Assessment, prioritization, and design of riparian restoration opportunities in the middle Santa Cruz River, Arizona

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Acknowledgements

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Finally, we extend our deepest thanks to Michael Campbell. Their thoughtful, detailed research and alignment with the spirit and vision of this project have left an indelible mark on the final report. Without Michael's contributions, this work would not be nearly as impactful or complete.

About Sonoran Institute

Sonoran Institute is a conservation-focused 501(c)(3) nonprofit organization based in Tucson, Arizona, working throughout the Colorado River watershed. Since our founding in 1990, we have connected people and communities to the natural resources that nourish and sustain them through collaborative, science-based solutions. Our Santa Cruz River program envisions *"a living, flowing Santa Cruz River, from Mexico to Marana, as the foundation of community health and prosperity."*

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Abstract
This final report for R22AP00310 entitled “Assessment, prioritization, and design of riparian restoration opportunities in the middle Santa Cruz River, Arizona” summarizes the results of a federally supported planning project to assess riparian restoration opportunities along the Middle Santa Cruz River (MSCR) in Pima County, Arizona. Led by the Sonoran Institute and supported through the Bureau of Reclamation’s WaterSMART program, the project focused on identifying viable, water-secure strategies for introducing in-stream flows that support ecological and community benefits.

Through hydrologic analysis, infrastructure review, and stakeholder consultation, the project confirmed that treated effluent is the most reliable and renewable source of water for restoring perennial surface flow in the MSCR. The Green Valley Water Reclamation Facility (WRF) was identified as the best near-term option due to its upstream location, high-quality discharge, and infrastructure readiness.

Three restoration scenarios were developed: (1) a modest flow created by redirecting currently available surplus effluent; (2) a mid-scale effort using the WRF’s full production capacity; and (3) a long-term concept involving regional WRF consolidation and extended conveyance infrastructure, resulting in over six miles of restored flow. These scenarios were evaluated using a structured scoring matrix and aligned with regulatory permitting pathways through ADEQ and ADWR.

The project also addresses practical constraints, including the need to avoid discharge impacts on tribal lands and the opportunity to earn long-term storage credits through in-channel recharge. Future implementation is supported by existing regional collaboration via the Santa Cruz Watershed Collaborative.

The findings demonstrate strong technical feasibility and broad stakeholder support for effluent-based flow restoration. The MSCR now stands as a prime candidate for BOR implementation funding to support near-term regulatory filings and infrastructure work, with a clear path to long-term, multi-benefit restoration outcomes.

Executive summary

The Middle Santa Cruz River (MSCR) in southern Arizona represents one of the few remaining stretches of the Santa Cruz River in Pima County without consistent, managed surface flows. This project, supported by the Bureau of Reclamation (BOR) WaterSMART program, was designed to identify viable, water-backed opportunities for riparian restoration along the MSCR. Project goals included locating feasible restoration sites, identifying sustainable water sources, and developing implementable concepts for surface flow reintroduction. Through data analysis, site evaluation, and stakeholder collaboration, the project confirmed that high-quality effluent represents the most feasible and renewable water source for in-channel flow restoration.

Effluent-based flows are already transforming other sections of the Santa Cruz River and other Arizona rivers. These engineered flows have produced ecological, recreational, and groundwater recharge benefits. However, the MSCR has yet to see these improvements. Our study emphasized solutions that are practical, locally acceptable, and likely to succeed under current regulatory and operational conditions. Crucially, all concepts were developed to avoid impacting lands of the Tohono O'odham Nation, respecting tribal sovereignty while aligning with managed recharge frameworks under Arizona law.

Key findings demonstrate that the Green Valley Water Reclamation Facility (WRF) is the most suitable near-term effluent source. Its effluent quality, volume, and upstream location relative to tribal lands make it ideal for initiating surface flow restoration. A long-term opportunity also exists through the proposed Future Consolidated Project, which would unify subregional WRFs into a single, high-capacity regional facility. If designed to include conveyance back to the Green Valley outfall, this would support over six miles of perennial surface flow, greatly expanding restoration potential.

Three conceptual restoration scenarios were developed. The first involves modest in-channel discharge using current surplus effluent volumes, creating approximately 0.75 miles of surface flow. The second, more ambitious scenario would repurpose all available effluent from Green Valley WRF, creating 2.75 miles of flow. The third scenario envisions future effluent consolidation and infrastructure build-out to support 6.15 miles of restored river. Each scenario presents increasingly significant ecological, recreational, and groundwater recharge benefits, with planning pathways already outlined through regional stakeholder engagement.

Effluent-based flows offer low evaporative losses, locally and regionally proven recharge efficiency, and rapid habitat recovery. Evidence from similar reaches shows riparian communities reestablish quickly, including hydrophilic plant species and aquatic insects. These conditions foster broader ecosystem resilience while improving recreation access and supporting economic activity. Outdoor recreation already contributes over $14 billion to Arizona's GDP, and restored flows would enhance this sector in Pima County.

This work builds on existing regional coordination, notably through the Santa Cruz Watershed Collaborative (SCWC), and integrates community water system data, WRF performance, and land-use plans. With broad local support and a strong foundation in practical hydrology and governance, the MSCR project is well-positioned for next-phase implementation.

Recommendations for Future Funding and Implementation:

- Pima County Board of Supervisors should adopt in-channel effluent recharge as a policy goal and initiate relevant regulatory filings.
- BOR implementation funds should prioritize infrastructure supporting this project's Concept 1 and enable expansion toward Concepts 2 and 3.
- Agencies should pursue long-term storage credit (LTSC) parity for in-channel recharge, enhancing return on investment.
- Tucson Water and Pima County RWRD should continue evaluating effluent routing options as part of regional WRF planning.
- Collaboration with the Tohono O'odham Nation is essential for long-term restoration alignment and mutual benefit.
- Restoration strategies should avoid unnecessary bank protection, promoting dynamic floodplain function.

This project confirms that effluent-based flow restoration is a technically sound, ecologically beneficial, and cost-effective investment in Arizona's future water resilience.

Acronyms used

AAC	Arizona Administrative Code
ADEQ	Arizona Department of Environmental Quality
ADWR	Arizona Department of Water Resources
AMA	Active Management Area
APP	Aquifer Protection Permit
AF/yr	Acre-Feet per Year
AWBA	Arizona Water Banking Authority
AWP	Advanced Water Purification
AZPDES	Arizona Pollution Discharge Elimination Program
BEA	Bureau of Economic Analysis
BOR	Bureau of Reclamation
CAGRD	Central Arizona Groundwater Replenishment District
CAP	Central Arizona Project
CWS	Community Water System
FICO	Farmers Investment Company
GSF	Groundwater Savings Facility
GPCD	Gallons per capita per day
HUC	Hydrologic Unit Code
LTSC	Long-Term Storage Credit
MSCR	Middle Santa Cruz River
MUSF	Managed Underground Storage Facility
NLCD	National Land Cover Database
NIWTP	Nogales International Wastewater Treatment Plant
PAG	Pima Association of Governments
PRISM	Parameter-elevation Regressions on Independent Slopes Model
RFCD	Pima County Regional Flood Control District
RWRD	Regional Wastewater Reclamation Department
SCWC	Santa Cruz Watershed Collaborative
SCRHP	Santa Cruz River Heritage Project
TNCAZ	The Nature Conservancy in Arizona
USF	Underground Storage Facility
USGS	United States Geological Survey
WRF	Water Reclamation Facility
WRRC	Water Resources Research Center

Glossary of Terms

Acre-Foot (AF):
A unit of volume commonly used in water resource management, equal to the volume of water required to cover one acre to a depth of one foot (approximately 325,851 gallons).

Aquifer Protection Permit (APP):
A permit issued by ADEQ to ensure discharges do not degrade groundwater quality beyond established limits.

Effluent:
Treated wastewater that can be reused for purposes such as irrigation, recharge, or environmental restoration.

Effluent-Based Flow:
Surface water flows in riverbeds derived primarily from discharged treated effluent.

In-Channel Recharge:
The process of recharging groundwater by allowing water (typically effluent) to flow through a natural or managed stream channel.

Long-Term Storage Credit (LTSC):
Credits awarded by ADWR and AWBA for storing water underground in a permitted recharge facility. These can be recovered for future use.

Managed Underground Storage Facility (MUSF):
A natural watercourse designated and permitted for groundwater recharge activities that qualify for LTSCs.

Reclaimed Water:
Wastewater that has been treated to a standard suitable for beneficial use, such as irrigation or recharge.

Restoration Scenario:
A conceptual model describing the volume and extent of effluent discharge for riparian restoration under different conditions or infrastructure assumptions.

Riparian Restoration:
The process of rehabilitating streamside ecosystems, often by reintroducing water flow and native vegetation.

Santa Cruz Watershed Collaborative (SCWC):
A regional partnership of agencies, nonprofits, and stakeholders working collaboratively on Santa Cruz River watershed stewardship and restoration.

Scoring Matrix:
A tool used in the report to prioritize potential water sources for restoration based on availability, volume, permanence, proximity, and infrastructure readiness.

Subregional Facility:
A localized wastewater treatment facility serving a specific geographic area, as opposed to a regional facility serving multiple subregions.

Treated Effluent:
Wastewater that has undergone treatment and meets regulatory standards for discharge or reuse.

Water Reclamation Facility (WRF):
A facility that treats wastewater to a level suitable for reuse or environmental discharge.

Watershed:
A land area that channels rainfall and snowmelt into creeks, streams, and rivers, eventually leading to outflow points such as reservoirs or oceans.

Introduction

The Santa Cruz River holds profound environmental, cultural, and economic significance, serving as a vital natural resource and a cornerstone for community heritage in the region. Recognizing its importance, this project was designed with the primary goal of identifying viable riparian restoration opportunities that are highly likely to succeed upon implementation. The project's search criteria were deliberately stringent: candidate projects must have an associated water source, be feasible, and offer substantial restoration benefits.

Through comprehensive analysis and stakeholder engagement, our work led to a clear conclusion—effluent stands out as the most reliable, renewable, and feasible water source for riparian restoration along the Santa Cruz River. Effluent is not only of high quality but also scales naturally with potable water demand. Furthermore, its management is supported by an established regulatory framework governing its discharge into Arizona watercourses, and it has already delivered commendable results in other sections of the river.

A key practical constraint emerged during our study: the necessity to ensure that effluent-based flows do not encroach upon tribal lands. This critical consideration has significantly influenced the conceptual frameworks and recommendations presented in this report.

Additional details regarding methodologies, analyses, and conceptual designs are provided in the attached project proposal. The findings documented herein lay a robust foundation for future efforts to restore and enhance the ecological, cultural, and economic vitality of the Santa Cruz River.

Current and ongoing stewardship

This project builds on a strong foundation of existing stewardship and regional collaboration, led by the Santa Cruz Watershed Collaborative (SCWC), which was created with a BOR Phase 1 WaterSMART grant. Sonoran Institute has partnered with SCWC and its diverse membership—including water managers, resource experts, riparian restoration specialists, and key stakeholders—to advance the restoration of the Santa Cruz River. Monthly working group meetings (S1A) provide a central forum for discussing progress, reviewing data, and refining restoration strategies, ensuring consistent communication and robust stakeholder engagement.

SCWC, as detailed on its home page, serves as the nexus for regional water stewardship, offering up-to-date information on watershed conditions and fostering collaborative efforts among local governments, conservation organizations, academic institutions, and community groups. The SCWC partners page further highlights the extensive network of entities—ranging from municipal agencies and water utilities to tribal and non-profit organizations—that actively support watershed restoration initiatives. The SCWC Restoring Flows & Floodplains monthly working group functioned as a routine sounding board for information gathering, concept review, and product evaluation, ensuring that the products of this grant were reviewed in-line and are peer reviewed.

In addition to routine meetings, quarterly reports (see below, section S1C) are produced to document project findings and inform the prioritization evaluation process. These reports are shared with the SCWC Coordinating Team and presented at semi-annual watershed forums, further integrating our work into the broader regional framework. The collaborative process extends to the development of water budgets, conceptual designs, and addenda to the SCWC Watershed Restoration Plan (S2B, S3A, and S3C), with direct input from engaged water users and managers.

Through continuous engagement with municipal agencies, water utilities, agricultural and industrial stakeholders, and tribal representatives, this stewardship framework ensures that restoration efforts are informed by local needs and best practices. This integrated, collaborative approach not only leverages past successes but also lays the groundwork for sustainable, region-wide riparian restoration in the Santa Cruz River watershed.

Study area

The goal of the is project was to identify conservation opportunities on the Middle Santa Cruz River (MSCR), which we define as the Santa Cruz River and its tributaries from the Santa Cruz County–Pima County line (upstream end) to the San Xavier District of the Tohono O'odham Nation (downstream end). Because water resources in the focus area are managed at the regional level, the study also considers water management in the broader Santa Cruz River watershed.

We use the phrases "project context area", "study focus area," "opportunity search area," and "MSCR corridor" in reference to the systems described in **Table 1** and shown in ***Figs. 1-3***.

