Automated Soil and Groundwater Monitoring to Support Adaptive Management of Actively Managed Riparian Restoration Areas

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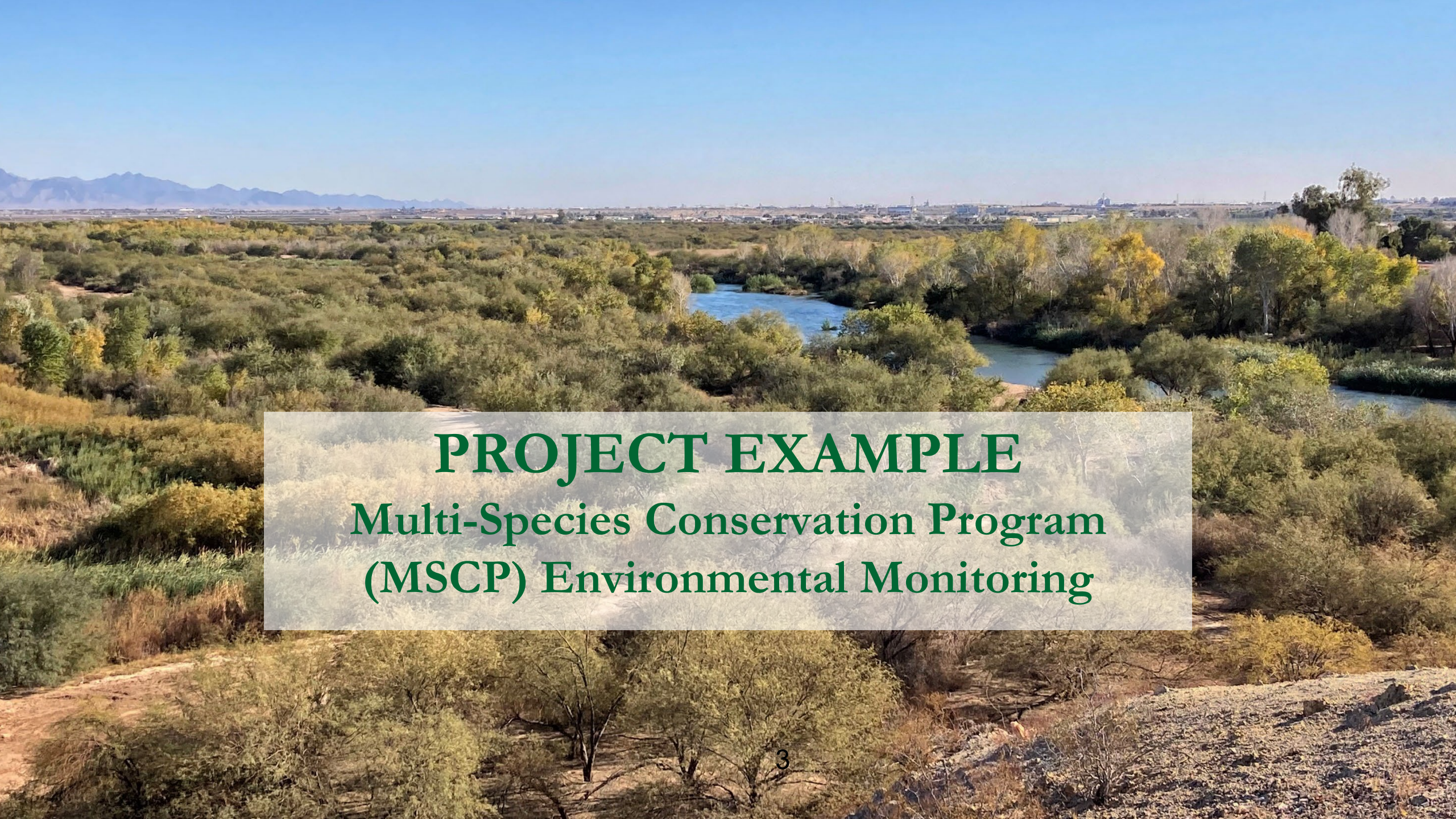
Lower Colorado River Multi-Species Conservation Program

Actively Managed Riparian Restoration

- Groundwater Dependent Ecosystems (GDEs)
  - Shallow groundwater needed (10-12 ft)
  - Low salinity (<4-8 dS/m)
- Active management
  - Irrigation for plant establishment
  - Deep and/or saline groundwater
  - Habitat quality – moist soil for bugs!
- Soil and groundwater monitoring for active and adaptive management
  - Meeting habitat requirements?
  - Conditions within tolerance thresholds?
  - Irrigation Management
    - Uniformity
    - Duration
    - Schedule/timing

