FINAL REPORT | JUNE 2022

# Annual Report of the Prado Basin Habitat Sustainability Committee
## Water Year 2021

**PREPARED FOR**

Chino Basin Watermaster and
Inland Empire Utilities Agency

**PREPARED BY**

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# Annual Report of the Prado Basin Habitat Sustainability Committee Water Year 2021

Prepared for

## Chino Basin Watermaster and Inland Empire Utilities Agency

Project No. 941-80-21-55

06-02-2022

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06-02-2022

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| | |
|---|---|
| ACOE | Army Corps of Engineers |
| af | Acre-Feet |
| afy | Acre-Feet Per Year |
| AMP | Adaptive Management Plan |
| Annual Report | Annual Report of The Prado Basin Habitat Sustainability Committee |
| ACOE | Army Corps of Engineers |
| CAL FIRE | California Department of Forestry and Fire Protection |
| CBMWD | Chino Basin Municipal Water District |
| CBWM | Chino Basin Watermaster |
| CCWF | Chino Creek Well Field |
| CDA | Chino Basin Desalter Authority |
| CDFM | Cumulative Departure from The Mean |
| CDFW | California Department of Fish and Wildlife |
| CEQA | California Environmental Quality Act |
| Chino Basin | Chino Groundwater Basin |
| DBH | Diameter at Breast Height |
| EC | Electrical Conductivity |
| EROS | Earth Resources Observation and Science |
| ESPA | Center Science Processing Architecture |
| FD | Fusarium Dieback |
| ft-amsl | Feet Above Mean Sea Level |
| ft-bgs | Feet Below Ground Surface |
| FRAP | Fire And Resource Assessment Program |
| GIS | Geographic Information System |
| GMP | Groundwater Monitoring Program |
| GMZ | Orange County Groundwater Management Zone |
| HCMP | Hydraulic Control Monitoring Program |
| IEUA | Inland Empire Utilities Agency |
| In/yr | Inches Per Year |
| LEDAPS | Landsat Ecosystem Disturbance Adaptive Processing System |
| $mi^2$ | Square Miles |
| MWD | Metropolitan Water District of Southern California |
| NDVI | Normalized Difference Vegetation Index |
| NASA | National Aeronautics and Space Administration |
| NEXRAD | Next Generation Radar |
| OBMP | Optimum Basin Management Program |

| | |
|---|---|
| OC-59 | The OCWD’s Imported Water Turnout Tributary to Prado Basin |
| OCWD | Orange County Water District |
| Parties | Parties to The Chino Basin Judgment |
| PBHSC | Prado Basin Habitat Sustainability Committee |
| PBHSP | Prado Basin Habitat Sustainability Program |
| PBMZ | Prado Basin Management Zone |
| POTWs | Publicly Owned Treatment Works |
| ppm | Parts Per Million |
| Prado Basin | Prado Basin Management Zone |
| PSHB | Polyphagous Shot Hole Borer - *Euwallacea Fornicates* |
| QA/QC | Quality Assurance and Quality Control |
| RHMP | Riparian Habitat Monitoring Program |
| SAWA | Santa Ana Watershed Association |
| SAR | Santa Ana River |
| SARWM | Santa Ana River Watermaster |
| SEIR | Subsequent Environmental Impact Report |
| SWMP | Surface-Water Monitoring Program |
| TDS | Total Dissolved Solids |
| USBR | United States Bureau of Reclamation |
| USGS | United States Geological Survey |
| USDA | United State Department of Agriculture |
| USFWS | United States Fish and Wildlife Service |
| VOCs | Volatile Organic Compounds |
| Watermaster | Chino Basin Watermaster |
| WEI | Wildermuth Environmental Inc. |
| WRCRWA | Western Riverside County Regional Wastewater Authority |
| WY | Water Year |

# Annual Report of the Prado Basin Habitat Sustainability Committee

## 1.0 BACKGROUND AND OBJECTIVES

This *Annual Report of the Prado Basin Habitat Sustainability Committee for Water Year 2021* (Annual Report) was prepared on behalf of the Prado Basin Habitat Sustainability Committee (PBHSC), convened by the Inland Empire Utilities Agency (IEUA) and the Chino Basin Watermaster (Watermaster) pursuant to the mitigation monitoring and reporting requirements of the Peace II Subsequent Environmental Impact Report (SEIR) (Tom Dodson, 2010).

This introductory section provides background on the general hydrologic setting of the Prado Basin Management Zone (Prado Basin); the Chino Basin Judgment; the Optimum Basin Management Program (OBMP), its Programmatic EIR and the Peace Agreement; the Peace II Agreement and its SEIR; and the formation of the PBHSC and the development of the adaptive management plan (AMP) for the Prado Basin Habitat Sustainability Program (PBHSP).

## 1.1 Prado Basin

The Prado Basin is the flood control area behind Prado Dam, which was constructed in 1941 as the major flood-control facility within the Santa Ana River (SAR) Watershed. The US Army Corps of Engineers (ACOE) regulates releases of water from Prado Dam for both purposes of flood control and groundwater recharge in Orange County Groundwater Management Zone (GMZ). Releases of water temporarily held in storage in the Prado Basin for groundwater recharge in Orange County is coordinated with the Orange County Water District (OCWD). Figure 1-1 shows the location of the Prado Basin in the southern portion of the Chino Groundwater Basin (Chino Basin). The Prado Basin boundary shown on Figure 1-1 is the Prado Basin Management Zone (PBMZ) boundary as defined in the Santa Ana Region Basin Plan (Regional Board, 2016), which approximately follows the 566 feet above mean sea level (ft-amsl) elevation contour behind Prado Dam.