Santa Cruz watershed and project context area

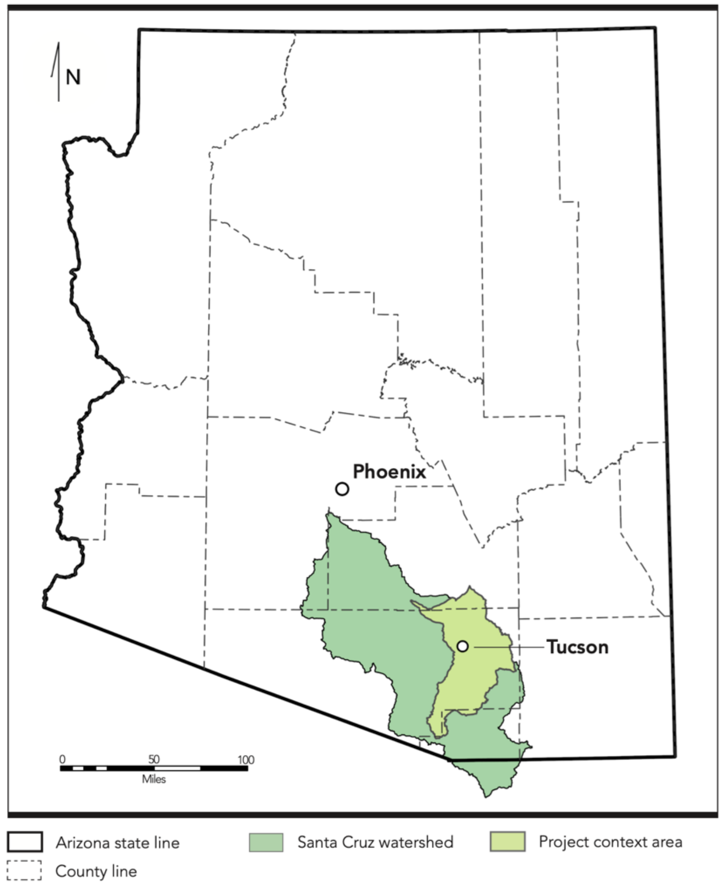


Figure 1. *An orientation map showing the Santa Cruz watershed and the project context area in relation to the state of Arizona.*

Study area	Description	Inclusion criteria	Exclusion criteria
Opportunity search area	Riparian habitat in and near the Middle Santa Cruz River	Watercourses in watersheds HUC 10-1505030106 and HUC 10-1505030107 and in subwatershed HUC 12-150503010405. Riparian areas corresponding to the above watercourses.	Lands and waters of the Tohono O'odham Nation. Land and water outside Pima County. Portions of HUC 12-150503010405 that lie west of Arivaca Junction.
Study focus area	Opportunity search area watersheds and their associated engineered and natural water systems	Opportunity search area watersheds and subwatersheds. Engineered and natural water systems within the above areas.	Lands and waters of the Tohono O'odham Nation. Portions of the HUC 10-1505030104 watershed lying west of the Arivaca Junction census designated place (CDP) or south of Pima County.
Project context area	Santa Cruz Watershed Collaborative planning area	HUC-10 watersheds that contain or convey surface flow into Pima County reaches of the Santa Cruz River.[a]	Outlying watershed HUC 10-1505030201.
Middle Santa Cruz River corridor	Roughly 1-mile-wide corridor centered on river channel	Lands located within the study focus area and lying within one-half mile of the Middle Santa Cruz River channel	None. (Note that tribally governed lands fall outside the defined inclusion criteria.)

Table 1. Spatial definitions. *a*. These include HUC 10-1505030104, HUC 10-1505030106, HUC 10-1505030107, HUC 10-1505030108, HUC 10-1505030109, HUC 10-1505030202, HUC 10-1505030203, HUC 10-1505030301.

Project context area and project focus area

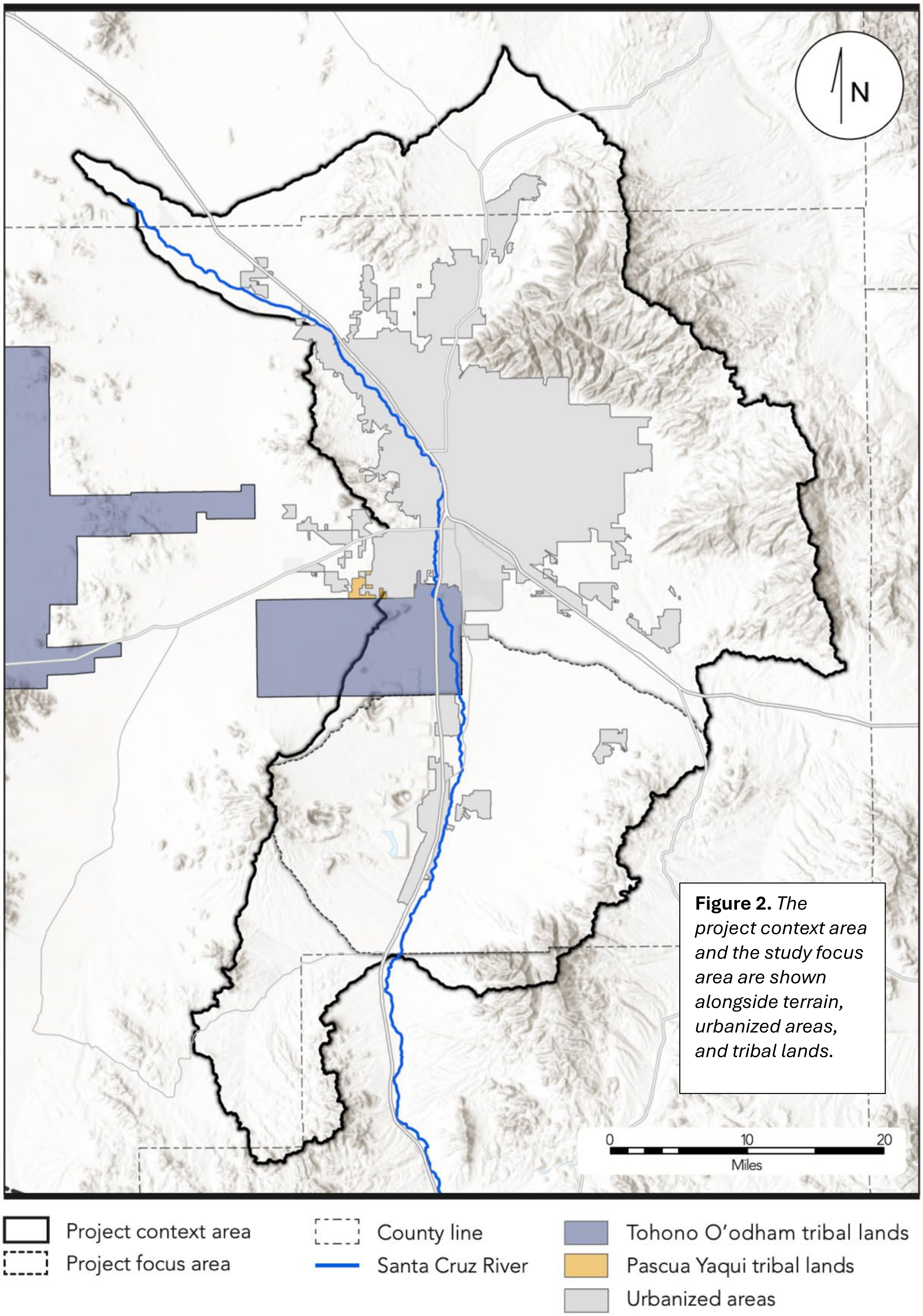
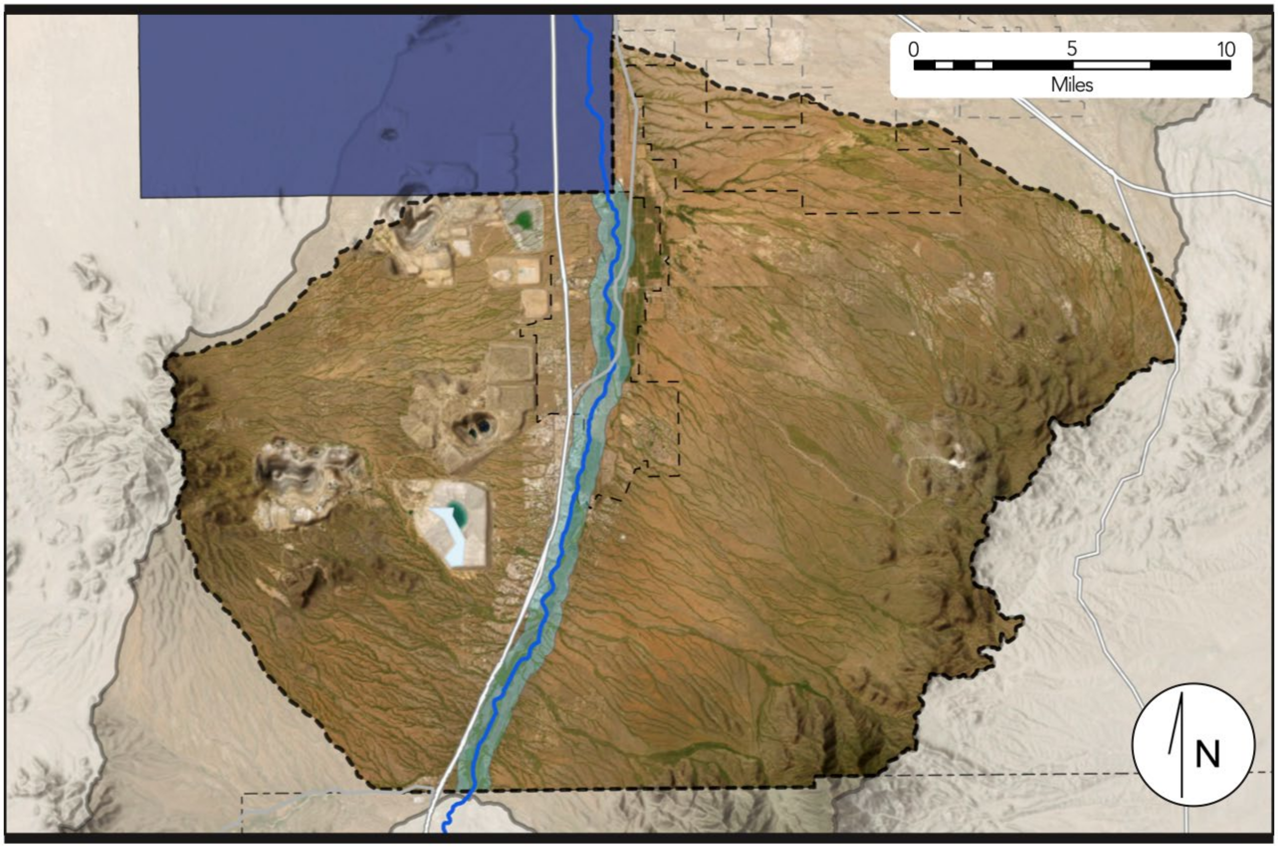


Figure 2. *The project context area and the study focus area are shown alongside terrain, urbanized areas, and tribal lands.*

Middle Santa Cruz River corridor and study focus area



Project context area
Project focus area
County line
Incorporated community
Santa Cruz River
1-mile corridor centered on Middle Santa Cruz River
Riparian areas within study focus area
Tohono O'odham tribal lands

Figure 3. *The Middle Santa Cruz River, centered within the one-mile corridor shown above, bisects the study focus area. Riparian areas and tribal lands are overlaid on the terrain. Major lands uses, such as mining (east of the river) and agriculture (at the north end of the MSCR) are apparent.*

Regional overview

The Middle Santa Cruz River flows across eastern Pima County. Here the river overlies the Tucson/Avra Valley Aquifer. Groundwater recharge occurs via infiltration of local and imported water sources. Local sources include mountainfront recharge via natural systems. Imported sources include Colorado River water delivered via the Central Arizona Project.

The study focus area includes the Town of Sahuarita, incorporated in 1994, and the community of Green Valley, an unincorporated census-designated place. The area did not experience marked residential growth until the 1960s in Green Valley. However, the study focus area remains characterized by ongoing agricultural land uses along the MSCR, especially the extensive pecan orchards owned and operated by Farmers Investment Company (FICO). Other major land uses in the study focus area include Freeport McMoRan mining operations.

Population and economy

The recent history of Pima County is characterized by population and economic growth. During this era, local water portfolios diversified, and the arrival of Colorado River Water via the Central Arizona Project has led to groundwater levels beginning to recover in some areas. Water resources in Pima County, Arizona afford the same benefits as those seen elsewhere on the Colorado River system — agricultural, industrial, municipal, tribal, recreational, and environmental. An overview of the regional population and economy is given in **Table 2**, and populations of incorporated communities in the broader project context area are given in **Table 3**. Community populations in the study focus are shown in given in **Table 4**, with their spatial distribution shown in ***Fig. 4***.

Region	Population	GDP
Arizona [a, b]	7,582,384	$522,767,200,000
Pima county population [c, d]	1,080,149	$62,169,929,000

Table 2. Regional populations and GDP (2023). Sources: *a*. (US Census Bureau, 2024b). *b*. (Federal Reserve Bank of St. Louis, 2024a) citing (Woodruff et al., 2024) *c*. (US Census Bureau, 2024a) *d*. (Federal Reserve Bank of St. Louis, 2024b) citing (Hinson et al., 2024).

Incorporated communities	Population
Tucson	543,348
Marana	54,487
Oro Valley	47,595
South Tucson	4,601

Table 3. Incorporated community populations in the project context area (2023). Source: (US Census Bureau, 2024c).