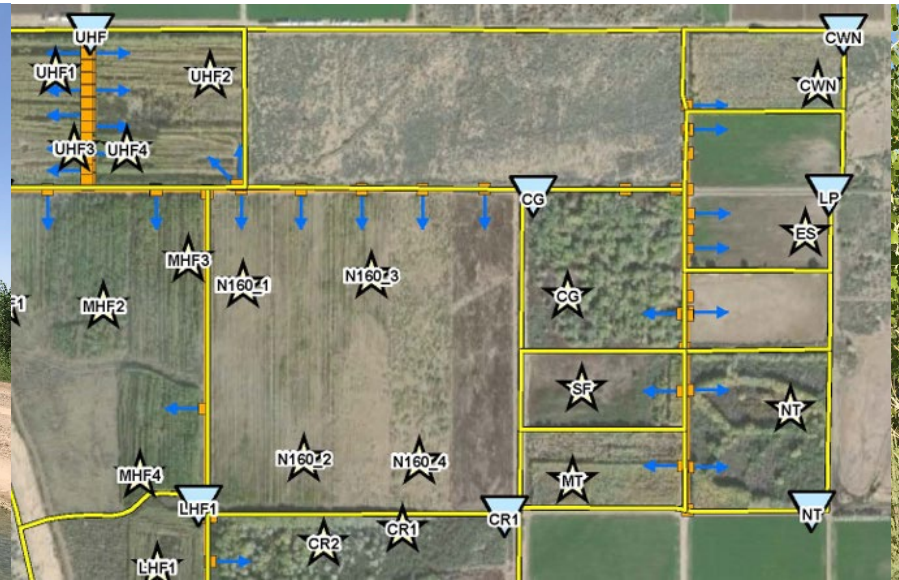


PROJECT EXAMPLE

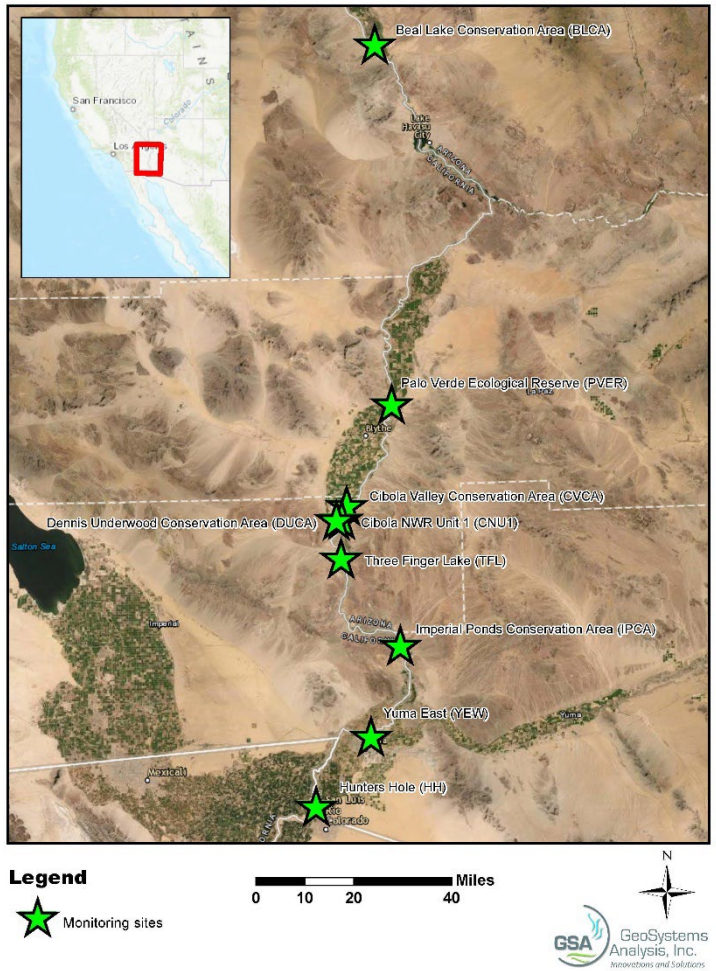
Multi-Species Conservation Program (MSCP) Environmental Monitoring

Project Objectives

1. Is groundwater depth and salinity maintained within plant tolerance thresholds during period of peak ET?
2. Are moist surface soils maintained during avian nesting period?
3. Can irrigation be optimized to meet project goals?
4. Can we use vegetation greenness as a proxy for vegetation health? If so, are there relationships between soil and groundwater data and vegetation health?



Monitoring Network – as of Year 7



- Nine monitoring sites
- 148 Monitoring Stations
  - 53 Groundwater stations
  - 95 Soil Moisture stations

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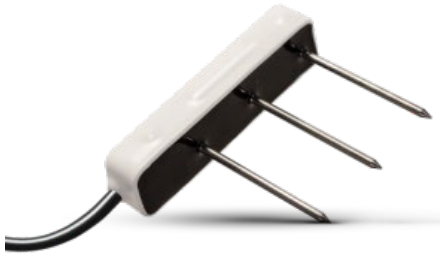
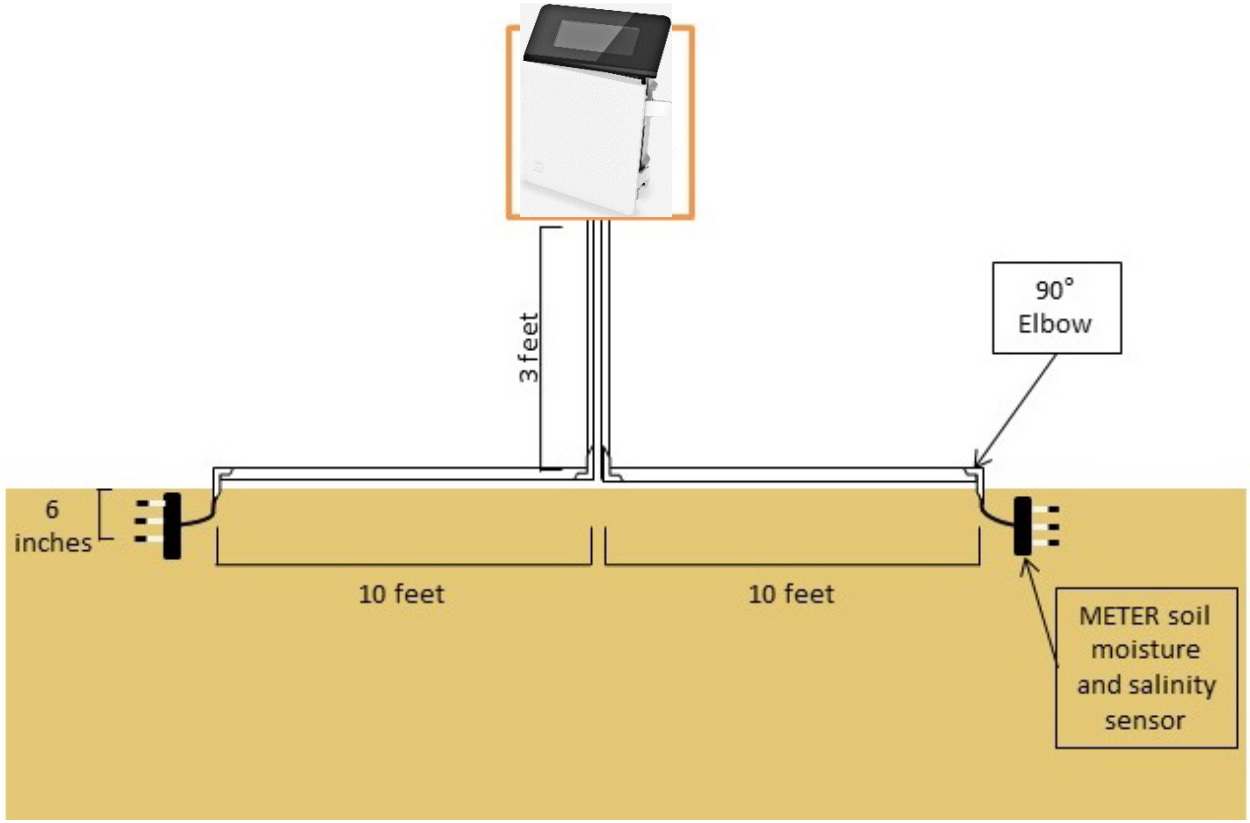
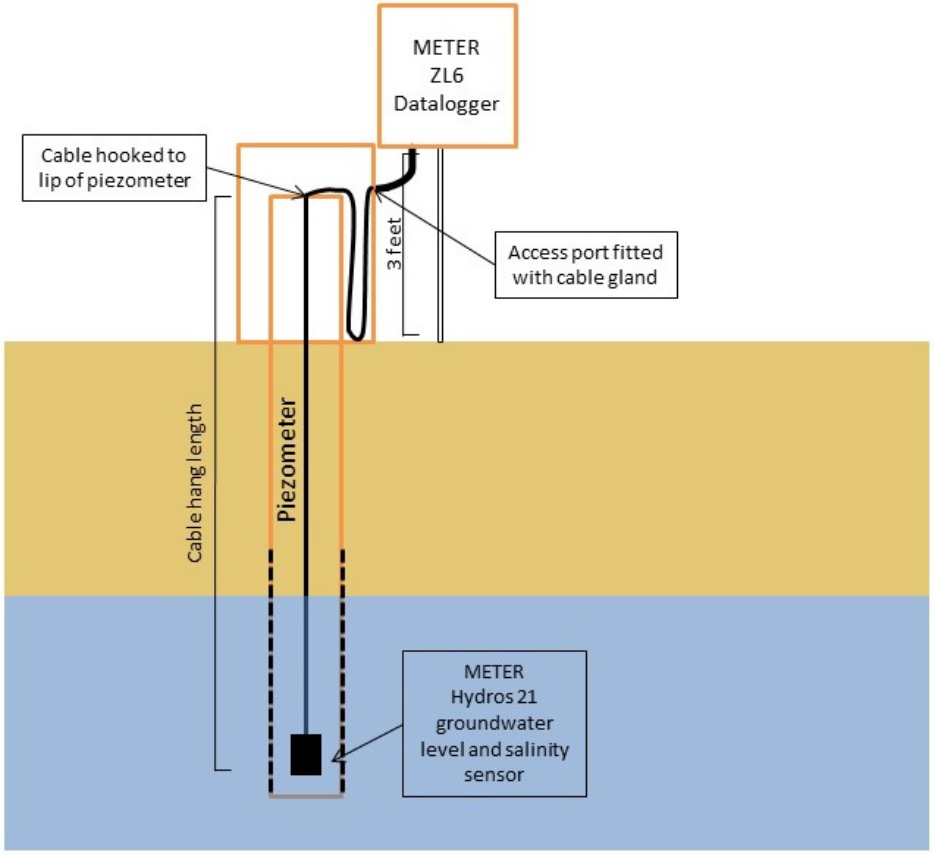
Soil Moisture Stations





