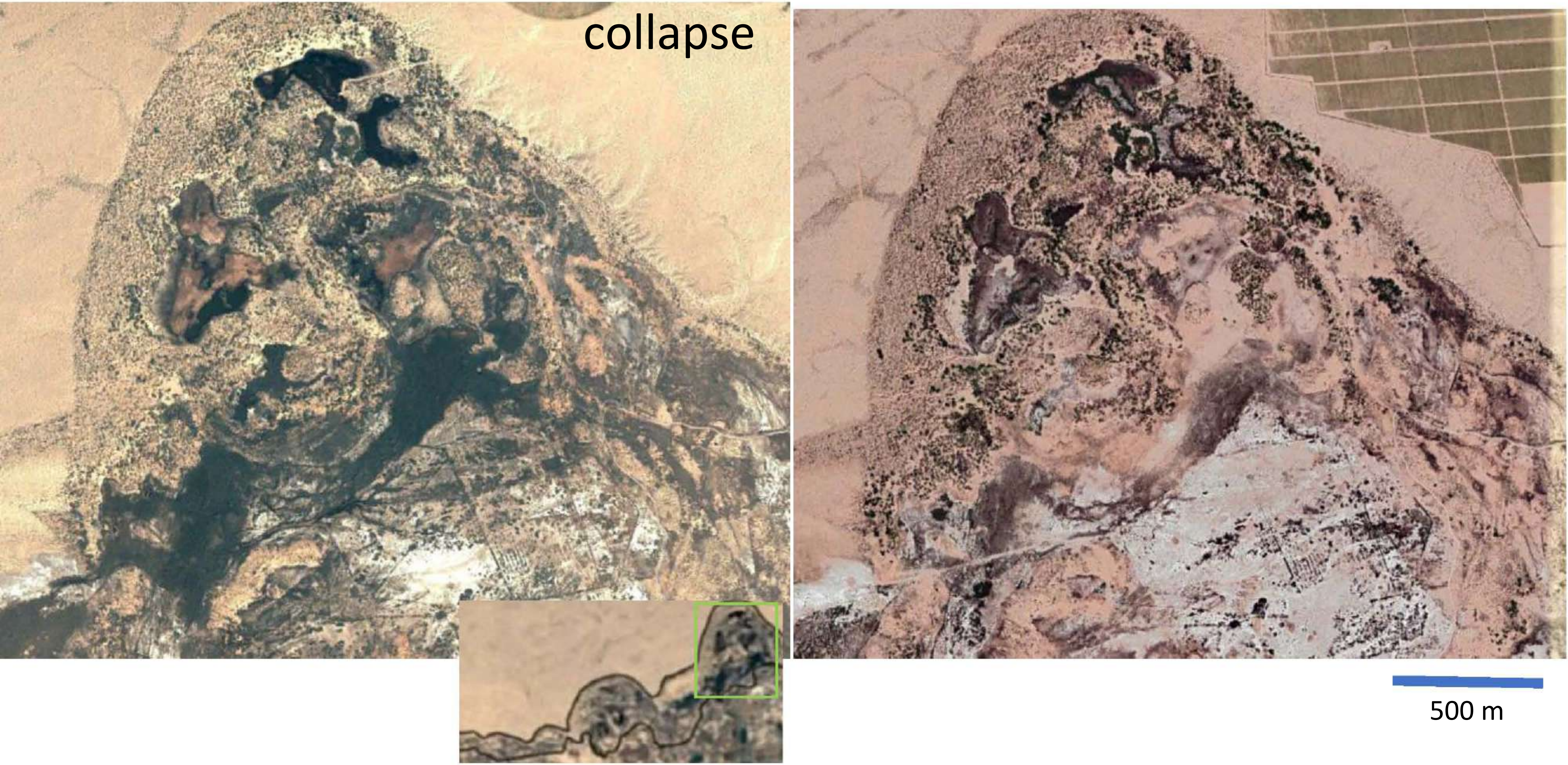
Pond drying

2004



2022

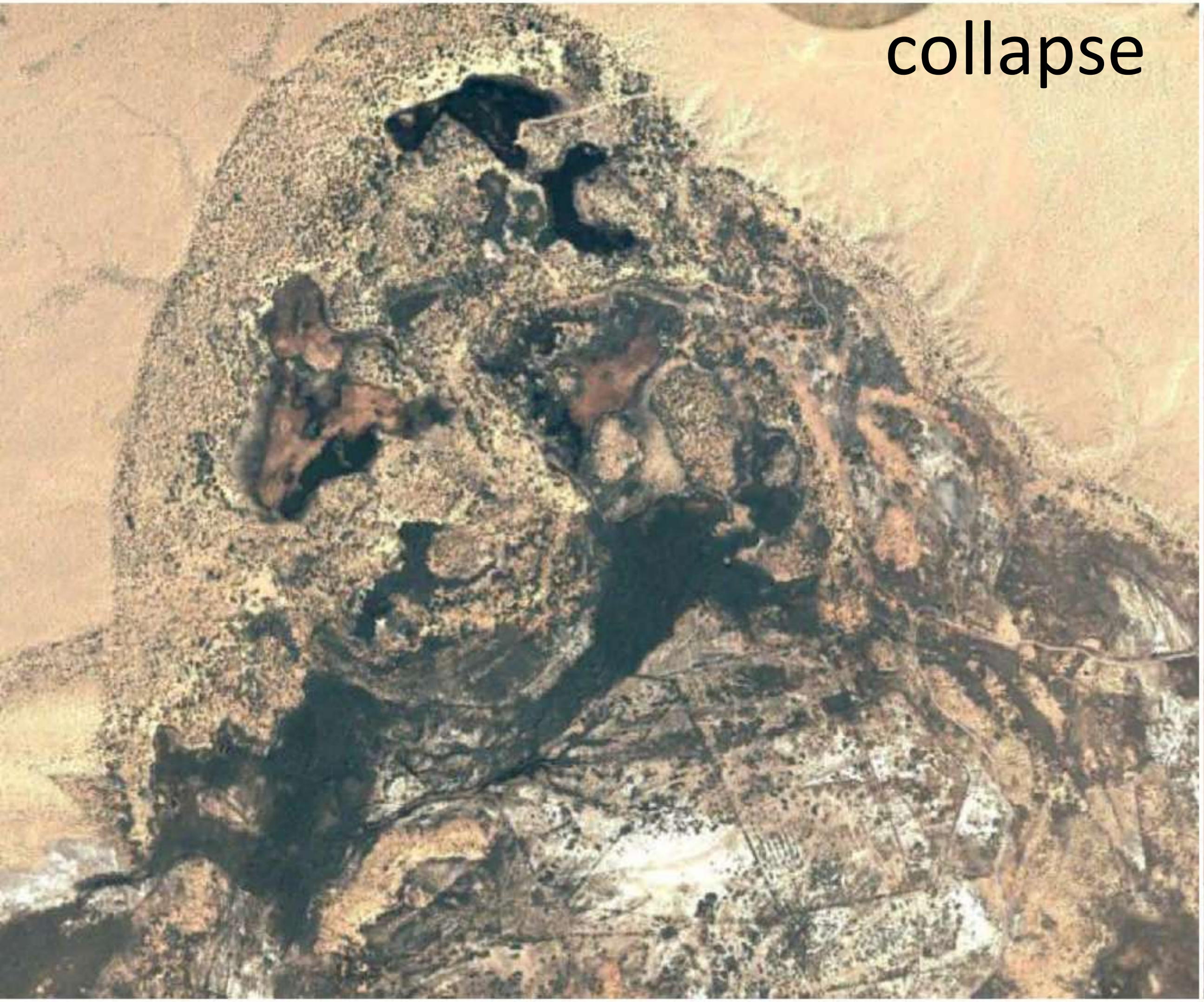
2004 Vegetation collapse 2022



2004

Vegetation collapse

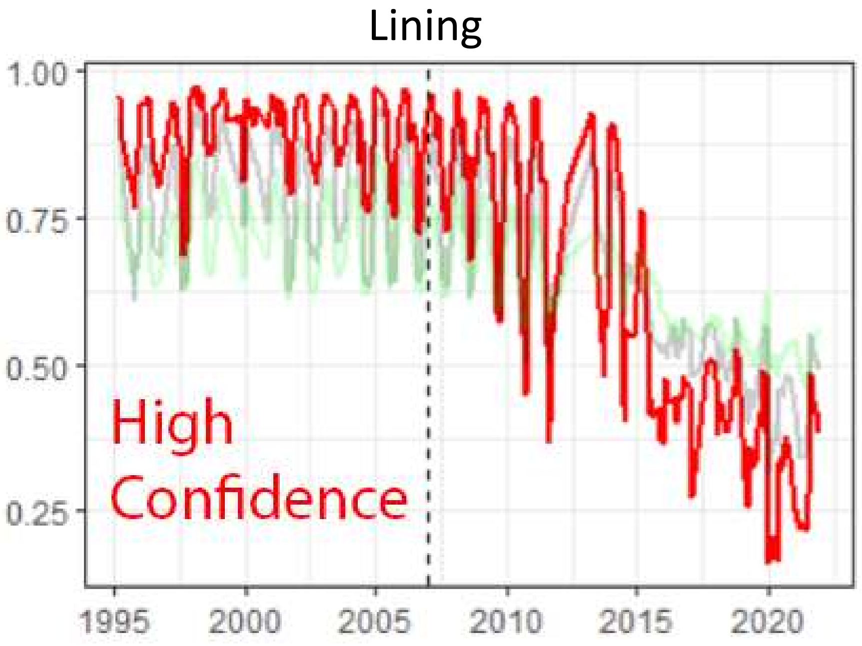
2022