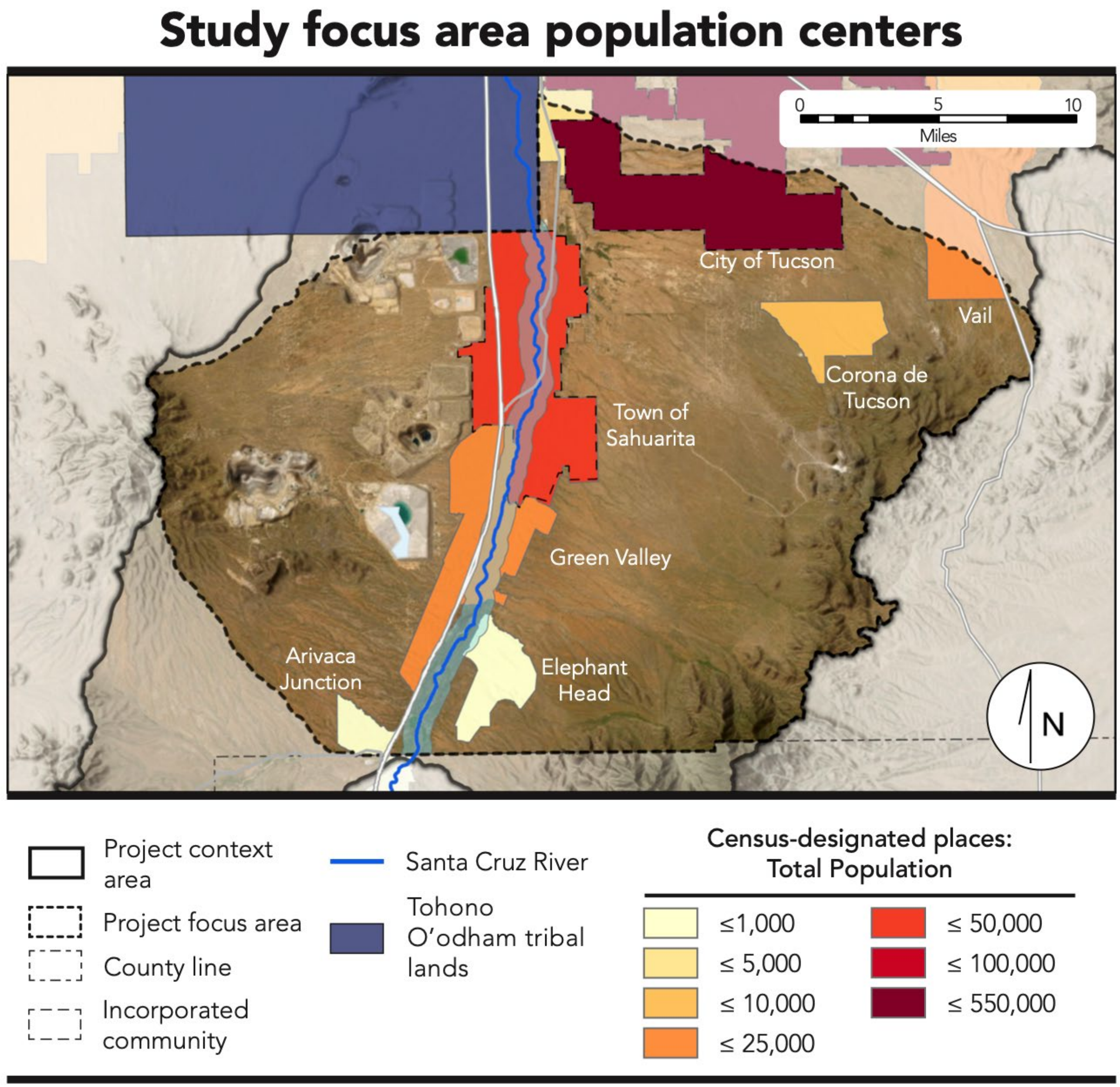


Figure 4. *Population centers and their distribution across the study focus area. The incorporated limits of Tucson, a major population center in Southern Arizona, extend into boundaries of the study focus area. However, City of Tucson land within the study focus area is, compared to the rest of the city, either undeveloped or sparsely populated.*

Study focus area communities[a]	Population
Sahuarita (incorporated town)	35,012
Green Valley (CDP)	21,581
Corona de Tucson (CDP)	9,039
Elephant Head (CDP)	572
Arivaca Junction (CDP)	650
CDP and town subtotal	66,854
Study focus area aggregate population[b]	75,349

Table 4. Incorporated community, CDP, and aggregate populations for study focus area (2023). [a] Populations are given only for towns or CDPs located entirely within the study focus area. Summit (CDP, population 4,410), Vail (CDP, population 15,722), and Tucson (incorporated city, population of 543,348), partially overlap the study focus area. [b.] Aggregate population is the sum of populations for all census tracts whose footprint overlaps that of the study focus area by at least fifty percent. Source: (US Census Bureau, 2024d)

Land use, land cover, and climate

Data derived from the Annual National Land Cover Database (USGS, 2024) show that the study focus area remains dominated by open lands, but with increasing development over the last several decades (***Fig. 5***, next page). **Table 5** shows spatial extent of land cover in the study focus area in both absolute and fractional terms in 1985 and 2023. **Table 6** provides the same figures for a one-mile corridor centered on the Middle Santa Cruz River within the study focus area.

	Land cover within study focus area				Change in land coverage, 1985-2023	
	1985		2023			
Land cover	**Area (sq. mi)**	**Percent**	**Area (sq. mi)**	**Percent**	**Area (sq. mi)**	**Percent**
Developed, open space	5.2	1.0%	13.0	2.6%	7.8	149.7%
Developed, low intensity	8.4	1.7%	15.9	3.1%	7.5	90.0%
Developed, medium intensity	2.0	0.4%	8.6	1.7%	6.6	322.3%
Developed, high intensity	0.1	0.0%	0.4	0.1%	0.2	185.1%
Any developed land	**15.8**	**3.1%**	**37.9**	**0.1%**	**22.1**	**140.5%**
Open water	0.4	0.1%	1.0	0.2%	0.6	142.4%
Barren land (rock/clay/sand)	13.2	2.6%	18.4	3.6%	5.2	39.0%
Evergreen forest	11.7	2.3%	10.0	2.0%	-1.7	-14.2%
Shrub/scrub	456.0	90.2%	430.5	85.2%	-25.5	-5.6%
Cultivated crops	7.4	1.5%	6.8	1.3%	-0.6	-8.7%
Undeveloped land	**489.3**	**96.8%**	**467.2**	**92.4%**	**-22.1**	**-4.5%**

Table 5: Land cover by year for 1985 and 2023. Categories with less than 0.1% coverage are omitted. Open water includes tailing ponds at mines and does not reflect riparian flows. Derived from NLCD annual data sets (USGS, 2024).

	Land cover within MSCR corridor				Change in land coverage, 1985-2023	
	1985		2023			
Land cover	**Area (sq. mi)**	**Percent**	**Area (sq. mi)**	**Percent**	**Area (sq. mi)**	**Percent**
Developed, open space	1.0	4.9%	1.9	9.1%	0.9	86.0%
Developed, low intensity	1.6	7.7%	2.3	11.2%	0.7	44.8%
Developed, medium intensity	0.6	2.7%	1.5	7.0%	0.9	161.7%
Developed, high intensity	0.0	0.0%	0.0	0.2%	0.0	331.8%
Any developed land	**3.2**	**15.3%**	**5.8**	**27.5%**	**2.5**	**79.0%**
Shrub/scrub	13.0	61.7%	10.7	51.0%	-2.3	-17.4%
Pasture/hay	0.3	1.4%	0.3	1.5%	0.0	3.6%
Cultivated crops	4.4	20.8%	4.1	19.6%	-0.3	-6.2%
Woody wetlands	0.1	0.5%	0.1	0.5%	0.0	-9.8%
Undeveloped land	**17.8**	**84.5%**	**15.2**	**72.5%**	**-2.5**	**-14.2%**

Table 6: Land cover by year for 1985 and 2023. Categories with less than 0.1% coverage are omitted. Open water includes tailing ponds at mines and does not reflect riparian flows. Derived from NLCD annual data sets (USGS, 2024).

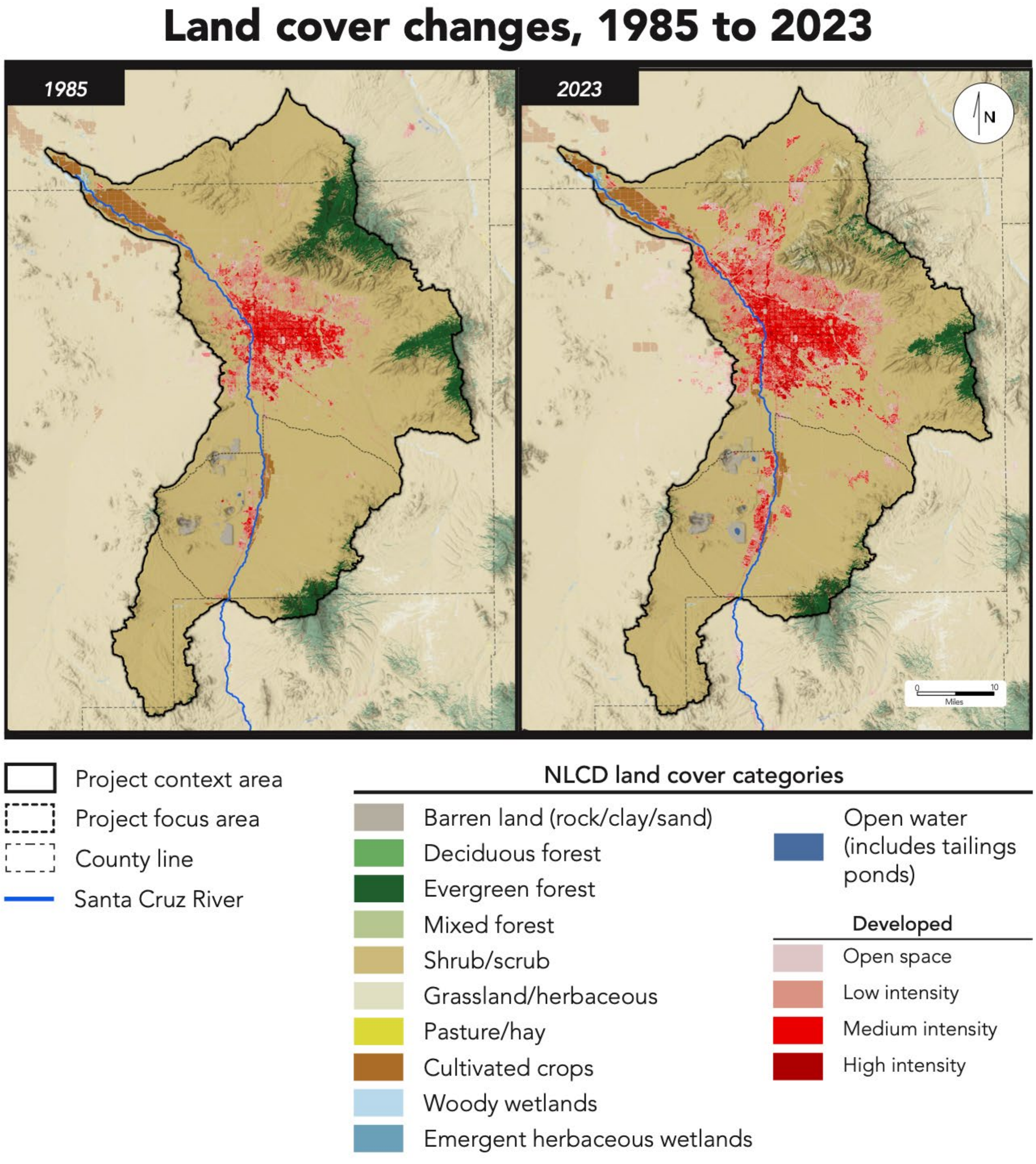


Figure 5. *Changes in NLCD land cover classification extents for the project context area between 1985 and 2023.*

Crop	Total acres planted (2023) Pima County	Study focus area	1-mile corridor
Fallow/idle	16,554	17	5
Cotton	8,123	8	5
Alfalfa	6,161	126	103
Pecans	5,239	4,546	2,730
Corn	1,906	8	7
Barley	1,107	0	0
Durum wheat	1,101	1	0
Other hay/non-alfalfa	651	64	36
Oats	301	24	24
Oat/corn double crop	141	2	1
Triticale	131	0	0
Sorghum	129	115	74
Winter wheat	76	0	0
All other crops	59	2	1
Total	41,701	4,914	2,986

Table 7. Study area cropland for 2023, derived from data published by USDA National Agricultural Statistics Service, (2024).

The study focus area contains approximately 4,900 acres of cropland, about 12% of all cropland in Pima County (USDA NASS, 2024). **Table 7** shows crop acreages for Pima County, the study focus area, and the MSCR corridor.

The Study context area spans two different level III ecoregions, Sonoran Basin and Range (lowlands) and Madrean Archipelago (highlands), subdivided into Level IV ecoregions as shown in ***Fig. 6*** (next page). The spatial extent of Level III and Level IV ecoregions are given in **Tables 8** and **9**, respectively.

	Project context area		Study focus area	
Level III Ecoregion	**Area (sq. mi)**	**Percent**	**Area (sq. mi)**	**Percent**
Madrean Archipelago	917	46.1%	243	48.0%
Sonoran basin and range	1,072	53.9%	263	52.0%

Table 8. Level III ecoregion extent in project context area and study focus area.

	Project context area		Study focus area	
Level IV Ecoregion	**Area (sq. mi)**	**Percent**	**Area (sq. mi)**	**Percent**
Lower Madrean Woodlands	305	15.3%	49	9.8%
Madrean Basin Grasslands	123	6.2%	34	6.7%
Apachian Valleys and Low Hills	378	19.0%	158	31.2%
Madrean Pine-Oak and Mixed Conifer Forests	110	5.6%	2	0.3%
Arizona Upland/Eastern Sonoran Mountains	131	6.6%	—	—
Arizona Upland/Eastern Sonoran Basins	877	44.1%	263	52.0%
Gila/Salt Intermediate Basins	42	2.1%	—	—
Middle Gila/Salt River Floodplains	23	1.1%	—	—

Table 9. Level IV ecoregion extents in project context area and study focus area.