Groundwater Stations



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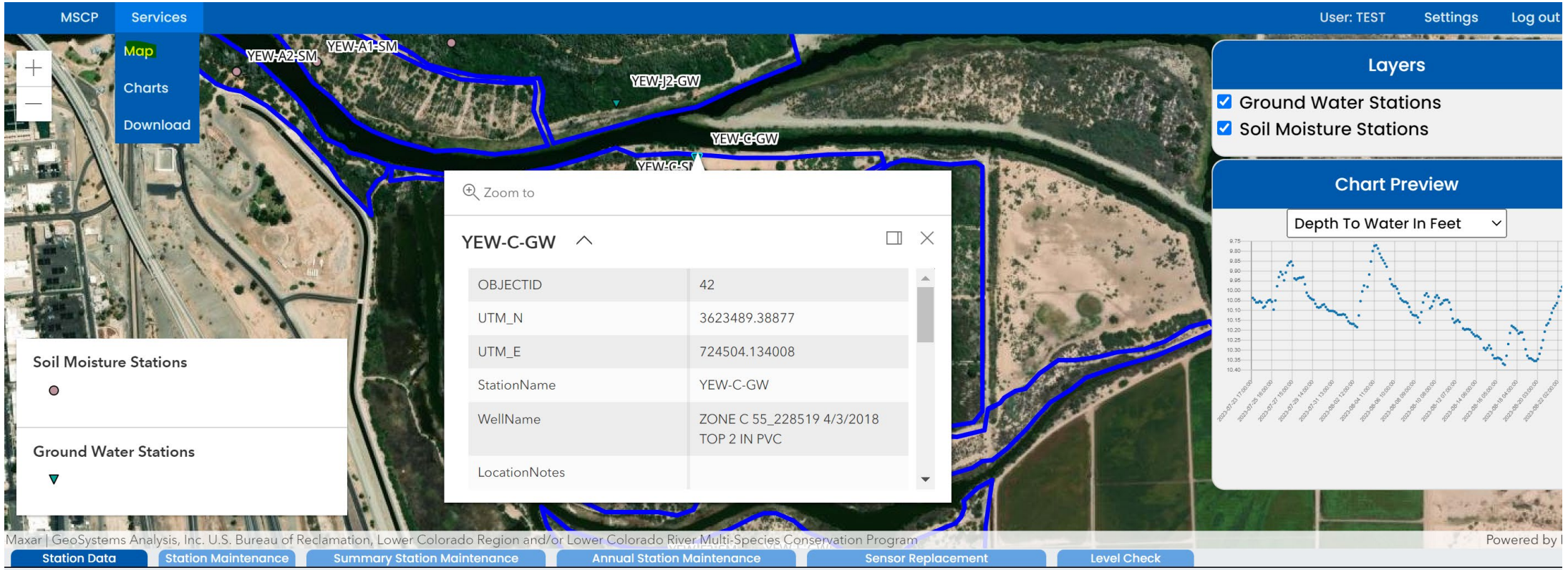
Web Application/Geodatabase