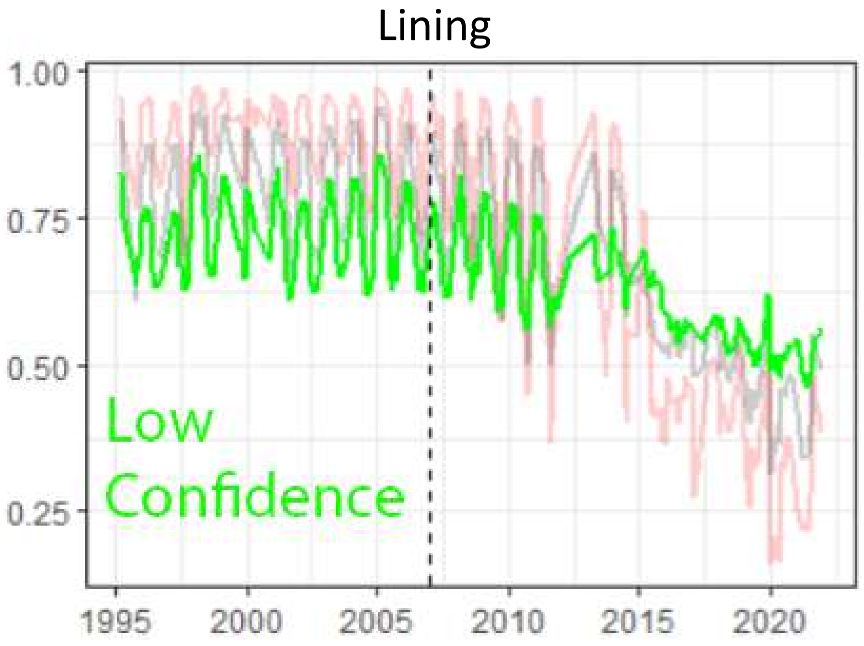


What was the timing? Stacks of Landsat imagery □ Machine Learning

500 m

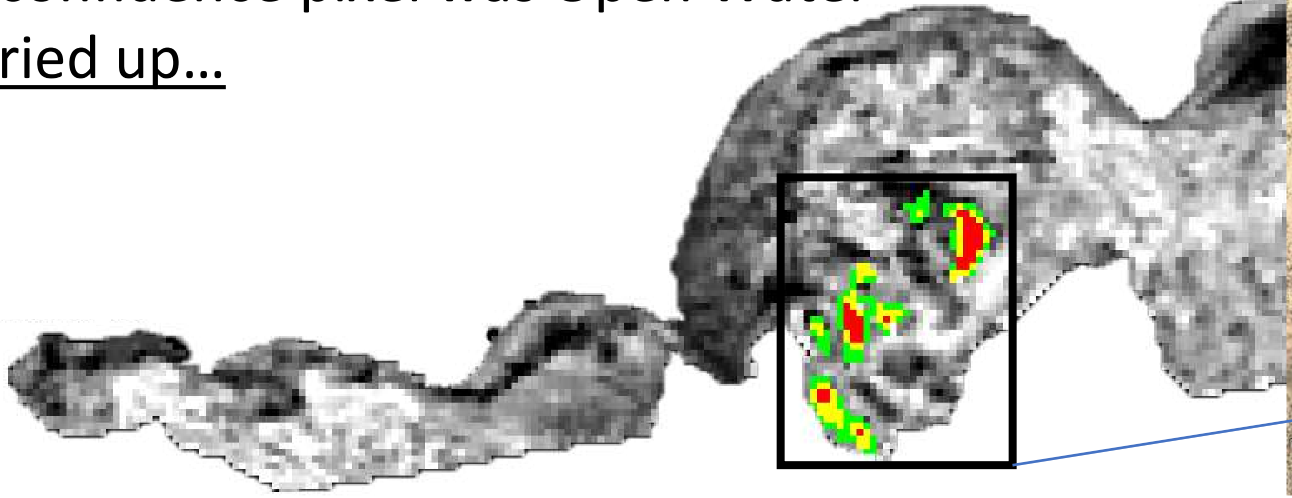
Time series "Dark fraction" (wet): Most open water dried, 2010-2015