Ecoregions

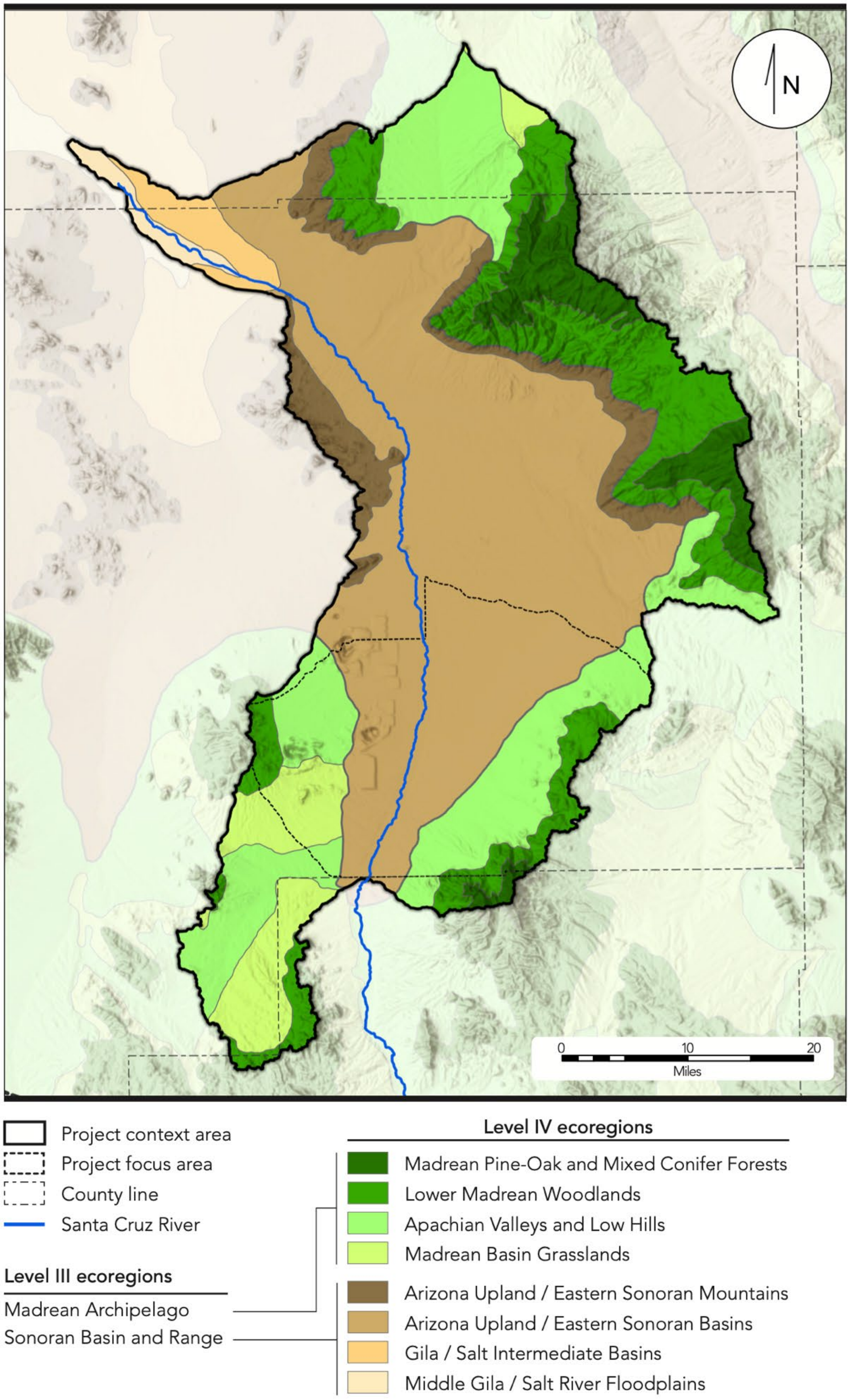


Figure 6. *In the study focus area, the Middle Santa Cruz River flows through Eastern Sonoran Basin lowlands surrounded by various subcategories of the Madrean Archipelago ecoregion.*

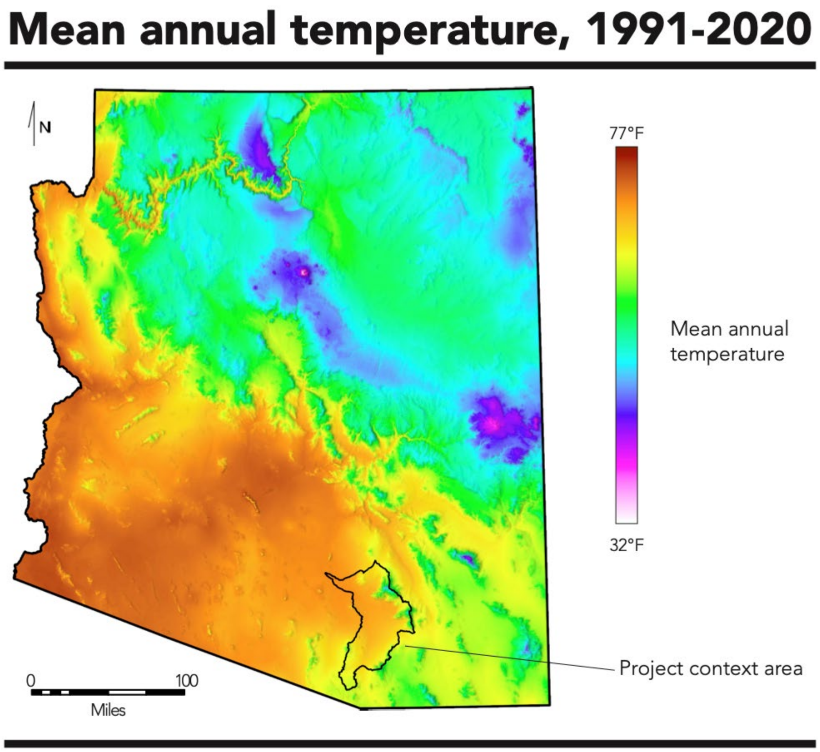


Figure 7 (left). *The mean annual temperature for the project context area exceeds that of high-elevation regions elsewhere in the state, but generally remains cooler than the hyperarid southeast corner of the state.*

Figure 8 (next page). *Seasonal precipitation patterns are apparent in month-to-month changes in mean precipitation. Monsoonal precipitation (which can vary considerably from year to year) is typically preceded by a late-spring and early-summer dry season.*

30-year mean temperature and annual precipitation (1991-2020) from the nearby Green Valley weather station[1] are 68.4° F and 12.85 inches (NCEI, n.d.-b). The average summer high temperature and winter low temperatures reported by the same dataset are 98.6°F and 37.1°F respectively (NCEI, n.d.-b). Additional 30-year mean data is reported in **Table 10**.

The Köppen climate classification system categorizes lowlands in the study area as a mix of BWh (hot arid climate) and BSh (hot semi-arid climate). The study focus area lies in or near the boundary between these two zones.

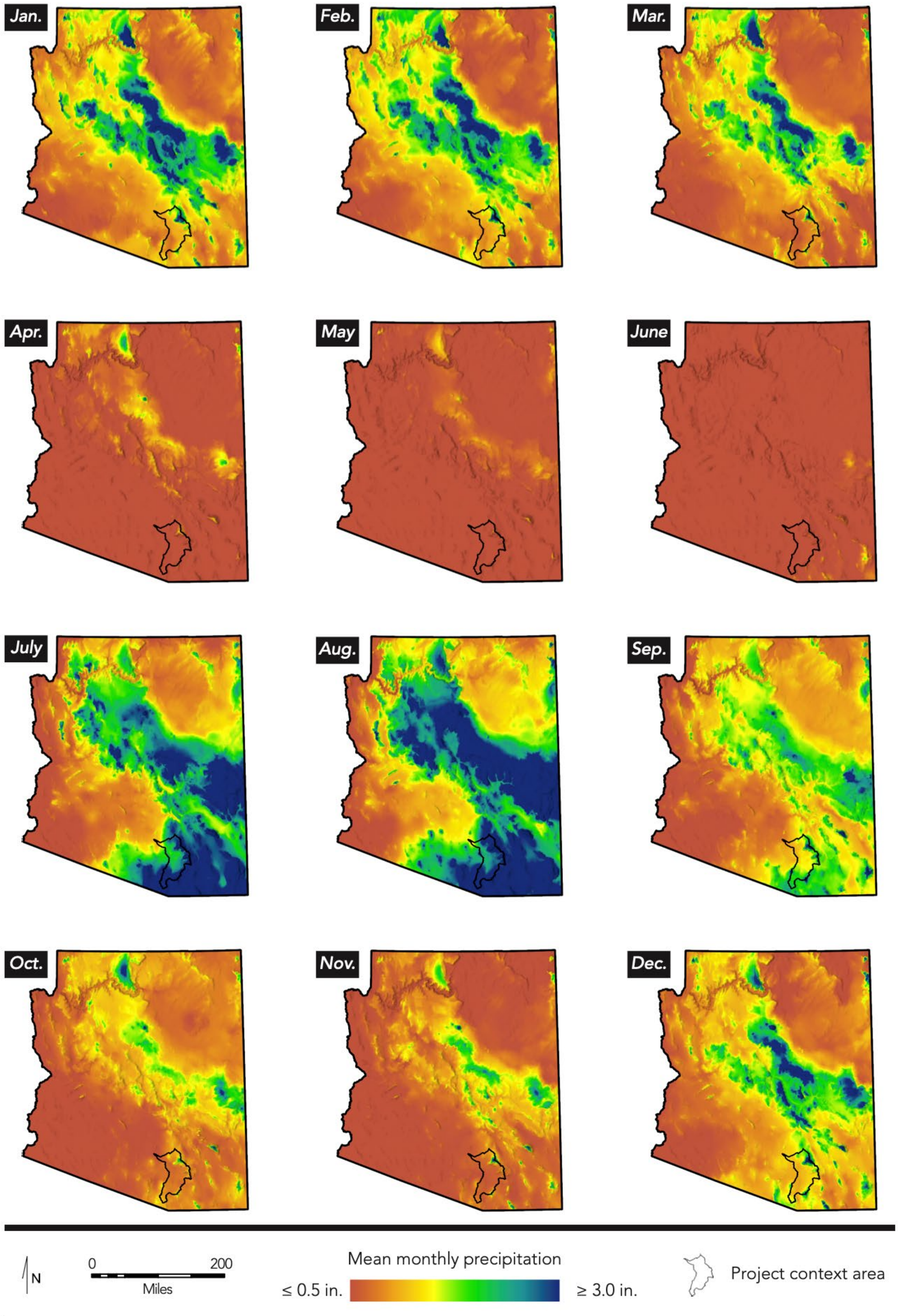
Mean annual temperature for the project context area is shown alongside the rest of the state in ***Fig. 7***. Seasonal variations in precipitation patterns are evident both locally and statewide in ***Fig. 8***.

Season	Maximum temperature (°F)	Minimum temperature (°F)	Average temperature (°F)	Precipitation (in.)	Snow (in.)
Winter	67.5	37.1	52.3	2.78	0.0
Spring	82.8	51.0	66.9	1.03	0.1
Summer	98.6	70.3	84.5	5.99	0.0
Autumn	88.5	54.7	70.1	3.05	0.0
Annual	**83.6**	**53.3**	**68.4**	**12.85**	**0.1**

Table 10. Annual mean weather data for study focus area (NCEI, n.d.-b).

[1] Weather station USC00023668 (NCEI, n.d.-a)

Mean monthly precipitation, 1991-2020



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The Colorado River Basin has experienced persistent drought since 2000 (USGS, 2023), complicating water management. Pima County has experienced the basin-wide drought at varying intensity over the years, including a handful of years where drought was locally absent (***Fig. 9***).

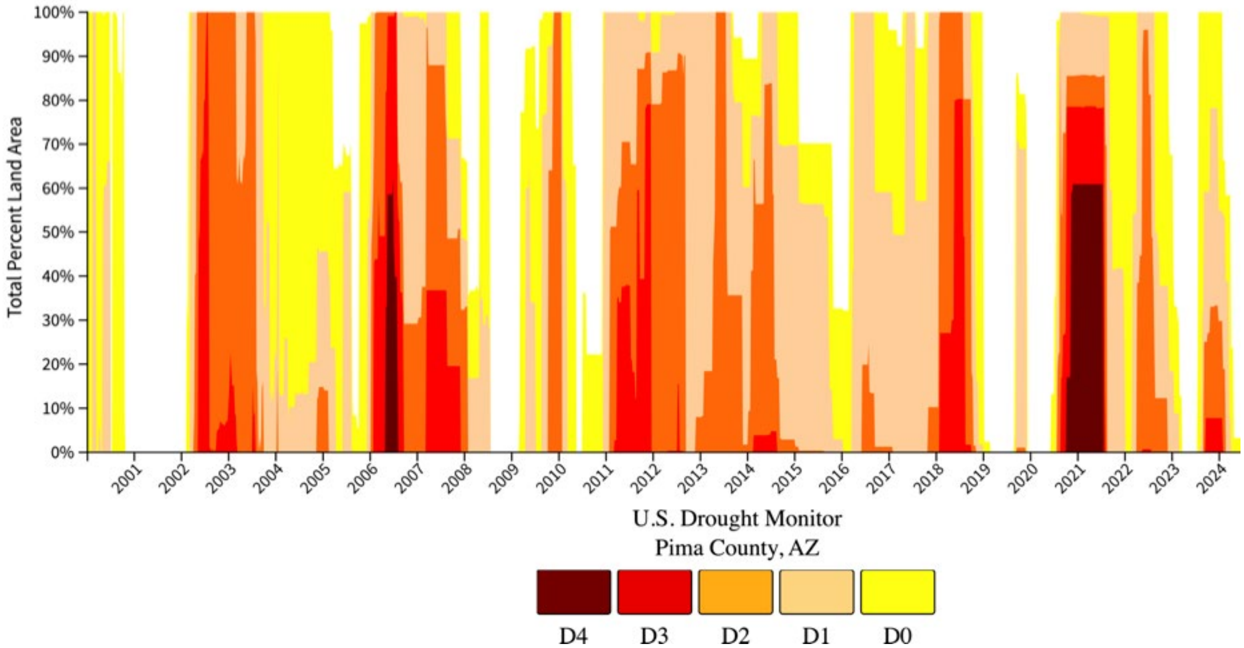

Figure 9. *Persistence, extent, and severity of drought conditions in Pima County since 2000 (NIDIS, 2024).*

Water infrastructure: Community water systems

The project context area is serviced by myriad community water systems (CWS) (***Fig. 10***, next page). The largest of these is Tucson Water, a municipally owned CWS whose service range includes households whose wastewater is processed at Corona de Tucson Wastewater Reclamation Facility (WRF) near the study focus area**.** Of these, Tucson Water is by far the largest, serving much of incorporated Tucson and its surrounding communities.

Within the study focus area, we 16 community water systems of varying sizes serving communities located along the MSCR. These systems vary in scale, serving anywhere from a few dozen people to tens of thousands. Data on CWSs within the study focus area is summarized in **Table 11.** This data is taken from water system plans and annual reports filed with ADWR. Because of incomplete reporting, certain data is missing.