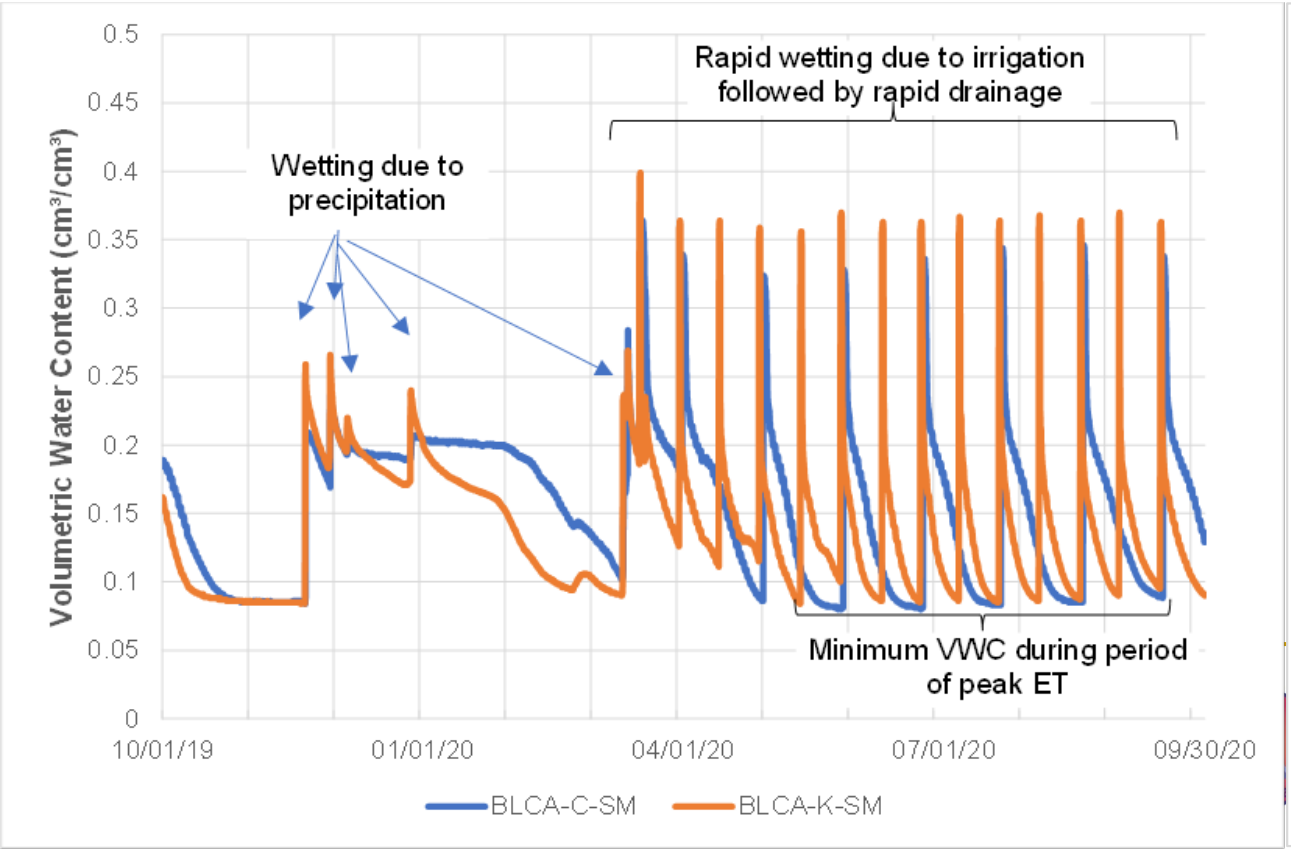
Timestamp	Depth To Water (ft) port 1	Groundwater Elevation (ft) port 1	Groundwater EC (dS/m) port 1	Water Temperature (C) port 1	Logger Temperature (C) port 8	Reference Pressure (kPa) port 8	Battery Percent (%) port 7	Battery Voltage (mV) port 7
2023-08-23 00:00:00	10.0	117.0	5.321	24.0	48.9	100.52	79.0	7627.0
2023-08-22 20:00:00	10.0	117.0	5.272	24.0	52.4	100.76	78.0	7619.0
2023-08-22 16:00:00	10.0	117.1	5.224	24.0	29.0	100.76	74.0	7588.0
2023-08-22 12:00:00	10.0	117.1	5.2	24.0	21.4	100.69	74.0	7589.0
2023-08-22 08:00:00	10.0	117.0	5.224	24.0	24.3	100.78	73.0	7577.0
2023-08-22 04:00:00	10.0	117.0	5.212	24.0	31.1	100.66	79.0	7624.0
2023-08-22 00:00:00	10.1	117.0	5.224	24.0	41.6	100.8	78.0	7621.0
2023-08-21 20:00:00	10.1	117.0	5.284	24.0	39.9	100.99	76.0	7606.0
2023-08-21 16:00:00	10.1	117.0	5.297	24.0	28.7	100.96	75.0	7596.0
2023-08-21 12:00:00	10.1	116.9	5.346	24.0	22.6	100.76	75.0	7596.0