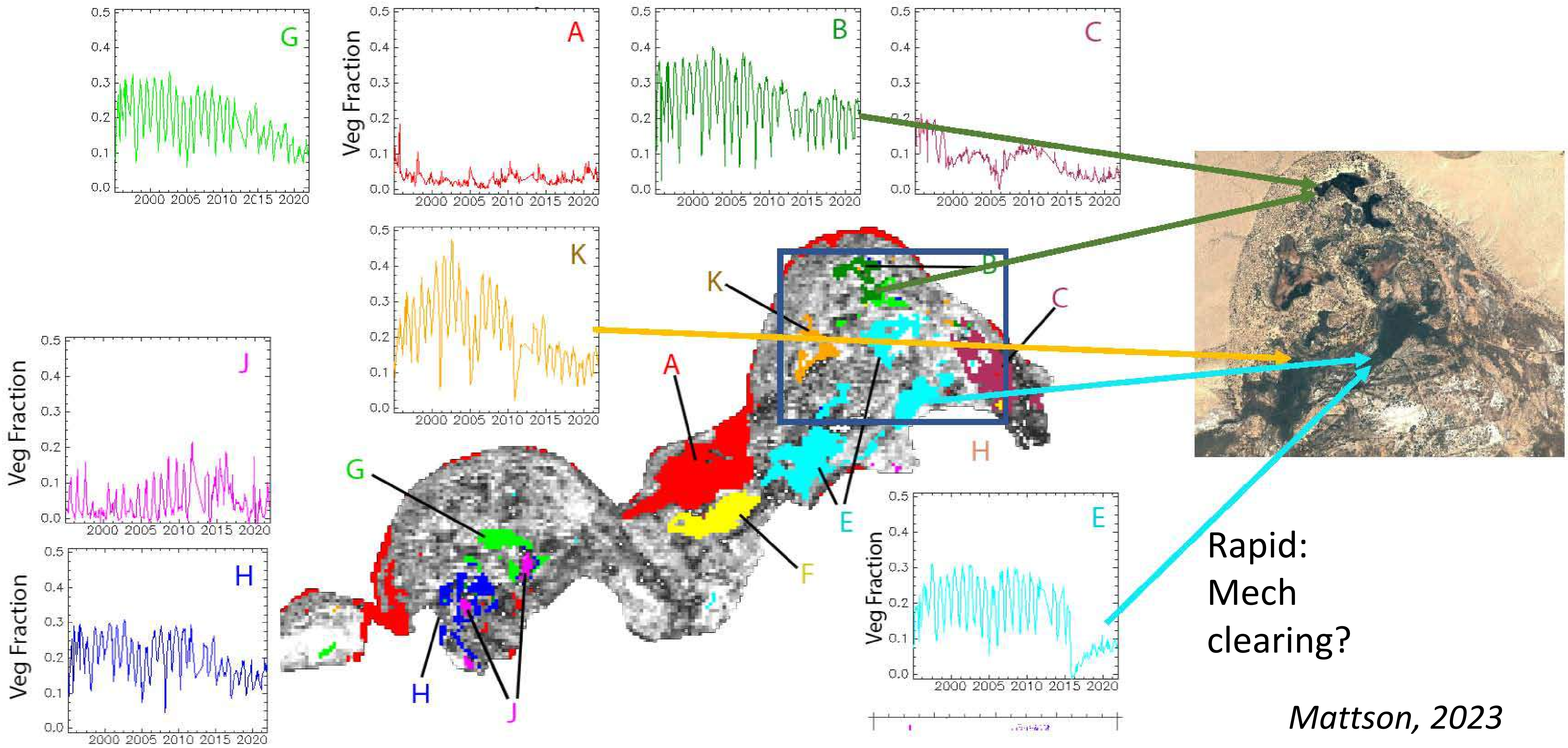
High and low(ish) confidence pixel was Open Water