Based on reported water sources currently on file with ADWR, CWSs rely mainly on groundwater to serve customers. Incomplete reporting data and unavailable reports made a complete list of CWC water demands impossible. Additionally, these records do not reflect if or when withdrawals are offset by dedicated sources of groundwater recharge like Project Renews (Community Water Company of Green Valley, 2015). However, a general overview of groundwater withdrawals is possible.

Community water system	**Reported water source**	**Reporting interval**	**Average annual water use (AF)**
Sahuarita Water Company	*	2016-2020	—
Sahuarita Village Water Company	*	—	—
Global Water Resources (Sahuarita)	Groundwater	2017-2021	136.9
Global Water Resources (Sahurita Highlands)	Groundwater**	2017-2021	48.8
Global Water Resources (Continental)	Groundwater	2016-2020	581.8
Global Water Resources (Santa Rita Springs)	Groundwater	2016-2020	255.7
Global Water Resources (Santa Rita Springs)	Groundwater	2016-2020	255.7
Global Water Resources (Las Quintas Serenas Water Company)	Groundwater	2016-2020	1.3
Santa Rita Heights MHP	Groundwater	2017-2021	10.4
Valle Verde del Norte Water Coop	Groundwater	2016-2020	282.6
Community Water Company of Green Valley	Groundwater	2016-2020	2,365.6
Quail Creek Water Company Inc.	Groundwater	2016-2020	627.0
Green Valley Domestic Water Improvement District	Groundwater	2016-2020	836.6
Desert Paradise MHP	*	2020, 2022-2023	1.3
Pita Water	Groundwater	2016-2023	3.6
Lakewood Estates Water Company	Groundwater	2017-2021	100.7

Table 11. CWCs in the study focus area, with data drawn from reporting in system water plans (ADWR, n.d.). Average annual water use is calculated based on the most recent available five-year reporting interval in located records, or shorter intervals when no other option was available. An em-dash (—) indicates that reported use data in located records was incomplete, unavailable, or zero. An asterisk (*) indicates that the no water source was reported in located records but is believed to be groundwater. A double asterisk (**) indicates that the records reported groundwater as the sole source for water use but also mentioned a certificate of assured water supply from CAGRD.

Community water systems

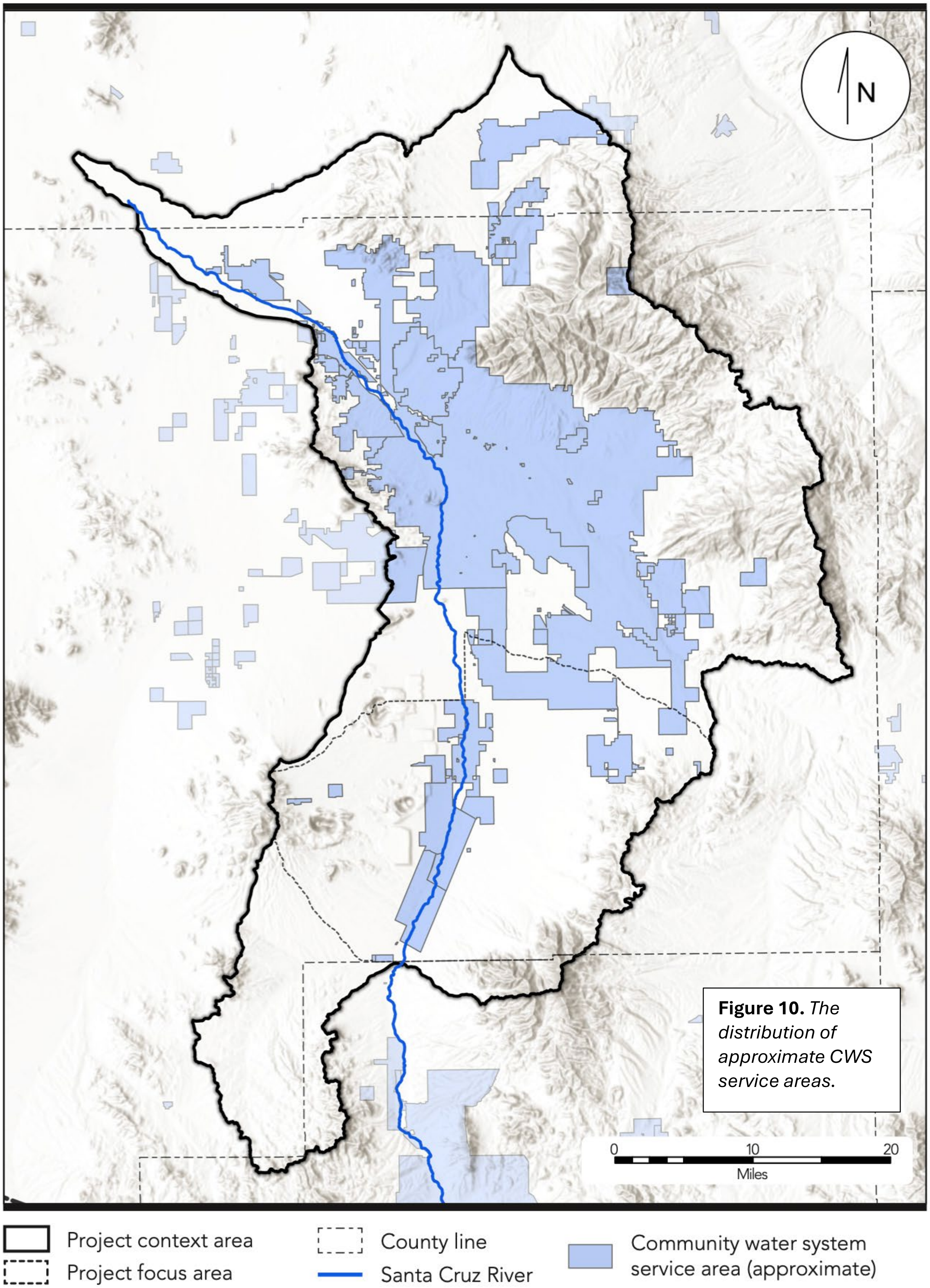

Figure 10. *The distribution of approximate CWS service areas.*

Water infrastructure: Reclaimed sources

The study focus area is currently served by several subregional wastewater reclamation facilities (WRFs): Sahuarita WRF, Green Valley WRF, Corona de Tucson WRF, and Arivaca Junction WRF (***Fig. 11***). These WRFs produce roughly 3,500 AF/yr of effluent, delivered or recharged as groundwater as shown in **Table 12**. We compare these to the regional WRFs elsewhere in the study context in **Table 13**. Sahuarita WRF is operated by the Town of Sahuarita; all others are operated by Pima County Regional Wastewater Reclamation Department (RWRD).

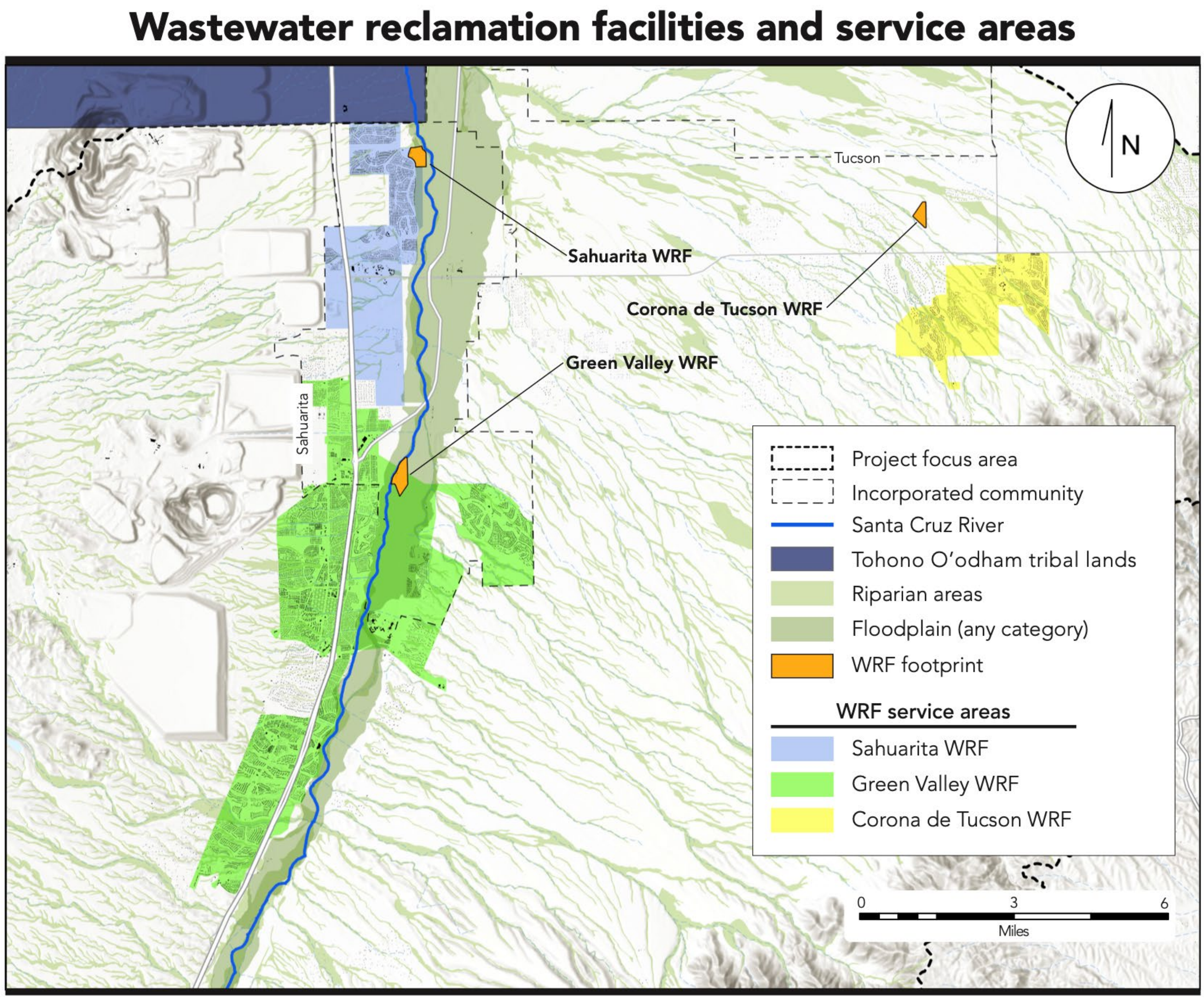

Figure 11. *WRF service areas and facility footprints. Note that the service area footprints do not necessarily follow jurisdictional boundaries. While the Sahuarita WRF, a municipal facility, serves portions of the Town of Sahuarita, other parts of Sahuarita are served by Green Valley WRF, a Pima County RWRD facility.*

Green Valley WRF			
Permitted capacity (MGD) and quality:	4.1 MGD (total) 2.8 to BNROD system (A+) 1.3 to lagoon/pond system (B)	2023 inflow (AF): 2023 effluent production (AF): Production ratio:	2,255.72 2,073.75 0.92
Effluent use:	Delivered to recharge basins		

Sahuarita WRF			
Permitted capacity and quality:	3.0 MGD (A+)	2023 inflow (AF): 2023 effluent production (AF): Production ratio:	1,142.80 1,028.50 0.90
Effluent use:	Delivered to recharge basins		

Corona de Tucson			
Permitted capacity and quality:	1.3 MGD (Unk.)	2023 inflow (AF): 2023 effluent production (AF): Production ratio:	482.25 428.66 0.89
Effluent use:	Delivered to recharge basins		

Arivaca Junction WRF			
Permitted capacity and quality:	0.1 MGD (C)	2023 inflow (AF): 2023 effluent production (AF): Production ratio:	39.73 25.40 0.64
Effluent use:	Agricultural deliveries (14.18 AF) and recharge in non-USF basins (11.20 AF)		

Table 12. Permitted capacities and current effluent production for wastewater reclamation facilities in the study focus area. Sources: (PAG, 2020a, 2020b, 2020c; PCRWRD, 2023)

Agua Nueva WRF			
Permitted capacity and quality:	35.2 MGD (A+) (Upgradable to 48 MGD)	2023 inflow (AF): 2023 effluent production (AF): Production ratio:	27,061.46 25,028.82 0.92
Effluent use:	"Purple pipe" reclaimed water deliveries (18,125.66) and delivery to Sweetwater Wetlands USF or in-channel flows via SCRMUSF (6,795.69), on-site reuse (107.42 AF)		

Tres Rios WRF			
Permitted capacity and quality:	50 MGD (A+)	2023 inflow (AF): 2023 effluent production (AF): Production ratio:	34,048.41 32,771.50 0.96
Effluent use:	In-channel flows via LSCRMRP (32,732.73 AF), on-site re-use (1.02 AF), reclaimed deliveries (37.75 AF)		

Combined regional WRF capacity (Agua Nueva and Tres Rios)			
Permitted capacity and quality:	85.2 MGD (A+) (Upgradable to 98 MGD)	2023 inflow (AF): 2023 effluent production (AF): Production ratio:	61,109.87 57,800.32 0.95
Effluent use:	As described above.		

Table 13. Permitted capacities and current effluent production for regional WRFs in the study context area. Sources: (PAG, 2020b; PCRWRD, 2024; Water Collaborative Delivery Association, 2018)

Site suitability: Planning context

As part of the conservation opportunity search, we reviewed planning documents and studies relevant to local water systems.

Compliance with existing land use plans can reduce implementation barriers for conservation project. Broadly, relevant planning documents emphasize the centrality of the Santa Cruz River itself as an essential cultural, recreational, and environmental resource. Existing land use plans suggest that stakeholders will likely realize the greatest benefits if conservation is implemented on the mainstem of the river instead of tributaries.

Additionally, in-channel discharge on the mainstem Santa Cruz River (sufficiently upstream of Tohono O'odham lands) presents the most straightforward opportunity for in-channel discharge. Land ownership here is minimally fragmented, which greatly simplifies the process of pre-project consultation.