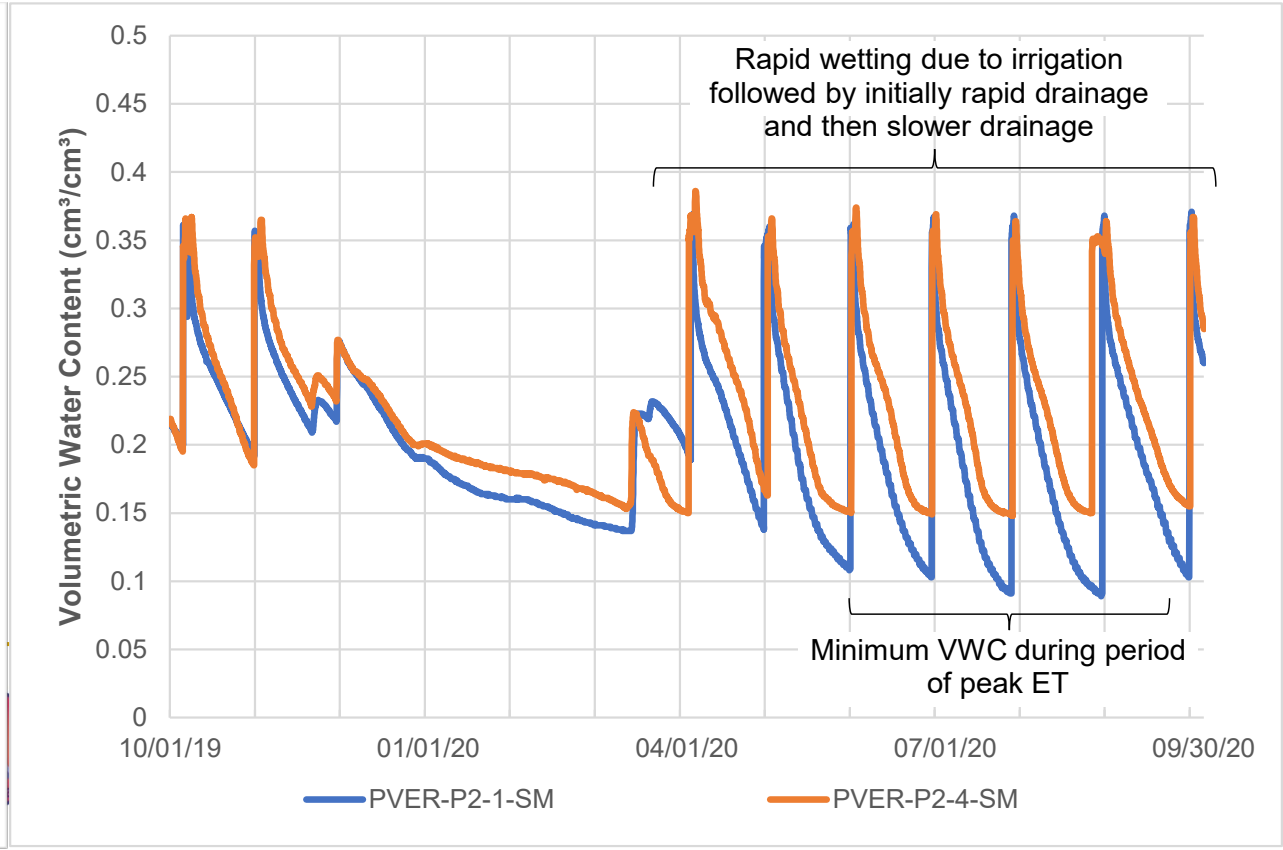
Results

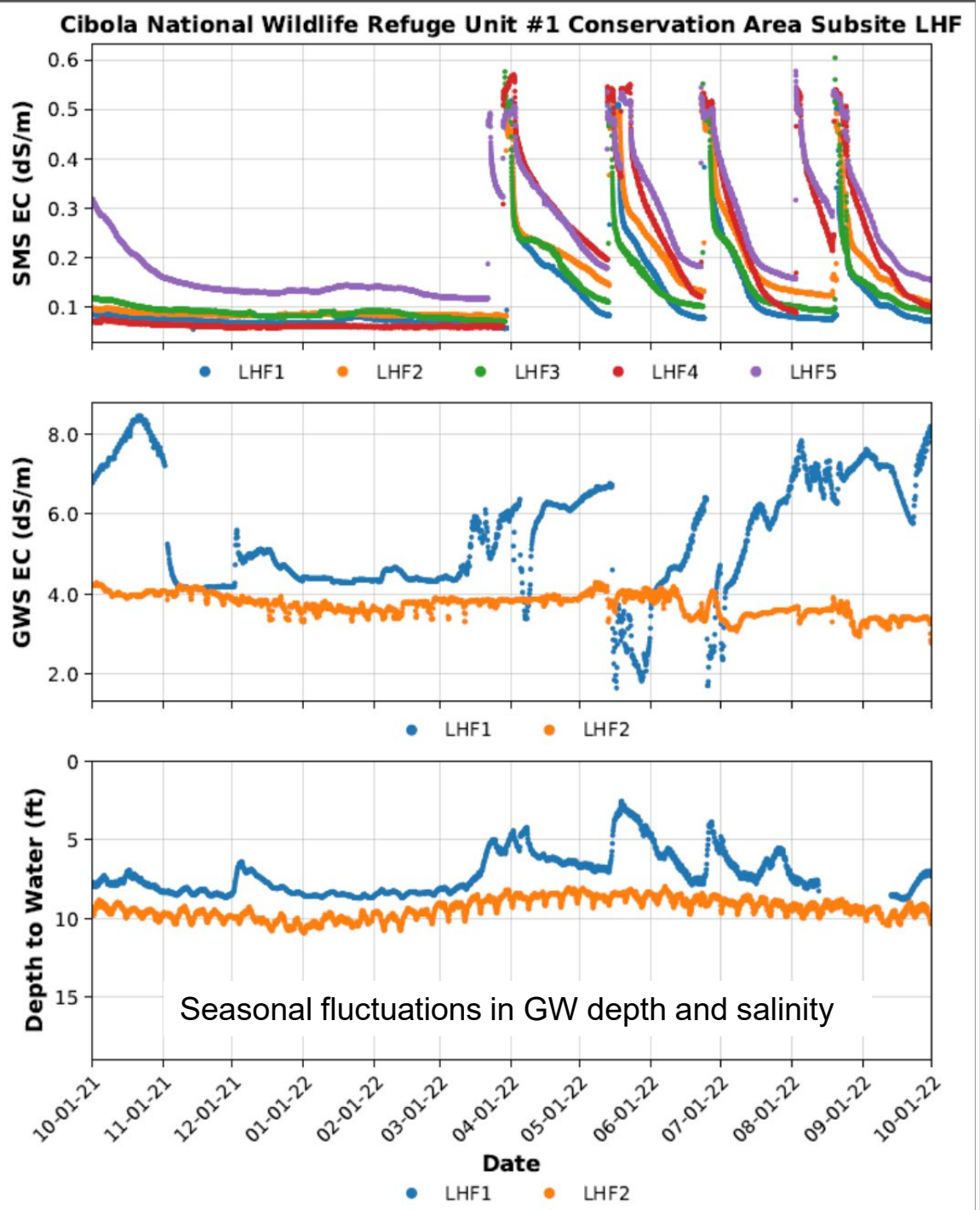
Monitoring Years 1-6

General Trends: Soil Moisture Data

- Number of irrigation events
- Number of days between irrigation events
- Max, Min, and Avg VWC during growing season
- Duration of maintenance of moist soils (T90)