<u>~22 ha of ponds dried up…</u>

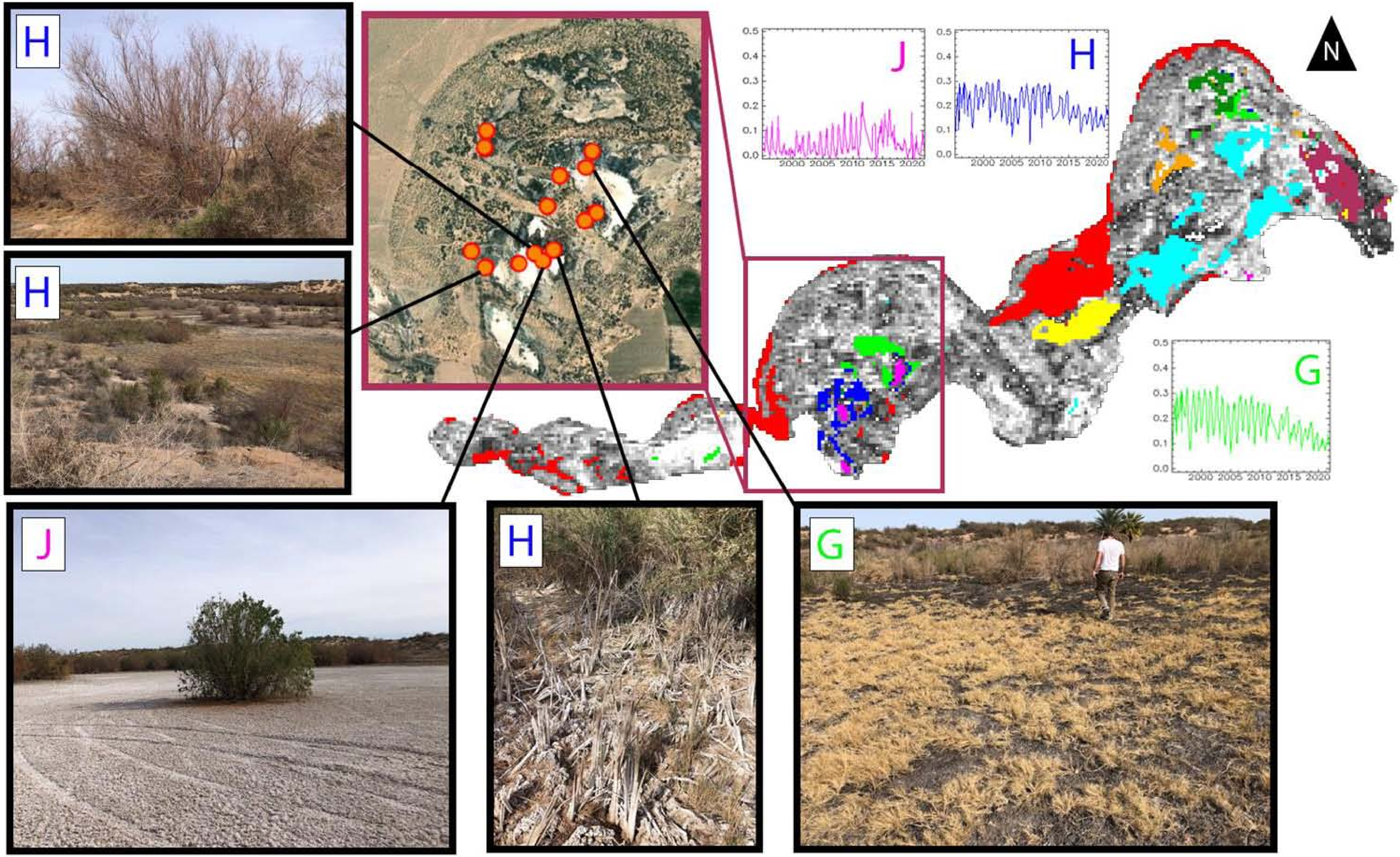


Mattson, 2023

Time series of Vegetation: Collapse by 2010-2015 by difft mechanisms



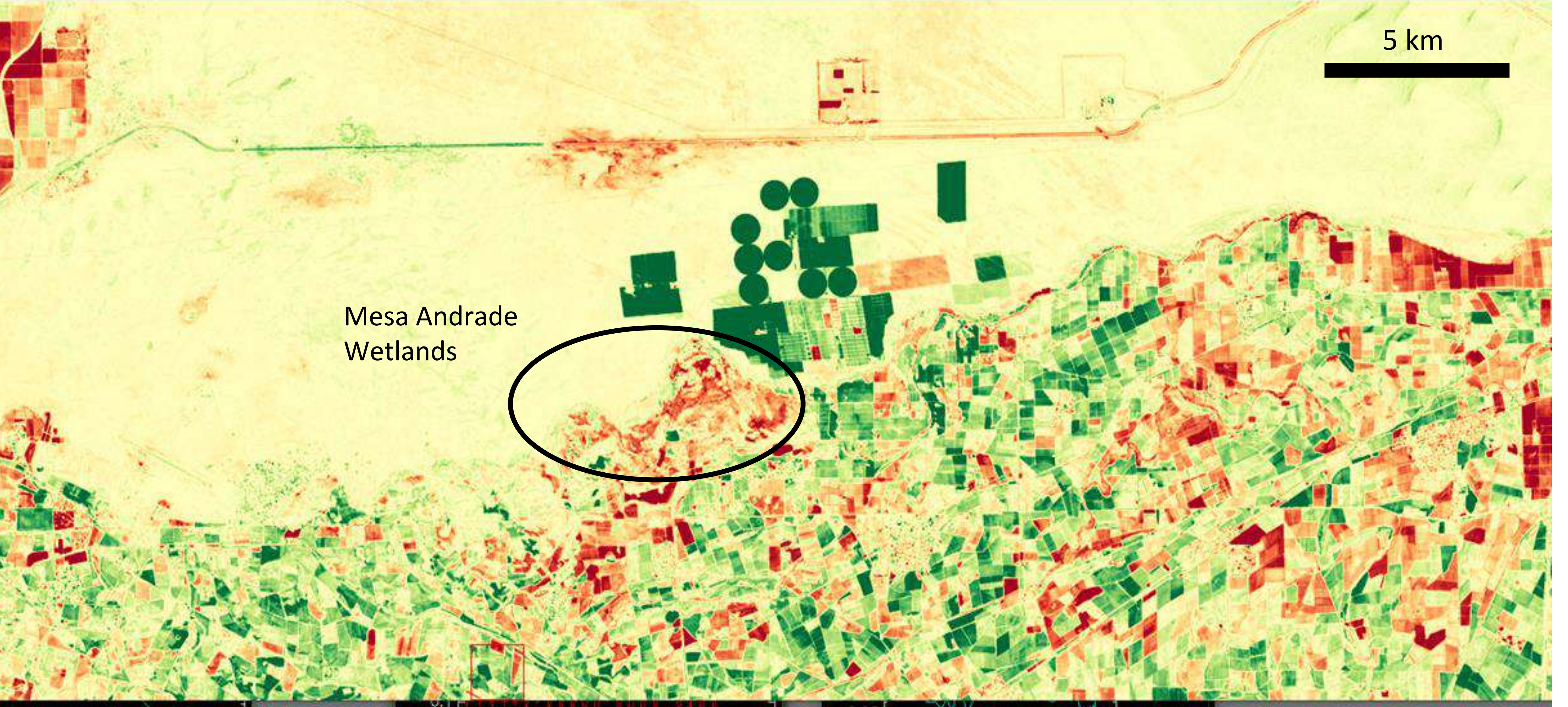
Mattson, 2023



H
H
J
H
G
J
H
G
N
0.5
0.4
0.3
0.2
0.1
0.0
2000