Conservation opportunity assessment (water sources)

Purpose and Methodology of the Scoring Matrix

The Scoring Matrix was developed as a structured decision-making tool to evaluate and prioritize potential sources of new water for the Santa Cruz River. Given the complexity of water resource management in the region, the matrix provided an objective framework for assessing multiple options based on their feasibility, infrastructure readiness, and long-term sustainability. By assigning weighted values to key criteria and structuring the calculation method to emphasize the most critical factors, the matrix ensured that only the most practical, viable, and reliable sources of effluent were selected for further consideration.

Each potential water source was scored on a standardized scale of 1 to 5 across multiple variables. However, the matrix was designed to weight certain factors more heavily based on their impact on project feasibility. The project viability score was calculated using the following formula:

Project Viability = (Availability) × (Volume + Permanence) + Proximity + Infrastructure

This structure introduces a multiplicative effect, giving greater weight to Availability, Volume, and Permanence than to Proximity and Infrastructure, which are treated as additive factors. The rationale for this approach is that Availability (the reliability of a year-round water source) is a crucial factor that amplifies the overall feasibility of a project—if a source is seasonal or unreliable, even a high-volume option would be less viable. By multiplying Availability with the sum of Volume and Permanence, the scoring model ensures that water sources with both high availability and substantial, long-term flow potential receive higher scores.

Proximity to the Santa Cruz River and Existing Infrastructure are treated as additive factors, meaning they contribute to the score but do not scale the viability of the water source in the same way as the multiplicative components. While important, these factors primarily influence logistical feasibility rather than the fundamental ability to sustain riparian flow.

Final Results and Prioritization

The Scoring Matrix **(Table 14)** represents the final product of this structured evaluation process, identifying the most suitable sources for effluent introduction into the Santa Cruz River. After assessing all potential options, only the Green Valley Water Reclamation Facility (WRF) emerged as the most practical, viable, reliable, and immediate choice for supplying effluent to the river. With high availability, substantial volume, and permanence, it outperformed other options based on the weighted scoring model. Additionally, its proximity to the river and existing infrastructure further strengthened its viability, confirming it as the best near-term solution.

The Future Consolidated Project—a proposed large-scale Pima County wastewater reclamation facility with tertiary treatment at the downstream end of the study area—was identified as the highest-potential long-term solution. While not yet constructed, its projected availability, high-volume output, and permanence position it as a key future investment for hydrologic stability and riparian restoration.

By applying a structured, data-driven approach that differentiates between multiplicative and additive weighting, the Scoring Matrix ensures that decision-making is rooted in quantifiable factors. This methodology prioritizes sources with high availability and lasting water volume, leading to the selection of both an immediate (Green Valley WRF) and a long-term (Future Consolidated Project) solution for restoring and sustaining flow in the Santa Cruz River.

		Project					
Criterion	Green Valley WRF	Community Water	Green Valley DWID	FICO Sahuarita	FICO Continental	Quail Creek	Future, consolidated effluent project
Water volume (treated AFY)	3	1	1	1	1	1	4
Year-round availability	5	1	1	1	1	3	5
Permanence	2	3	2	3	1	3	5
Existing outfall infrastructure	5	1	1	1	1	1	3
Proximity to Santa Cruz (km)	5	3	2	3	1	4	4
Total	35	8	6	8	4	17	52

Table 14. Final scoring matrix. Quartiles: 0-15 (red), 16-30 (yellow), 31-45 (light green), 46-60 (dark green).

Conservation opportunity assessment: Concept development

Discharge point selection

Current WRF placement, effluent generation, and future build-out scenarios determined the restoration concepts we present here. Because viability is a central concern, we exclude from consideration in-channel discharge off the mainstem Santa Cruz River, and we prefer a discharge point from an existing WRF.

An additional project constraint is the need to keep effluent-based flows from encroaching upon lands administered by the Tohono O'odham tribal government. There are two reasons for this constraint. The first is to respect the preferences of the tribal government. The second is a desire for groundwater recharge projects to accrue water banking credits, which is simplified when recharge takes place on a project located under the purview of state agencies.

The current outfall point at Green Valley WRF is located well upstream of tribal lands, is located along the mainstem MSCR, and is already connected to one WRF in the study focus area. We developed our concepts using this outfall as an originating point for in-channel flows.

Future growth introduces a strong rationale for consolidating subregional facilities into a single regional facility. Such a facility is a long-term planning goal for RWRD (Pima County RWRD, 2016). Compared to subregional facilities, Pima County RWRD reports a greater fraction of wastewater flows converted into effluent (see **Tables 12** and **13** above). This efficiency introduces water savings that can help offset riparian evapotranspirative demands for in-channel discharge, although Tucson Water reports this to be as low as 3.5% of total effluent discharge (Kmiec, 2021).

Under a build-out scenario with subregional WRF consolidation, a new regional facility would almost certainly be located downgradient from the service area population. The lowest-elevation subregional WRF currently operating in the study focus area is the Sahuarita WRF (~2,580 ft elevation). This site is located along Pima Mine Road, which runs parallel the border between Sahuarita and Tohono O'odham nation. We presume that Pima Mine Road represents an approximate north-south alignment for a future regional WRF.

Under regional consolidation, we assume Pima County RWRD would be the responsible agency: RWRD operates subregional facilities in the project focus area, operates regional-scale facilities elsewhere in the project context area, and benefits from economies of scale.

We further assume that consolidation would afford the ability to convey effluent upstream to the existing Green Valley WRF site. Upgradient conveyance for in-channel flows have already been deployed locally at the Santa Cruz River Heritage Project. Moreover, new wastewater mains would be necessary to transport Green Valley WRF inflows to a new regional facility. Depending on project constraints, pipeline for upstream effluent conveyance could conceivably be installed alongside this project. Finally, we note the existence of the Project RENEWS pipeline. This line carries CAP water upgradient from Pima Mine Road to FICO orchards and serves as a realized proof-of-concept in the MSCR area specifically (***Fig. 12***).

CAP delivery on Middle Santa Cruz River

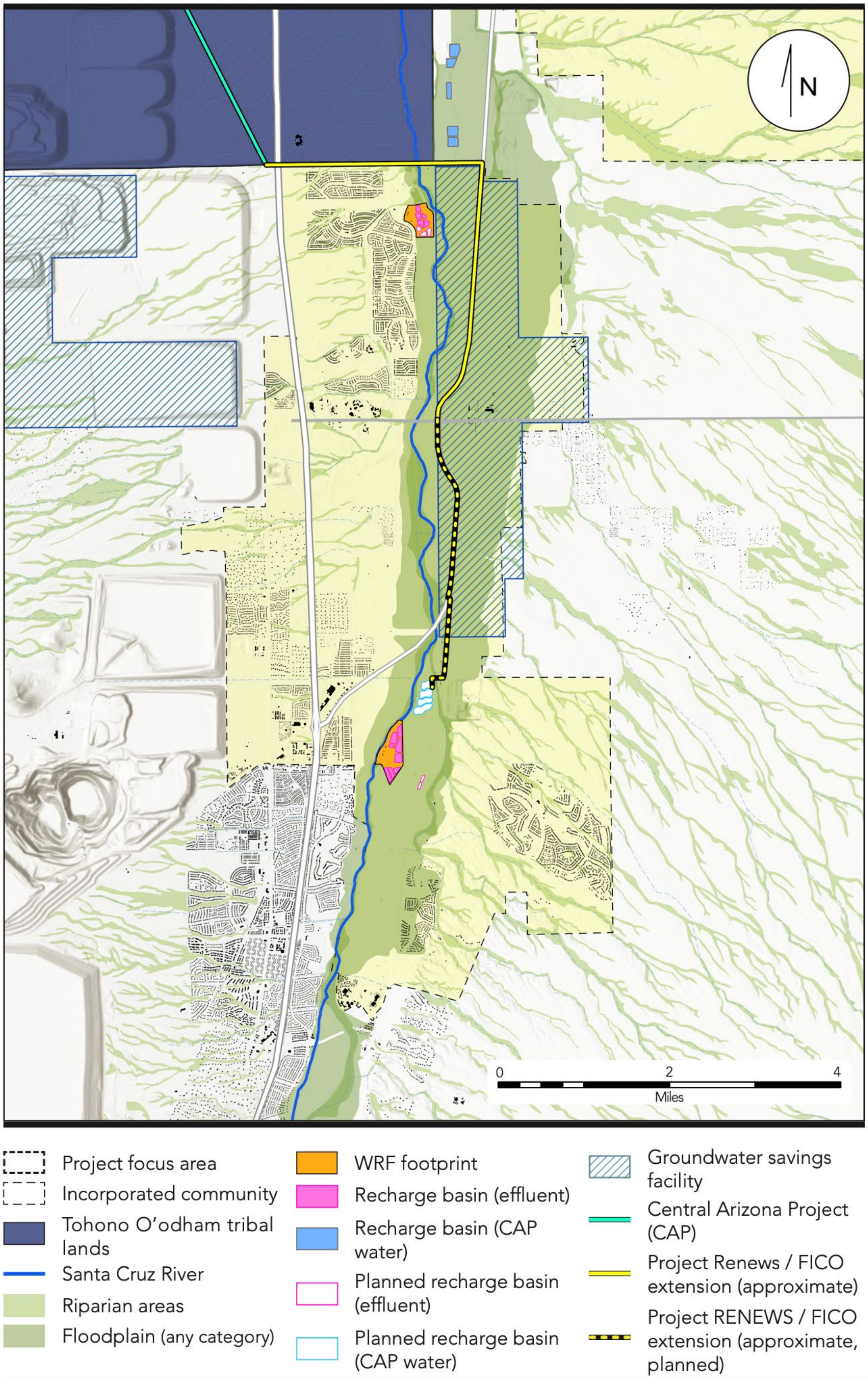

Figure 12. *At the southern terminus of CAP conveyance infrastructure, extensions serve local water needs. This map depicts the approximate route of an extension serving planned recharge basins and existing FICO orchards in a groundwater savings facility (GSF).*

Scenario development

We developed restoration concepts for several scenarios. These include effluent availability under status quo conditions at Green Valley WRF (current effluent capacity less delivery obligations), full future effluent output at Green Valley WRF, and effluent availability resulting from a hypothetical, as-yet unbuilt regional WRF. The full future effluent output from Green Valley WRF can also represent a partial effluent availability from consolidated operations at a regional WRF. We focus on Green Valley due the presence of an outflow point located sufficiently far upstream from tribal lands. Future scenarios with a regional WRF envision conveyance infrastructure (discussed above) to move effluent from the regional WRF to this discharge point.

Using then-current production volumes and service-area population estimates published in PAG's 208 Plan (PAG, 2020b), we calculated per capita wastewater generation of roughly 60 gallons per capita per day (GPCD) for study focus area WRFs shown in **Table 15**. Note that WRF service area populations differ from those of their namesake municipalities or census-designated places due to differing boundaries between WRFs and their namesakes. We omit the smallest WRFs from this analysis due to the possibility small absolute errors in service area population estimates might disproportionately affect per capita wastewater flows.

Facility	Population (2015)	Inflow (AF)	Inflow (MGD)	Per-capita wastewater (GPCD)
Sahuarita WRF	14,494.00	1,008	0.90	62.1
Green Valley WRF	31,488.00	2,061	1.84	58.4

Table 15. Per-capita wastewater flows for the largest WRFs in the study focus area, derived from figures published by PAG (2020b).

We projected future effluent production using 60 GPCD wastewater inflows, service planning area population projections reported in the PAG 208 plan, and a facility appropriate inflow-to-outflow ratio. For a regional build-out scenario with facility consolidation, we sum population estimates across relevant service planning areas. Based on regional experience with surface flows and expert consultation, we converted effluent production volumes into approximate surface flow extents using a ratio of 1 mile flow per million gallons daily discharge. Projected populations, and effluent productions, and flow extents are given in **Table 16**. The resulting concept parameters are summarized in **Table 17** (next page).

Service area	Service or planning area footprints in projected population	Projected population (2045)	Projected inflows (2045, MGD)	Projected effluent production (2045, AF)
Green Valley WRF	Green Valley FPA	48,997	2.95	3,027
Regional WRF	Green Valley FPA, Corona de Tucson FPA, Sahuarita DMA, Joint Planning Area DMA	105,639	6.34	6,745

Table 16. Population and effluent production scenarios used in concept development. FPA: Facility planning area. DMA: Designated management agency. Figures derived from those published by PAG (PAG, 2020b).

Concept	Scenario overview	Scenario description	Timeframe	Effluent volume (AF/yr)	Extent of flow (mi)
1	Current GVWRF availability	Present day production from Green Valley WRF, minus existing delivery obligations	Near term	873.75	0.78
2	Intermediate	Full production output from Green Valley WRF, or partial effluent production from hypothetical regional facility	Intermediate (2025-2045)	3027	2.7
3	Full future availability	Full production output from hypothetical regional WRF, conveyed to current GV WRF outfall point	Far future (~2045)	6745	6.02

Table 17. Overview of concept parameters.

We were unable to identify any MSCR channel crossing points that would be physically impacted by flows in Scenario 1. However, bridged crossings would become increasingly necessary in Scenarios 2 and 3, where flows would reach agricultural lands where workers and farm vehicles can currently cross the channel under normal conditions. Design implications are discussed in the next section.

Restoration concepts

Concept 1: Existing Green Valley WRF effluent availability (near-term)

This concept presents a scenario for in-channel release of effluent volumes that are currently delivered to PC RWRD recharge basins. PC RWRD would recharge the aquifer by in-channel release rather than through discharge to engineered basins. This concept can be implemented using existing RWRD water volumes (current GV WRF output, less existing delivery obligations). This would result in roughly 0.78 miles of surface flow alongside county-owned lands with planned recreational amenities (***Fig. 13***, following concept summaries).

Executing this concept would require RWRD to supplant the existing ADEQ APP for basin-based recharge with an additional APP covering in-channel discharge. As a best practice, RWRD would also fulfill ADWR requirements to create an MUSF (managed underground storage facility) covering the extent of flow.