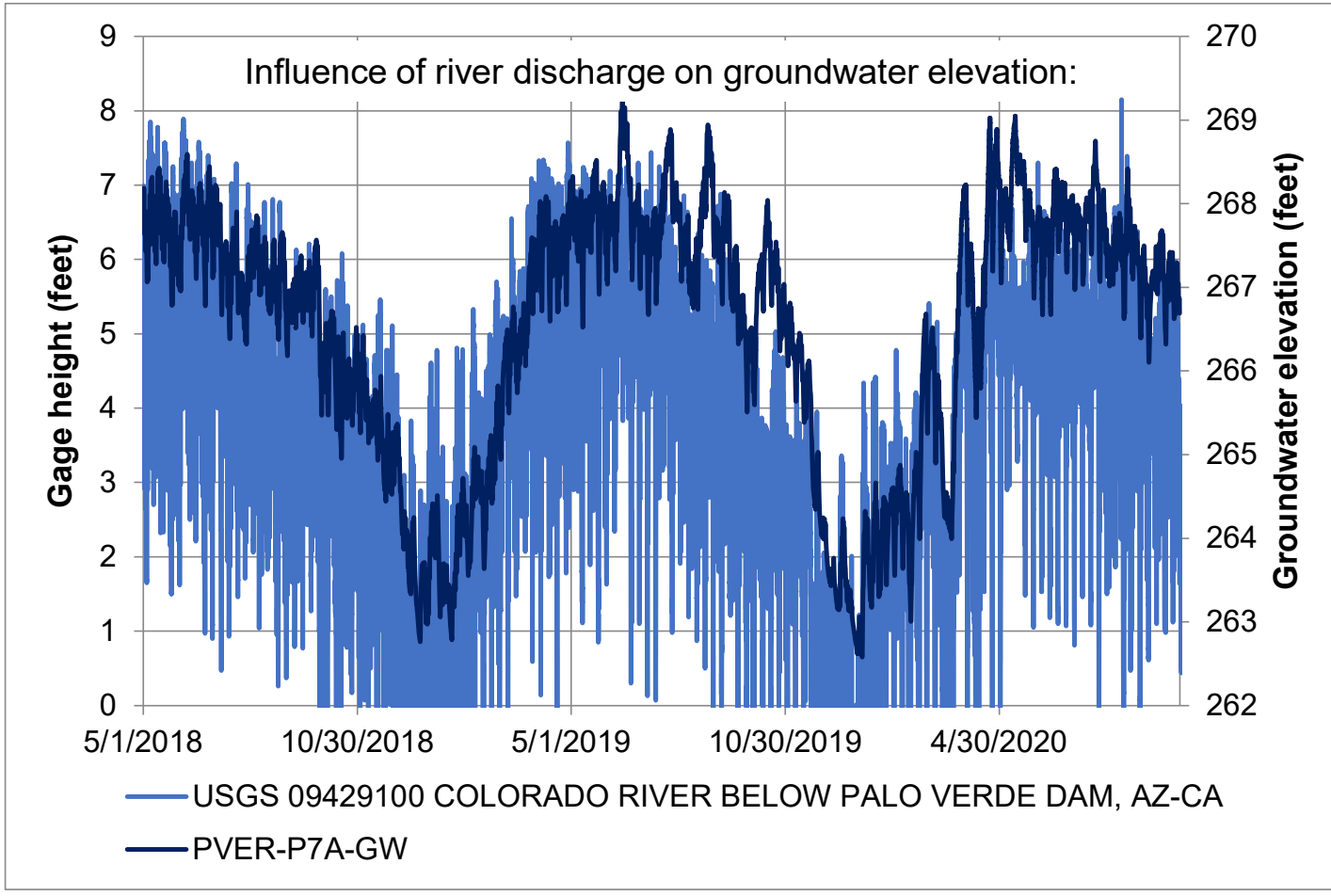






General Trends: Groundwater Data

- Max, min, and avg depth to water during growing season
- Degree of soil salt leaching or dilution of groundwater salinity
- Irrigation and river discharge influences on groundwater levels



Objective 1: Is groundwater depth and salinity maintained within plant tolerance thresholds?

Year 6:

Site	# GW Stations	Growing Season (April -Sept) Percent of Monitoring Stations with:		
		GW>10 ft	Salinity > 4 dS/m	Salinity > 8 dS/m
BLCA	5	0%	40%	0%
PVER	10	100%	0%	0%
CVCA	10	70%	20%	0%
Cibola NWR Unit #1	10	10%	40%	30%
Three Fingers Lake*	3	0%	67%	33%
IPCA*	5	0%	20%	20%
YEW	5	0%	80%	40%

*Sites that are not yet planted

Deep groundwater, low salinity

Shallow groundwater, high salinity

- Site specific
- Seasonal, interannual variability

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Objective 2: Are moist surface soils maintained during the avian nesting period?

Coarse-grained soils:

MSCP Subsite(s)	Number of sensors	Peak Evapotranspiration Period (May 1 - September 30)					Nesting Period	
		Average number of irrigation events	Maximum VWC (%)	Minimum VWC (%)	Average time between irrigation events (days)	Maximum time between irrigation events (days)	Average number of irrigation events	T90% of Max VWC (%) (Avg, Min-Max)
		Year 2					(March 1 – July 31)	
BLCA-C, F, I, KK, LL	10	6	40	10	28	29	6	2.1, 1-3.6
BLCA-K, P, FF	6	10	38	8	14	15	11	3, 1.5-4.9
BLCA-L	2	22	42	11	7		21	6.5, 6.4-6.5

Fine-grained soils:

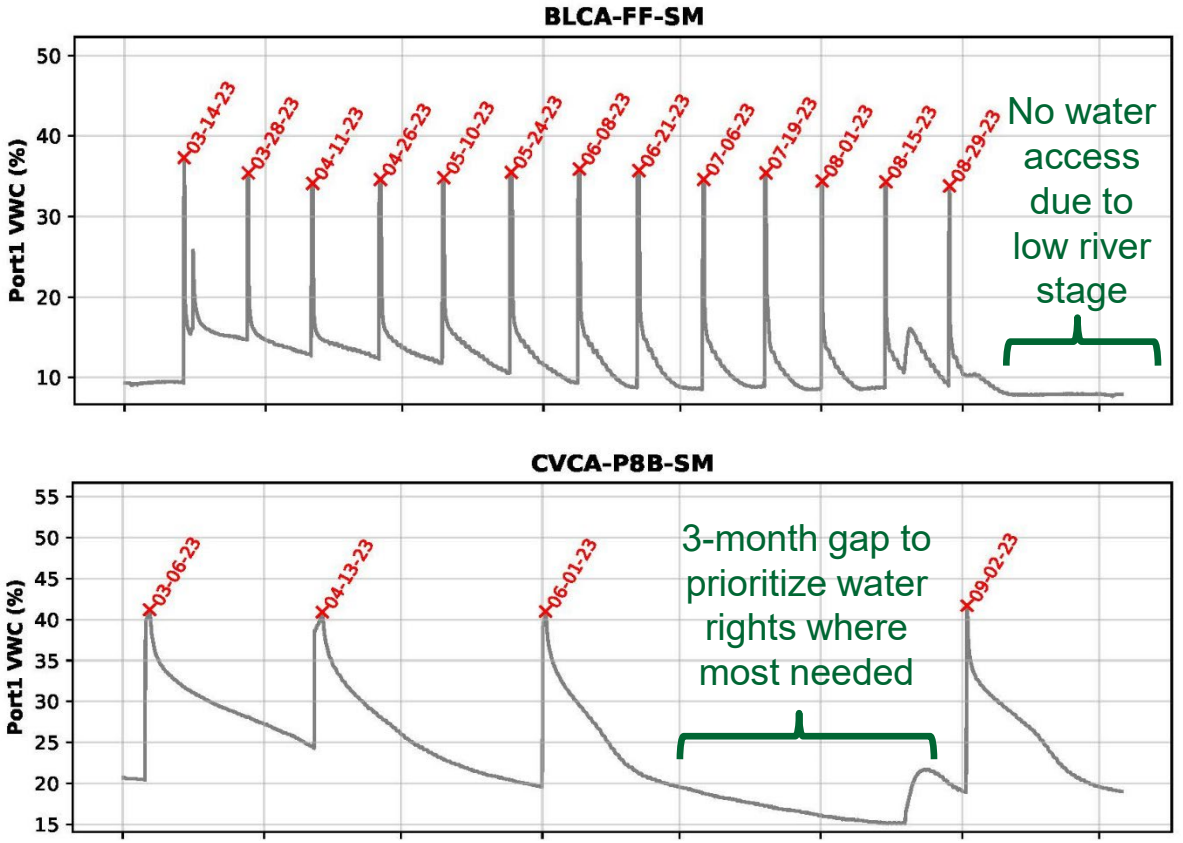
MSCP Subsite(s)	Number of sensors	Peak Evapotranspiration Period (May 1 - September 30)					Nesting Period (March 1 - July 31)[1]	
		Average number of irrigation events	Maximum VWC (%)	Minimum VWC (%)	Average time between irrigation events (days)	Maximum time between irrigation events (days)	Average number of irrigation events	T90% of Max VWC (%) (Avg, Min-Max)
		Year 2					(March 1 – July 31)	
CNU1-CG	2	3	44	12	48	79	6	8.1, 7.7-8.5
CNU1-CR	4	1	41	7	29	28	3	19, 16-22
CNU1-CWN	2	0	8	6	N/A		0	0
CNU1-MT	2	2	44	21	43	43	5	5.4, 4.7-6
CNU1-NT	2	5	53	24	48	77	5	13, 12-13
CNU1-N160	8	5	41	10	28	38	4	14, 9.7-22

- Soil texture is a key driver
- Limitations: what is the “moist soil” threshold for our target bird species?
- Need for ongoing soil moisture monitoring at established SWFL nesting sites

Objective 3: Can irrigation be optimized?