2005
2010
2015
2020

3. Where have farms been impacted? PCA annual Green fraction 1995-2023

Red = decrease, Green = increase



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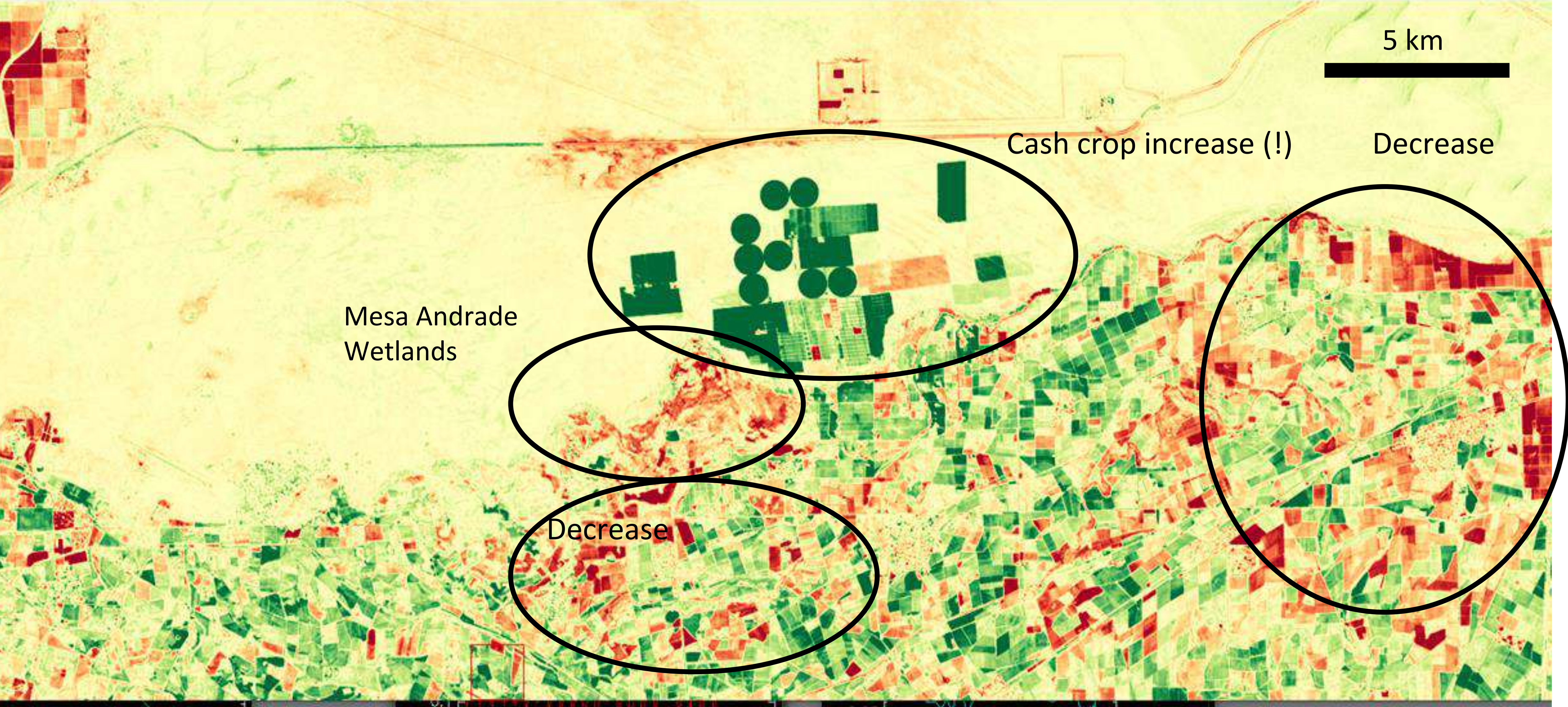
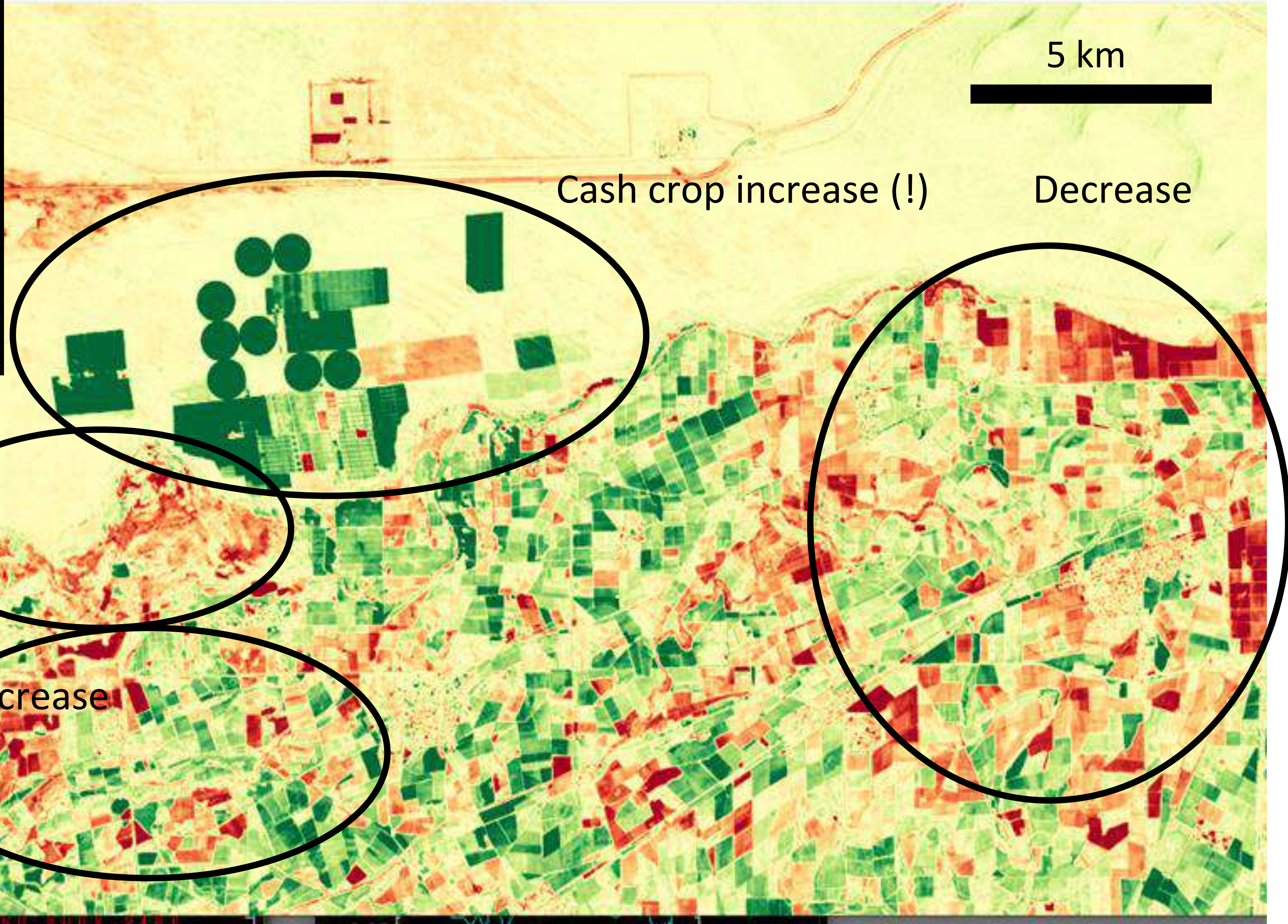