Concept 2: Full production capacity from Green Valley WRF (current volume)

This concept presents a scenario in which RWRD releases in channel all or nearly all effluent produced by GV WRF. This scenario presumes a future condition in direct effluent deliveries from RWRD are no longer required. In this concept, we depict roughly 2.7 miles of resultant surface flow with corresponding restoration benefits (***Fig. 14***, following concept summaries). At this scale, surface flow is no longer an isolated feature near the WRF, but a characteristic amenity of this stretch of the MSCR.

For Concept 2, we identify the same RWRD requirements and recommendations as Concept 1.

Concept 3: Full production capacity from a regional WRF

Concept 3 presents a hypothetical scenario (circa 2045) in which subregional WRFs (Green Valley, Sahurita, and Corona de Tucson) have been consolidated into a regional facility located on or near Pima Mine Road. This concept presumes that (a) the full volume of plant effluent is available for discharge. It relies on effluent conveyance infrastructure to move effluent upstream to ensure that perennial in-channel flows do not encroach onto Tohono O'odham tribal lands.

In this scenario, we model 6.02 miles of surface flow (***Fig. 15***, following concept summaries). At this scale, the river channel flows through much of the north-south length of Sahuarita.

Concept 1: Current availability, Green Valley WRF

Figure 13. *Concept 1 discharges into the MSCR the existing effluent production less current effluent deliveries from Green Valley WRF. The modeled extent of flow is 0.78 miles. Flow would run parallel to the planned Juan Bautista de Anza National Historic Trail.*

Concept 2: Intermediate future availability

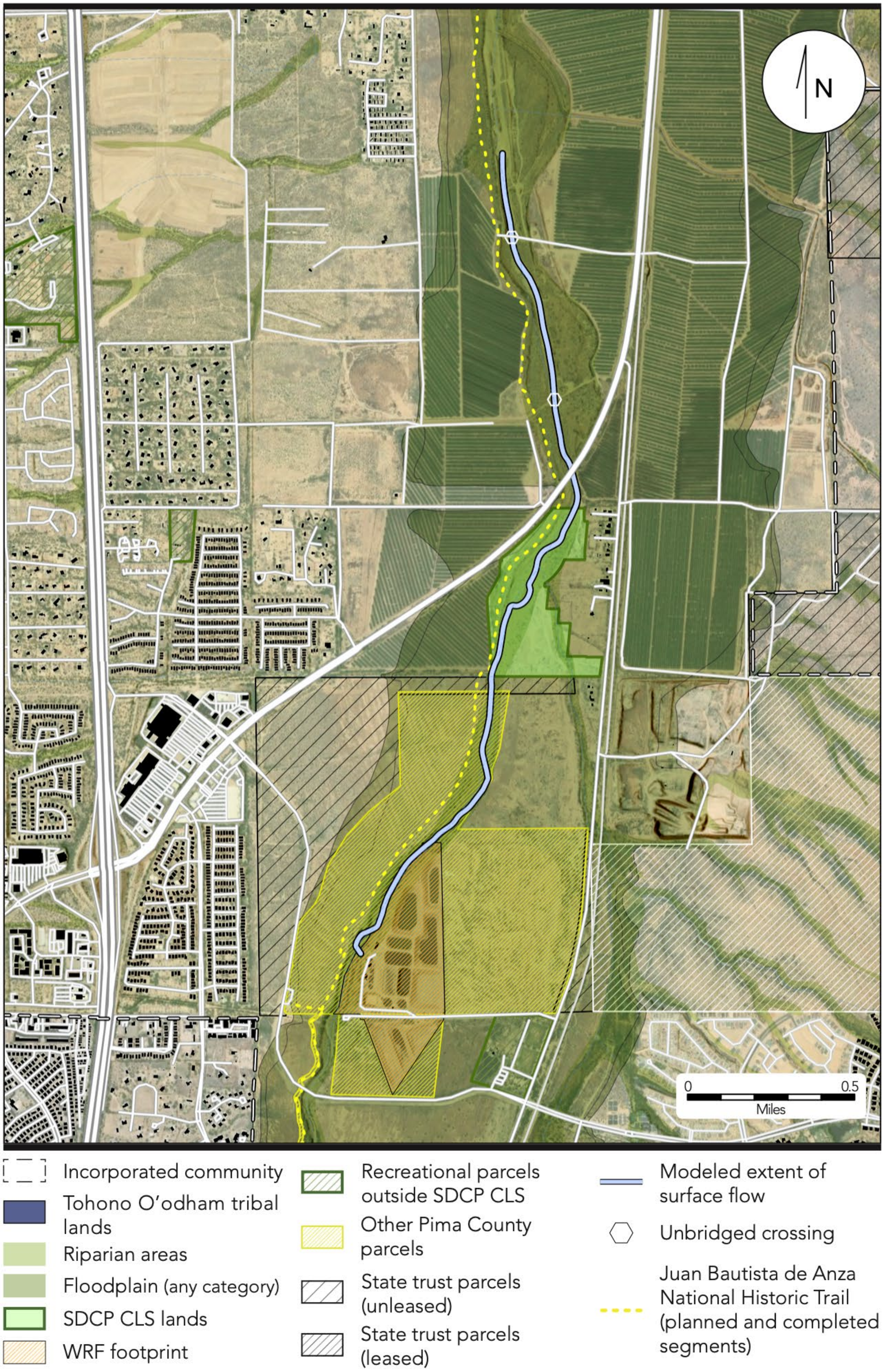

Figure 14. *Concept 2 discharges into the MSCR a volume of effluent equal to the current output of the Green Valley WRF, or the partial output of a future regional facility. The modeled extent of flow is 2.7 miles. Like Concept 1, this scenario envisions in-channel flow running alongside the planned Juan Bautista de Anza National Historic Trail. Flow would also cross existing county conservation lands. Unbridged crossings between orchards are located on downstream reaches, where stream width may be relatively narrow.*

Concept 3: Full production from regional WRF

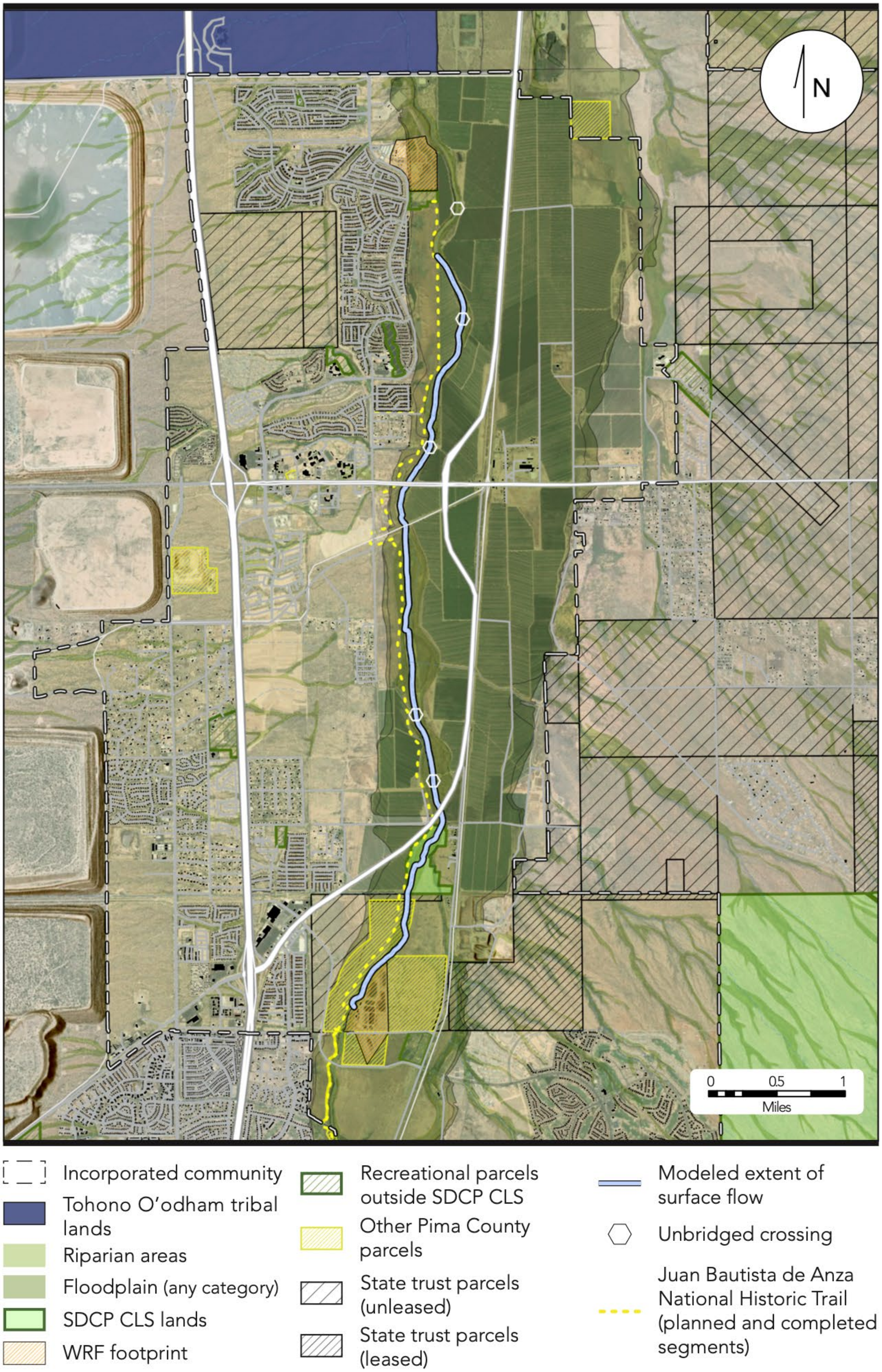

Figure 15. *Concept 3 discharges into the MSCR the full volume of effluent produced by a regional WRF under our 2045 growth scenario. The modeled extent of flow is roughly 6 miles. As with other concepts, in-channel flow would run alongside the planned Juan Bautista de Anza National Historic Trail and cross existing county conservation lands. Multiple unbridged crossings points on the flow path require additional consideration.*

Viability of effluent-based in-channel flows and successful deployment elsewhere

Effluent-based flows are widespread throughout Arizona (Uhlman et al., 2012). The Santa Cruz stands out among these rivers as an exemplar collection of successful deployments (***Fig. 16,*** next page). The Santa Cruz River is home to more miles of effluent-dependent streamflow than all other rivers in Arizona combined. **Table 18** summarizes the extent of these and other flows attributable to engineered water systems.

Flowing section	MUSF	Source description	Originating source(s)	Outfall location or beginning of flow	Length (miles)
Nogales International WWTP - Pima County line	No	Effluent	Nogales International WWTP	Santa Cruz River at Potrero Creek	23.4
Martinez Hill reach	No	Agricultural	Irrigated agriculture	Base of Martinez Hill	0.9
Downstream of Irvington Road	No	Treated groundwater	Tucson Airport Remediation Project	Irvington Road on Santa Cruz River	1.3
Santa Cruz River Heritage Project (SCRHP)	Yes	Effluent	Tucson Water dedicated distribution system for reclaimed water, delivering water from PCRWRD	Between Silverlake and Starr Pass Roads, near 26th St alignment	1.4
Santa Cruz River Managed Underground Storage Facility (SCRMUSF)	Yes	Effluent	Agua Nueva WRF	Agua Nueva outfall, between Sweetwater Dr alignment and W El Camino del Cerro	5.2
Lower Santa Cruz River Managed Recharge Project (LSCRMRP)	Yes	Effluent	Tres Rios WRF	Tres Rios outfall near Ina Road	21.5
Pinal County reach	No	Effluent-based flow from Tres Rios WRF extending downstream beyond LSCRMRP boundary			3
Total					56.7

Table 18. Effluent-based surface flows elsewhere on the Santa Cruz River.

Effluent-based flows need not originate at the point of effluent generation. On the Santa Cruz River Heritage Project (SCRHP), the City of Tucson conveys effluent upstream from Agua Nueva WRF to a historically flowing reach of the Santa Cruz River (ADEQ, 2018).

Effluent-based flows produce considerable environmental and economic benefits, especially in arid and semi-arid regions with dewatered streams (Hamdhani et al., 2023; Luthy et al., 2015).

Riparian woodlands on effluent-dominated reaches of the Santa Cruz River have a mix of woody species resembling those seen on the naturally flowing San Pedro River elsewhere in southern Arizona (M. S. White, 2011). Where effluent-based flows have re-watered urbanized reaches of the Salt River in Phoenix, researchers have found that vegetation and soil seed banks closely resemble those on naturally flowing rural reaches of the river (J. M. White & Stromberg, 2011). After the introduction of effluent-based flows, rapid species recruitment and establishment of odonates has been observed even on urbanized reaches near downtown Tucson (Bogan et al., 2020).