- Yes!
- Annual variability, and site specific
  - Improved schedule adherence (CNU1)
  - Improved irrigation distribution (PVER)
  - Occasional disruptions in very regular irrigation due to water and safety constraints (BLCA, HH)
- Monitoring → Adaptive Management

Script identifies irrigation event dates from soil moisture data:



Objective 4: Can we use vegetation greenness as a proxy for vegetation health?

- EVI data as an ongoing, quick proxy to monitor vegetation health in the absence of high-resolution site imagery or vegetation surveys
- Early vs. late growing season greenness:

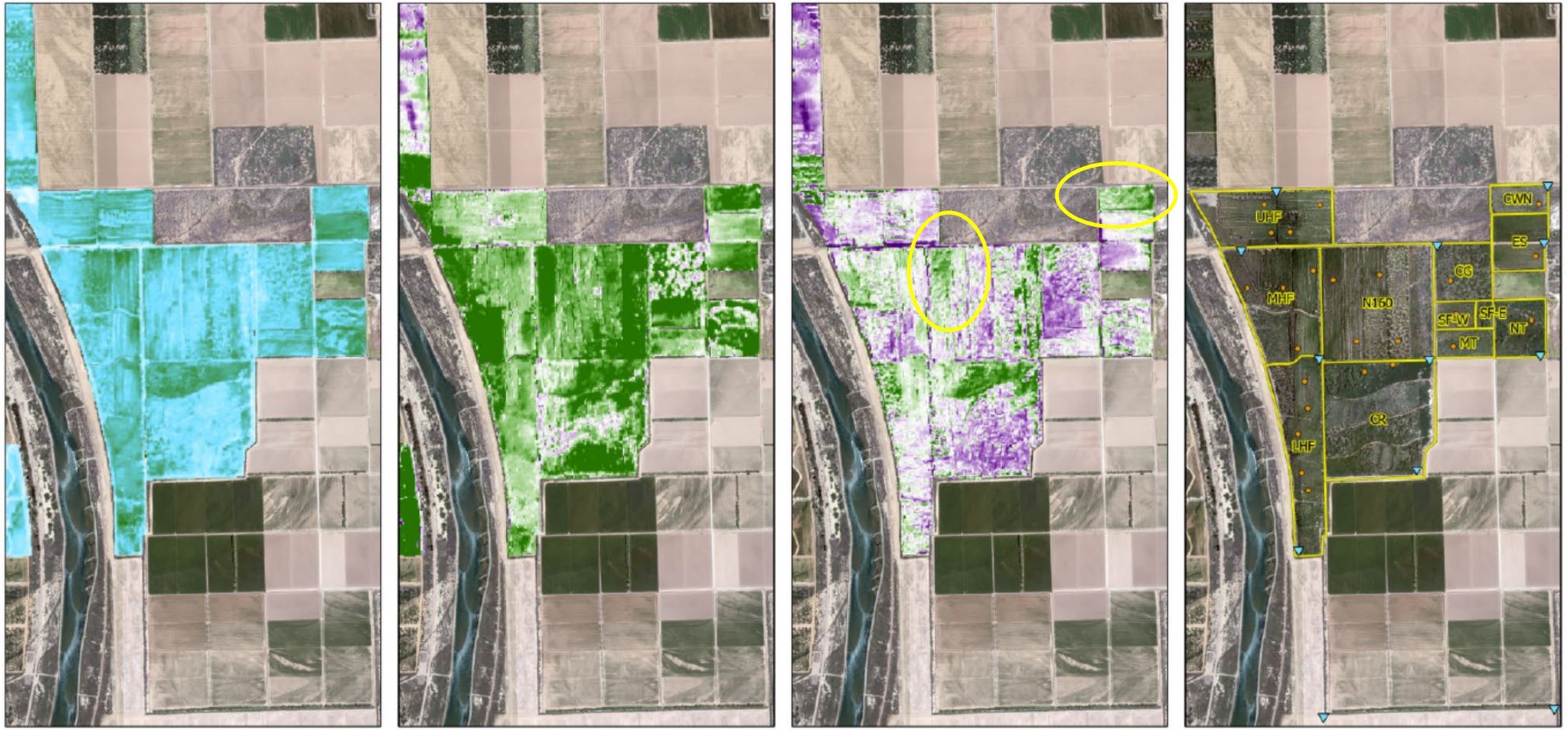
$$Relative\ Seasonal\ dEVI\ (\%) = \frac{(September\ or\ October\ EVI - April\ EVI)}{April\ EVI} \times 100$$

- Changes in vegetation health over time:

$$Relative\ Annual\ dEVI\ (\%) = \frac{(September\ or\ October\ 2023\ EVI - September\ or\ October\ 2022\ EVI)}{September\ or\ October\ 2022\ EVI} \times 100$$

- + dEVI = increasing greenness, stable or improved vegetation health
- - dEVI = decreasing greenness, declining vegetation health or changes in community composition
  - Water stress, high salinity, plant pathogens, herbivory, animal disturbance, interannual variability, wildfire