Interviews with farmers in 2017 (N=24):

100% of respondents in "Negative trend" areas: water scarcity is primary driver



Conclusions

1. GW levels fell 2-30m post-AAC lining.
   - Mean 9.5m near AAC

2. Reduced AAC seepage >> new pumping

2. GW flow to MX reduced, maybe ~30%

2. Wetlands dried, veg type change

2. Agriculture changed…but some increase, some decrease. Who was/will be impacted?

Next steps

1. Integrate US and MX GW data → Complete water balance
2. Role of new ag lands for the water balance?
3. Ground surveys of ecosystems--what vegetation type changes?
4. Interviews with more farmers → perceptions, economic impact?

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Questions?

1. AAC seepage loss >> New pumping
2. AAC seepage loss ~= Change in storage
3. Rate of fall declining □ Reduced gradient and flow to Mexico

Annual water balance, MCM/year

	INPUT		OUT in US		ΔS	OUT to MX
	Rain[a]	AAC seepage	Pumping other[c]	Pumping of seepage	Change in storage, US	Transbound. flow to MX
Pre-lining	<1	84-116[b]	?	0	0	75[b]
Post-lining	<1	0	?	-6 to 12.3 in 2017	22-64	0 to 48
Change	0	-84 to -116	0	-6 to -12.3	22-64	27-75

a. Montg. Watson, 1995
b. 94,206 AF/yr = 116 MCM/yr, Tompson 2008)
c. Tompson ea 2008, Coes ea 2015

CONAGUA, 2020
For 2004 GW levels

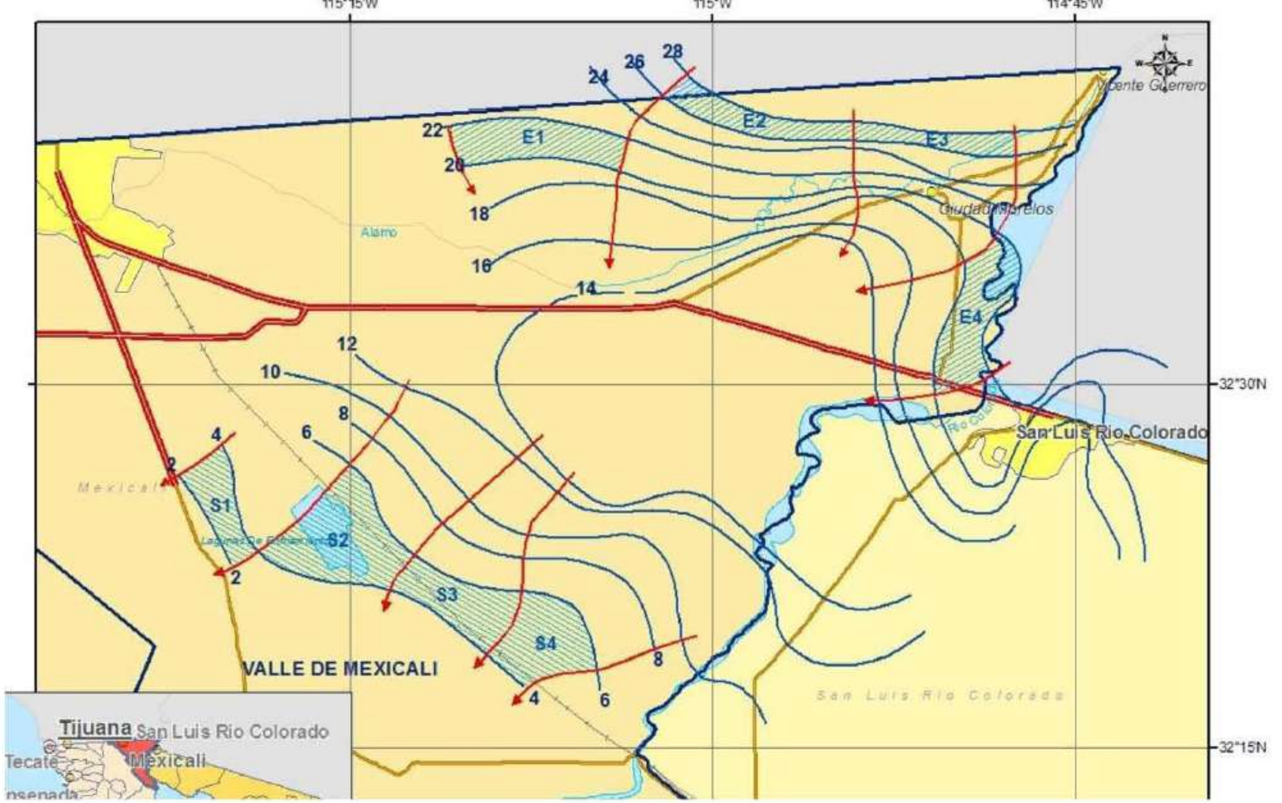
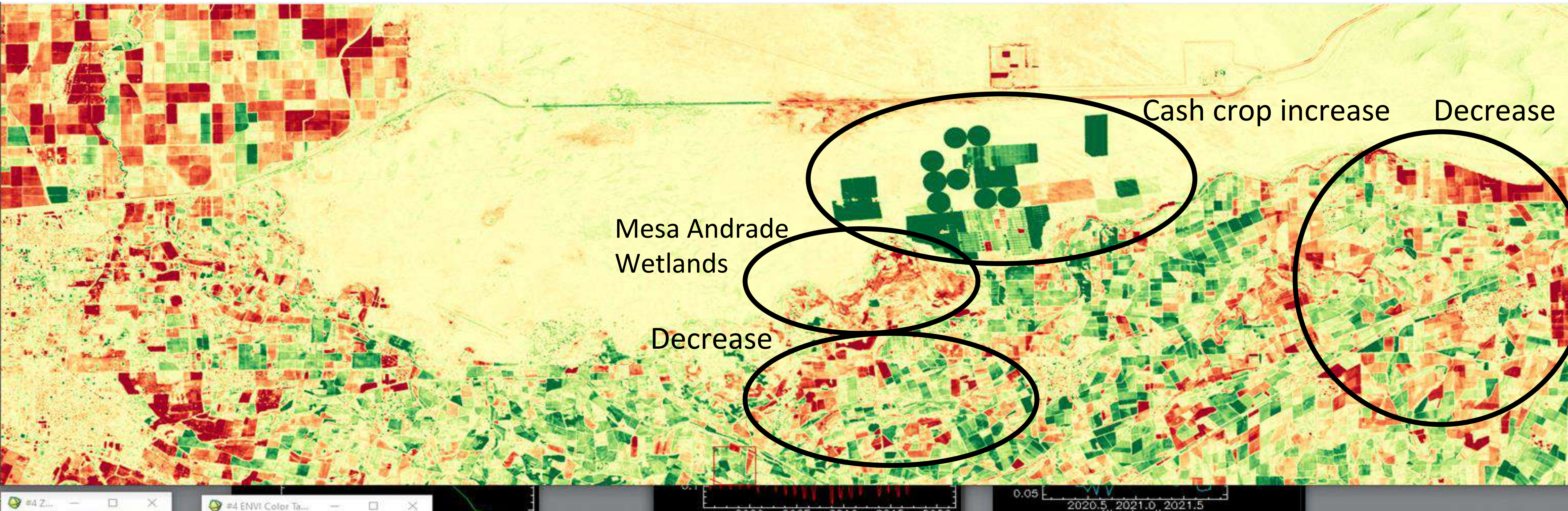