Flowing and ephemeral reaches on the Santa Cruz River north of the US-Mexico border

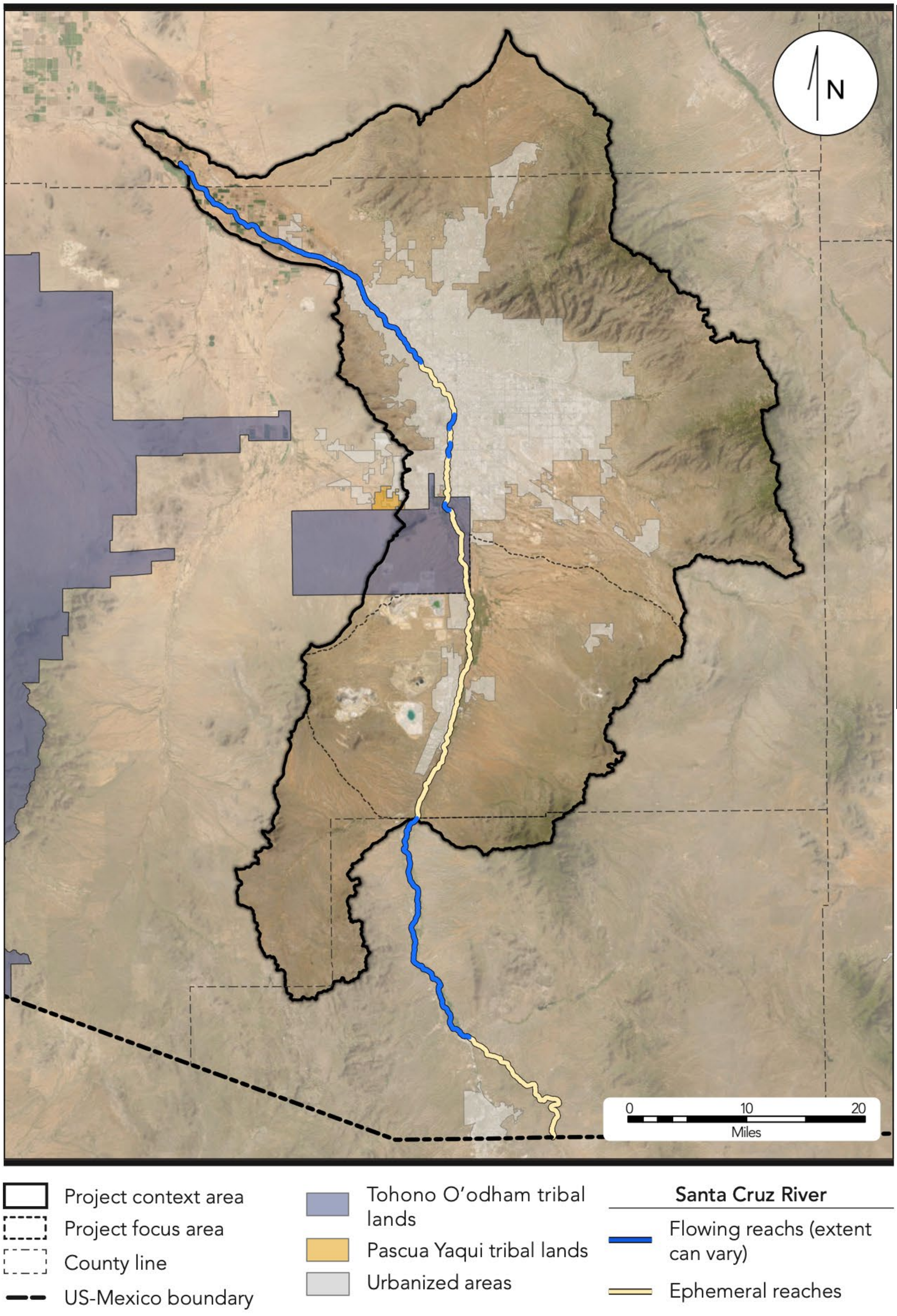

Figure 16. *Approximate current extent of flow on the Santa Cruz River between the US-Mexico border and southern Pinal County, where the channel becomes indistinct. The longest ephemeral reach shown bisects the project focus area.*

South of the study focus area, Sonoran Institute has previously catalogued diverse and complex riparian woodlands on the Santa Cruz River, where effluent-based perennial flows coexist seasonal high-flow events that periodically distribute seeds and scour the channel, improving water infiltration (Sonoran Institute & University of Arizona Remote Sensing Center, 2008). Effluent-based flows underlie similarly dynamic conditions resemble those seen north of the study focus area on the Lower Santa Cruz River. In most years effluent-based flows constitute most of the observed flow volume downstream of discharge points, with occasional high-volume years due to wet-season runoff (Pima County Regional Flood Control District et al., 2013).

On these reaches, RFCD has observed that "maintaining or restoring flood-dependent cottonwood-willow forests will be easier in reaches with floodplains lacking bank protection and having effluent flows" (Pima County Regional Flood Control District et al., 2013). The absence of nearly continuous bank protection seen in the heavily urbanized stream elsewhere in Pima County make the MSCR an excellent restoration candidate.

We expect that in-stream flows will improve recreation conditions, increasing the frequency and economic value of outdoor recreation on the MSCR. Arizona tourism relies on nature-based activities. In Pima County 60% of Tucson-area visitors report engaging in "outdoor desert activities," and their top reason for recommending the area to other travelers was the "surrounding natural environment (Coalition for Sonoran Desert Protection, n.d., citing information derived from Strongpoint Research, 2012)

A 2019 study commissioned by the Audubon Society estimates that Arizona's surface waters result in outdoor recreation that supports 114,000 jobs with $4.5 billion in household income. In total, these surface waters directly contribute $7.1 billion to Arizona's GDP and drive a total economic output of $13.5 billion (Audubon Society, 2019a). Of these jobs, the study attributes 12,000 to Pima County waterways, which see recreational use by 222,000 in-state residents per year (Audubon Society, 2019b). Collectively, Arizona watercourses and their nearby lands host 48.0 million user-days per year from the state's residents (Southwick Associates, 2019).

Figures from the 2019 study align well with those reported by the federal government for outdoor recreation in the state. The Bureau of Economic Analysis reports a 2023 statewide total economic impact of $14.1 billion (2.7% of statewide GDP) and 110,794 jobs (3.4% of statewide employment) with $6.7 billion in compensation (BEA, 2024b).

Nationwide, outdoor recreation accounted for 2.3% of GDP in 2023, adding $639.5 billion of value to the US economy (BEA, 2024a). Outdoor recreation also contributes over $65 billion in federal tax revenue per year, and more than $59 billion annually in state and local tax revenue (Outdoor Industry Association, 2017).

The Bureau of Economic Analysis also reports that, in 2023, outdoor recreation's contribution to growth in real GDP, real gross output, compensation, and employment, all outpaced the US economy as a whole (BEA, 2024a).

Various works have been published on the economic value of in-stream flows in undeveloped and rural areas (Lowe et al., 2020), but relatively few studies have examined the economic value of in-stream flows through developed areas. In a contingent valuation method study, Loomis (2012) reports a total economic value of $172 acre feet for in-stream flows through the Poudre River in Fort Collins, Colorado, or roughly $242 in inflation-adjusted dollars. This public good is an additional economic value realized beyond the dollar value of long-term storage credits realized through in-channel aquifer recharge.

Properties adjacent to in-stream flows may be able to realize higher property values. Past work in the Tucson area has shown a positive association between home value and nearby hydroriparian vegetation (Bark et al., 2009).

In-channel flows also receive widespread community support evident on social media at an in-person events, with over 300 in-person attendees present for the first in-channel release on the Santa Cruz River Heritage Project reach (Kmiec, 2019).

Finally, we observe the efficiency of using in-channel discharge to replenish groundwater while still achieving restoration goals. The USGS reports that infiltration rates on Santa Fe River reaches near La Bajada, New Mexico are 92-98%, with evaporative losses of 2-8% (Thomas et al., 2000). The authors do not attempt to determine the fraction of infiltrated water taken up by riparian vegetation, but unaccounted fraction (2% to 6%) is comparable to the 5% evaporative losses that authors may assume for groundwater recharge via engineered basins (Dillon & Arshad, 2016). Tucson Water reports evapotranspiration losses on its in-channel effluent-based flows as low as 3.5% (Kmiec, 2021).

Regulatory overview — Approved uses and discharge of high-quality effluent

The Sahuarita and Green Valley WRFs both produce grade A+ effluent (PAG, 2020b; PCRWRD, 2023). Grade A effluent is approved for direct application to food crops (18 AAC 11, 2023; WRRC, 2023). However, only 20% of effluent statewide is used for irrigation (WRRC, 2023). The fraction of effluent used statewide for aquifer recharge is even less — only 17% (WRRC, 2023).

However, in Pima County, the region's largest producer of effluent (Pima County RWRD) uses nearly 70% of all effluent for groundwater recharge (PCRWRD, 2023). This is done mostly through in-channel releases, north of the project focus area, with a small amount done mainly through recharge basins. Indeed, the Middle Santa Cruz River is the only portion of the Santa Cruz River in Pima County where RWRD facilities do not perform in-channel discharges.

Effluent releases into watercourses are regulated by ADEQ, ADWR, and the Arizona Water Banking Authority (AWBA). ADEQ permits allow the discharge of effluent into a watercourse, while ADWR and AWBA oversee matters related to groundwater use in AMAs.

Broadly, there are two avenues for converting effluent into groundwater. The first is via aquifer recharge in constructed basins. Within AMAs, these can be regulated by ADWR as underground storage facilities (USFs). The second is via discharge into a watercourse. Within AMAs, these are regulated by ADWR as managed underground storage facilities (MUSFs).

AWBA oversees the award and transfer of water banking credits stored in USFs and MUSFs. These credits are known as long-term storage credits (LTSCs). Crediting rates vary across project types and implementation dates as shown in **Table 19**.

		Cut to the aquifer	
Water source	**Type of recharge project**	**Annual storage and recovery**	**LTSC**
CAP water	Any	0%	5%
NCS/Plan 6	Any	0%	5%
Surface water	Any	0%	N/A
Effluent	Constructed USF basin	0%	5%
Effluent	Groundwater savings facility (GSF)	0%	5%
Effluent	In-channel MUSF approved on or before January 31, 2019	5%	5%
Effluent	In-channel MUSF approved after January 31, 2019	50%	50%

Table 19. LTSC crediting for different effluent-based recharge projects, adapted from (ADWR, 2019)

While the creation of an ADWR-sanctioned USF or MUSF confers benefits, it is not mandatory. Within the Santa Cruz AMA, effluent from the Nogales International Wastewater Treatment Plant (NIWWTP) is discharged into a portion of the Santa Cruz River not designated as an MUSF (ADWR, 2020). In-stream flows from NIWWTP do not result in the award of groundwater withdrawal rights, unlike Pima County flows within MUSFs.

Regardless of whether an entity is discharging effluent into a constructed basin, a natural watercourse, or an AMA, they must first obtain aquifer protection permit (APP) issued by ADEQ under the Arizona Pollution Discharge Elimination Program (AZPDES). The rights of Arizona municipalities to effluent discharge and conveyance through natural watercourses is affirmed by case law including *Arizona Public Service Corporation v. Long* and *West Maricopa Combine, Inc. v Arizona Department of Water Resources*.

Recommended actions

Based on our findings, we recommend the following actions be taken by various agencies:

Pima County Board of Supervisors should resolve to pursue groundwater recharge via effluent-based in-channel flow on the Middle Santa Cruz River. **Pima Association of Governments** should update their 208 Plan accordingly.

Pima County jurisdictions should partner with **jurisdictions in Maricopa County** and elsewhere to pursue LTSC crediting parity for new effluent-based in-channel recharge. Although LTSC credit parity is not a prerequisite to in-channel recharge projects (in fact, effluent-based flows in the Santa Cruz AMA receive no credits), it is a benefit.

Pima County RWRD should monitor the effects of flow cessation downstream from Trico Road due to construction of a new advanced water purification (AWP) facility. This information can inform future management decisions if outfall locations change.

Tucson Water should compare AWP plant construction and operational costs to those necessary for the construction and operation of an additional outfall point necessary to conduct in-channel recharge projects elsewhere within the Tuson AMA.

Pima County should consult with Tohono O'odham Nation on desired riparian restoration and determine whether any legal and operational framework could accommodate an MUSF project on tribal land, if mutually desired.

On the lower Santa Cruz River, recruitment and recovery of woody hydroriparian species seems has been most robust on reaches without bank protection (Pima County Regional Flood Control District et al., 2013). **Pima County RWRD and RFCD** should collaborate to minimize future needs for bank protection in restored reaches.

Concluding Remarks

The Middle Santa Cruz River (MSCR) restoration planning project presents a model approach for advancing riparian restoration using high-quality effluent in arid and semi-arid regions. Over the course of this two-year initiative, the project team applied a structured, data-informed methodology to assess hydrologic viability, infrastructure readiness, land use compatibility, and regulatory pathways. With support from the Bureau of Reclamation's WaterSMART program, the study identified the Green Valley Water Reclamation Facility (WRF) as the most practical near-term effluent source and developed implementable restoration scenarios grounded in real-world constraints and opportunities.

Beyond the immediate context of the MSCR, the study offers a replicable framework that can be applied across the Colorado River Basin, especially in regions of the arid Southwest facing similar challenges of groundwater depletion, limited surface flows, and effluent underutilization. The scoring matrix, stakeholder integration, and restoration scenario modeling introduced in this project provide a scalable toolkit for other jurisdictions seeking to reestablish flow and riparian habitat while navigating complex water governance environments. The report's emphasis on in-channel recharge, water reuse efficiency, and ecosystem co-benefits aligns directly with federal resilience goals under the WaterSMART initiative.

This project has produced fully implementable concepts, each backed by hydrologic data, infrastructure assessments, and permitting strategies. Concept 1 can be advanced immediately with BOR implementation funding, using surplus effluent to initiate flow restoration along a county-owned corridor. Concepts 2 and 3 represent medium- and long-term options involving expanded effluent use and future infrastructure development. Each concept integrates community and tribal input and avoids regulatory conflicts. As a technically sound, policy-aligned, and regionally supported initiative, the MSCR restoration effort stands ready for federal funding and serves as a model for similar projects throughout the Basin.

Key Findings and Project Deliverables

- Confirmed high-quality effluent as the most feasible water source for MSCR riparian restoration
- Identified Green Valley WRF as the top near-term opportunity for initiating perennial flow
- Developed three conceptual restoration scenarios spanning 0.75 to 6.15 miles of surface flow
- Constructed a replicable scoring matrix to evaluate water source viability across multiple variables
- Demonstrated a methodology transferable to other reaches in the Colorado River Basin and arid Southwest
- Integrated hydrologic, land use, infrastructure, and governance data into a unified planning framework
- Engaged municipal, tribal, utility, and community stakeholders through the Santa Cruz Watershed Collaborative and attendant community engagement

- Designed scenarios to comply with ADEQ and ADWR permitting while avoiding encroachment on tribal lands
- Evaluated potential for Managed Underground Storage Facility (MUSF) designation and Long-Term Storage Credit (LTSC) accrual
- Provided options that balance ecological, groundwater recharge, and recreational benefits
- Aligned proposed flows with regional land use plans and recreation infrastructure
- Positioned Concept 1 for immediate implementation using BOR WaterSMART funding
- Delivered a full set of planning tools and analyses adaptable to similar restoration efforts basin-wide

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