Cibola National Wildlife Refuge Unit #1 - Year 6



EVI Sep/Oct 2023 | dEVI Apr - Sep/Oct 2023 | dEVI 2022 - 2023 | Reference

N

0 0.25 0.5 1 Miles

EVI 0.75 / 0 **dEVI** 0.5 / -0.5

- Monitoring Wells
- Soil Moisture Stations
- SubsiteBoundaries

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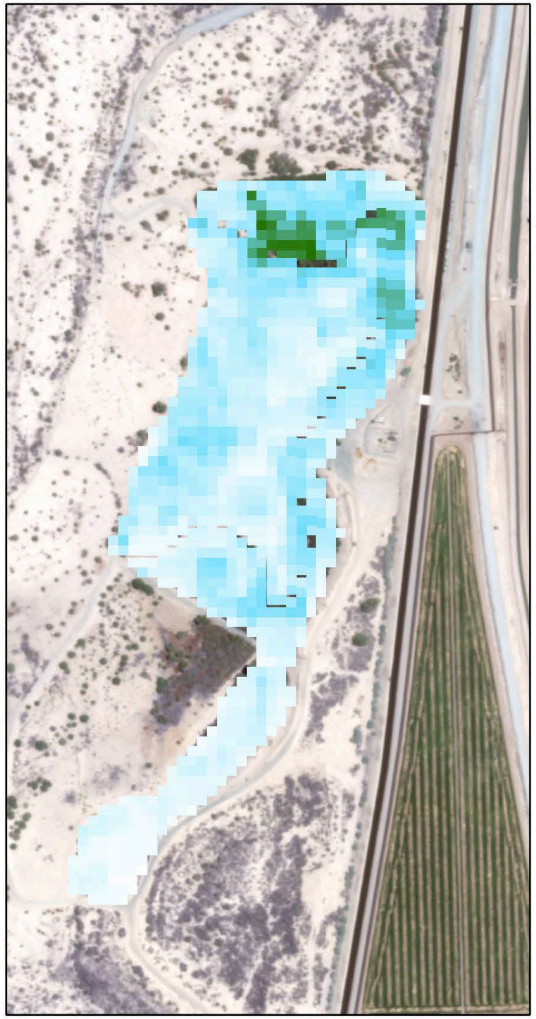
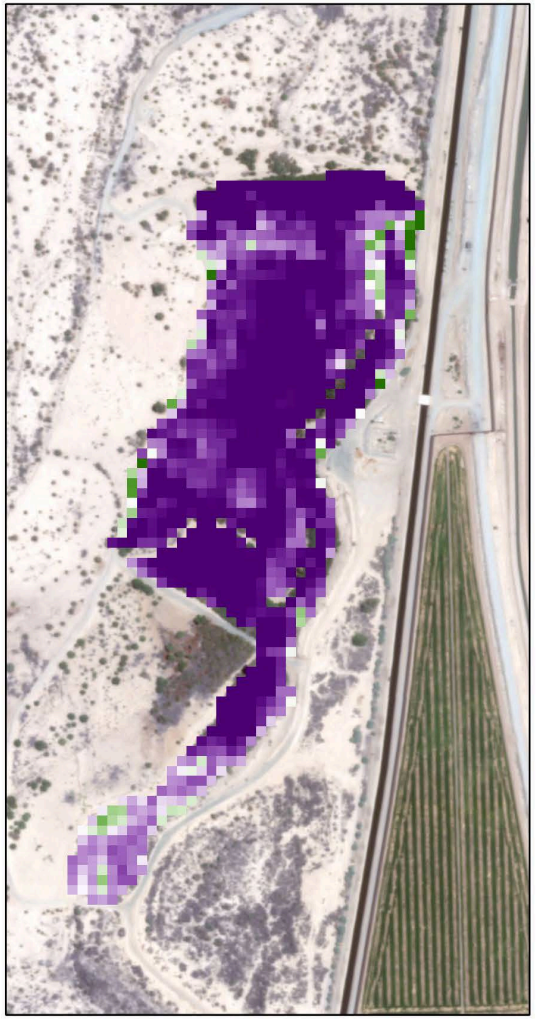
Source data: SkySat imagery collected July 2023 courtesy of MSCP. Management unit boundaries provided by MSCP. Monitoring locations measured with field GPS (varying accuracy). NAD 1983 UTM 11N

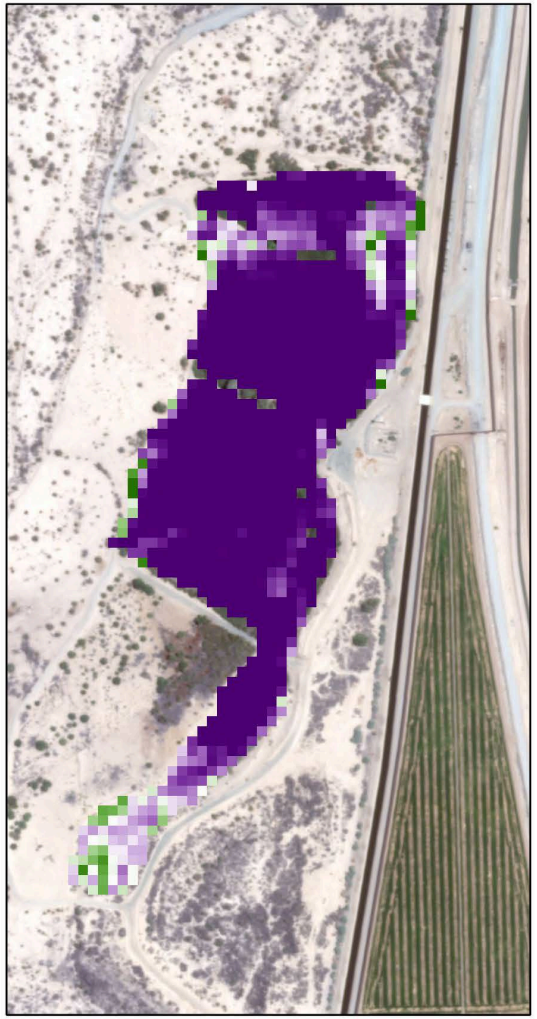
Hunters Hole



EVI Sep/Oct 2023



dEVI Apr - Sep/Oct 2023



dEVI 2022 - 2023

Reference

N

0 0.13 0.25 Miles

EVI
0.75
0

dEVI
0.5
-0.5

Monitoring Wells
Soil Moisture Stations
Subsite Boundaries

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Source data: Skysat imagery collected July 2023 courtesy MSCP; Management unit boundaries provided by MSCP. Monitoring locations measured with field GPS (varying accuracy). NAD83 UTM 11N

Applications of this work

- Pre-implementation monitoring and site selection
  - How much preparation/adaptive management would be required for a particular site?
  - Target sites requiring as little management as possible (e.g. low salinity), or design to meet plant needs (e.g. shallow groundwater)
- Post-implementation monitoring
  - Irrigation uniformity, timing, duration
  - Influence of nearby water sources on groundwater levels
  - Salinity management
  - Soil moisture for target species

Conclusions

- At most sites, soil and groundwater conditions were maintained within plant tolerance thresholds
- Maintenance of moist surface soils is influenced by
  - Soil type (sandy vs fine-grained)
  - Irrigation duration and frequency
- Vegetation health is strongly influenced by irrigation management where groundwater is deep (>10 ft) and/or salinity is above tolerance thresholds
- As of Year 6 at established sites, vegetation greenness:
  - Increased with improved irrigation management (CNU1)
  - Mostly consistent with interannual variability (CVCA, PVER, YEW)
  - Decreased due to changes in irrigation management (BLCA, HH)
  - Caveats: variability within sites, we can't attribute all greenness to cottonwood/willow

Thank you!

Acknowledgments:

Bureau of Reclamation - Lower Colorado River MSCP

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Photo: J Ladderud