Tabla 2. Entradas subterráneas por flujo horizontal en el acuífero Valle de Mexicali

CELDA	Longitud (m)	Ancho (m)	Delta h (m)	Gradiente	Transmisividad m²/s*	Caudal (m³/s)	Entradas (hm³/año)
E1	9700	3000	2	0.00066667	0.0775	0.5	15.6
E2	14130	1800	2	0.00111111	0.0775	1.2	38.3
E3	10500	1300	2	0.00153846	0.1500	2.4	76.0
E4	11550	3000	2	0.00066667	0.1500	1.2	36.1
Total de entradas subterráneas							166.0

E1-E3 AAC
129.9

3. Where have farms been impacted? PCA annual Green fraction 1995-2023



Appendix G. Groundwater elevations for the years 1990-1999.

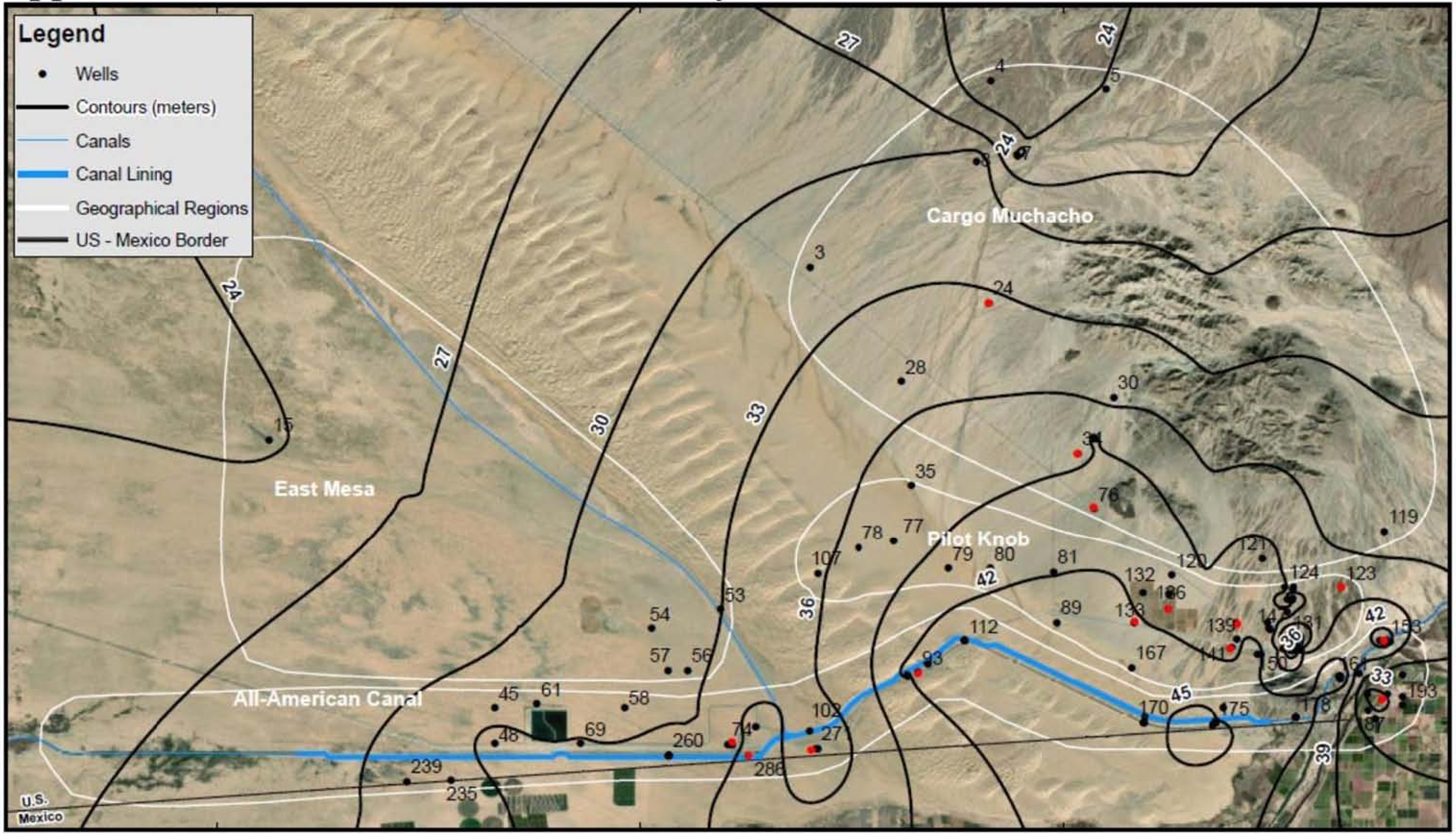


Figure S. Groundwater elevations for the year 2018.

GW elevations, 1990-1999 and 2018, m above mean sea level

Appendix G. Groundwater elevations for the years 1990-1999.

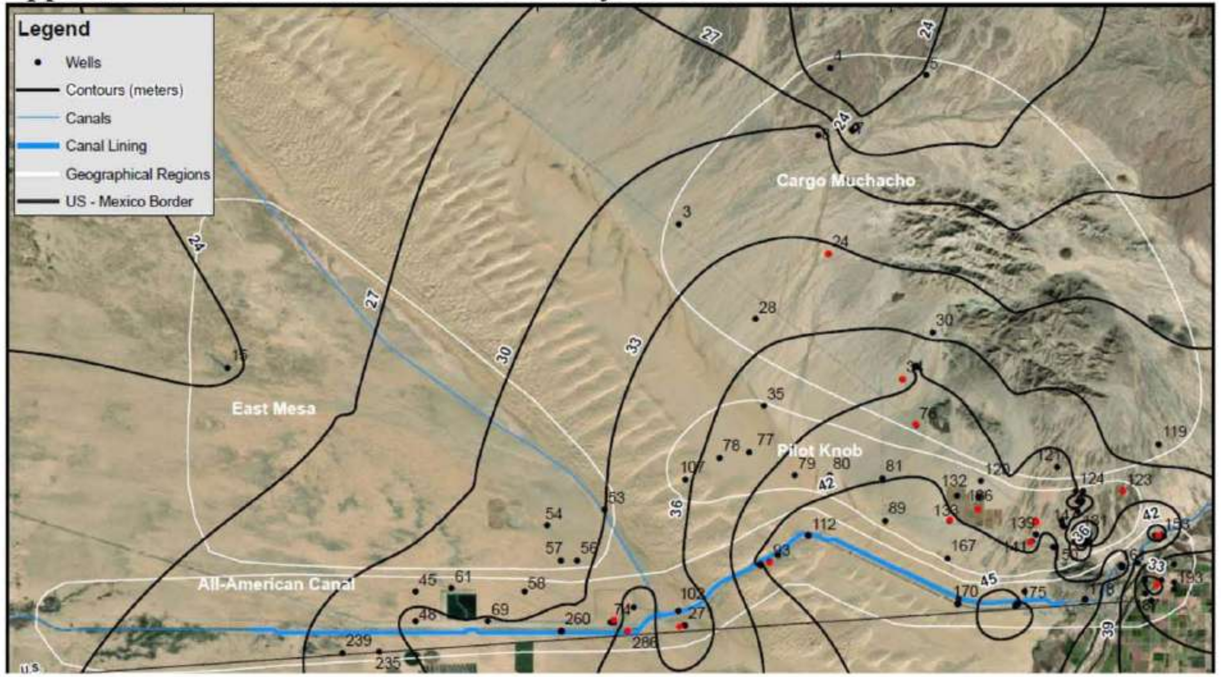


Figure S. Groundwater elevations for the year 2018.

How has GW balance changed?

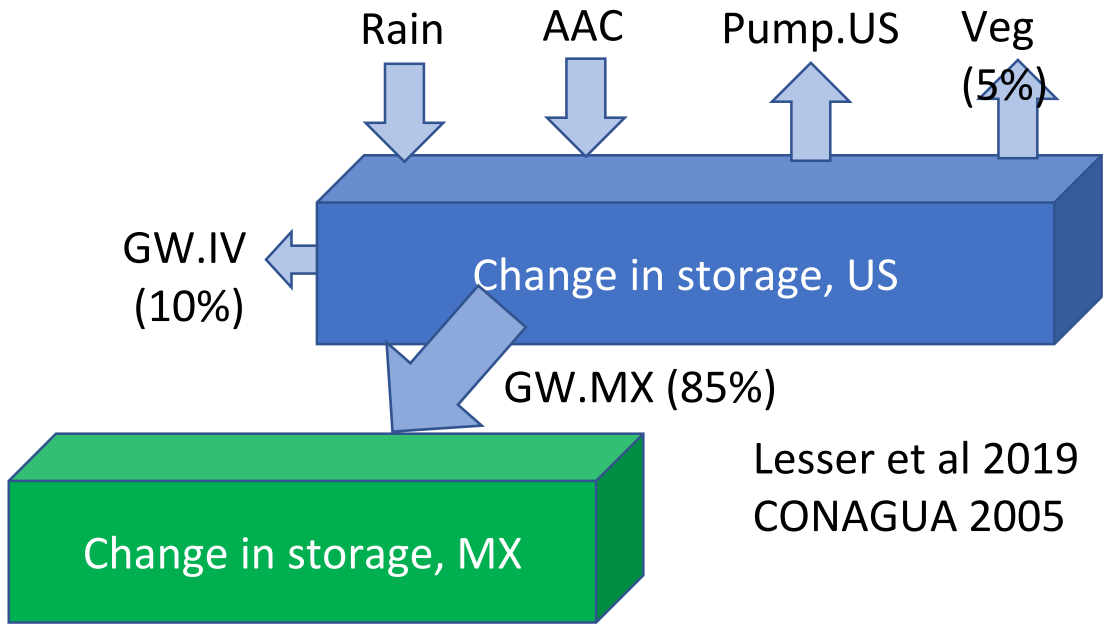
Change in storage ΔS

$\Delta S = RAIN + AAC - (PUMP.US + GW.MX + GW.IV + VEG)$

Solve for change: ΔGW.MX

Change in IN/OUT in US

$= 0.85(-\Delta(\Delta S) + \Delta AAC - \Delta PUMP.US)$



Lesser et al 2019
CONAGUA 2005

Annual water balance, MCM/year

	INPUT		PUMP.US		AAC + PUMP.US	ΔS	GW.MX
	Rain[a]	AAC seep[b]	Pump other[c]	LCWSP pumping			
Pre-lining	<1	84, 116, 130	-30?	0		0	75[d], 130[b]
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1. AAC seepage loss >> New pumping
2. AAC seepage loss > Change in storage –> reduced GW flow to MX

Interviews with farmers (2017): 1. Importance of 2010 earthquake.

2. 100% of respondents in “Negative trend” report water scarcity as primary driver