Approximately 4,300 acres of riparian habitat have developed within the Prado Basin, creating the largest riparian habitat in Southern California. Portions of the riparian habitat have been designated as critical habitat to several endangered or threatened species. Figure 1-2 shows the locations of the critical habitat, as defined by the United States Fish and Wildlife Service (USFWS). Most of the riparian habitat in Prado Basin is designated as critical habitat for one or multiple species, including the Santa Ana Sucker, the Southwestern Willow Flycatcher, and Least Bell's Vireo.

The SAR flows through the Prado Basin from east to west. The tributaries of the SAR that flow into the Prado Basin include San Antonio/Chino, Cucamonga/Mill, and Temescal Creeks. The major components of flow within the SAR and its tributaries are: runoff from precipitation, discharge of tertiary-treated effluent from wastewater treatment plants, rising groundwater, discharge of untreated imported water from the OC-59 turnout conveyed through the Prado Basin for groundwater recharge in Orange County GMZ, and dry-weather runoff.[1]

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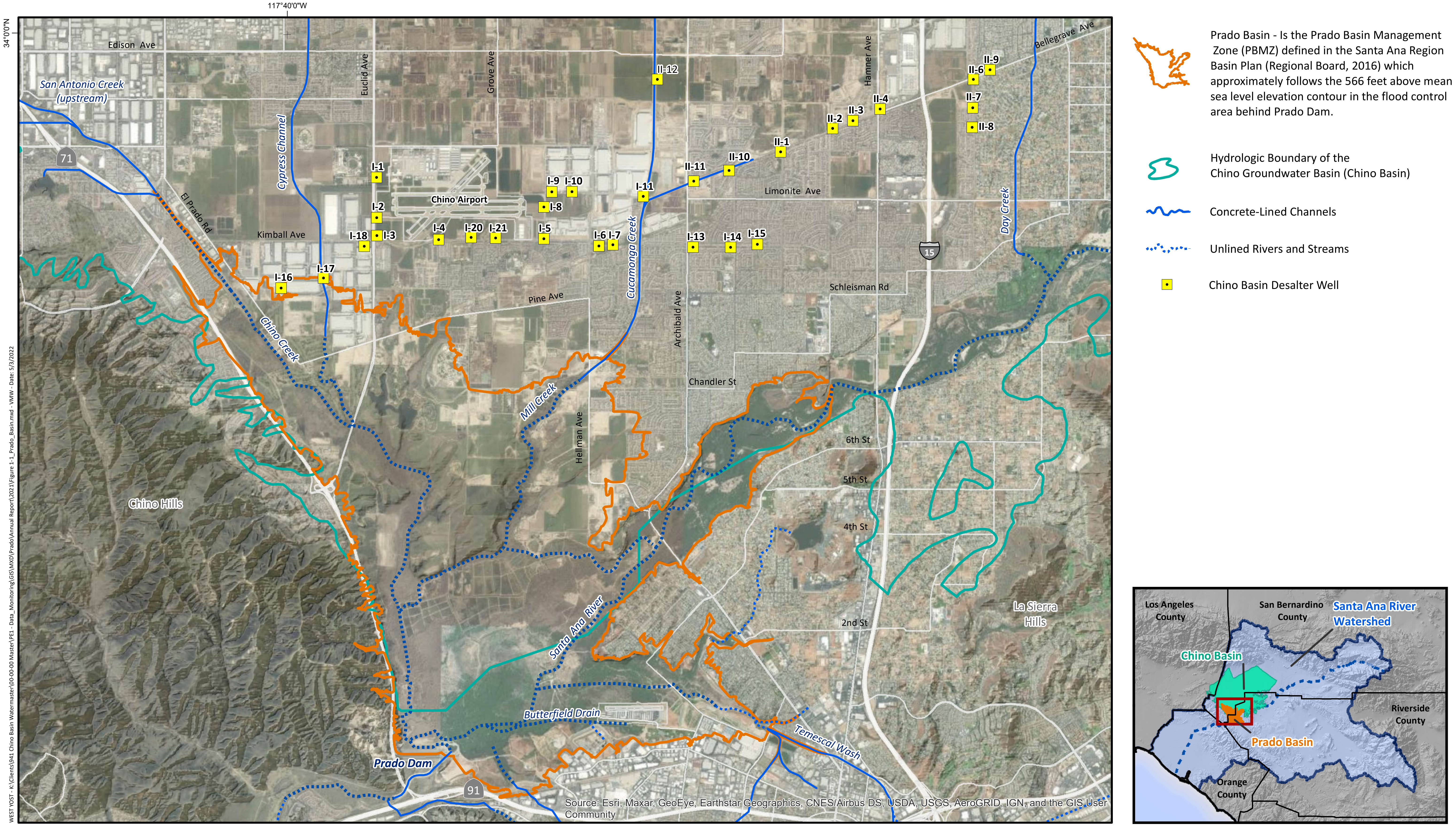
[1] Dry-weather runoff consists of excess irrigation runoff, purging of wells, dewatering discharges, etc.



Prado Basin - Is the Prado Basin Management Zone (PBMZ) defined in the Santa Ana Region Basin Plan (Regional Board, 2016) which approximately follows the 566 feet above mean sea level elevation contour in the flood control area behind Prado Dam.

Hydrologic Boundary of the Chino Groundwater Basin (Chino Basin)

Concrete-Lined Channels

Unlined Rivers and Streams

Chino Basin Desalter Well

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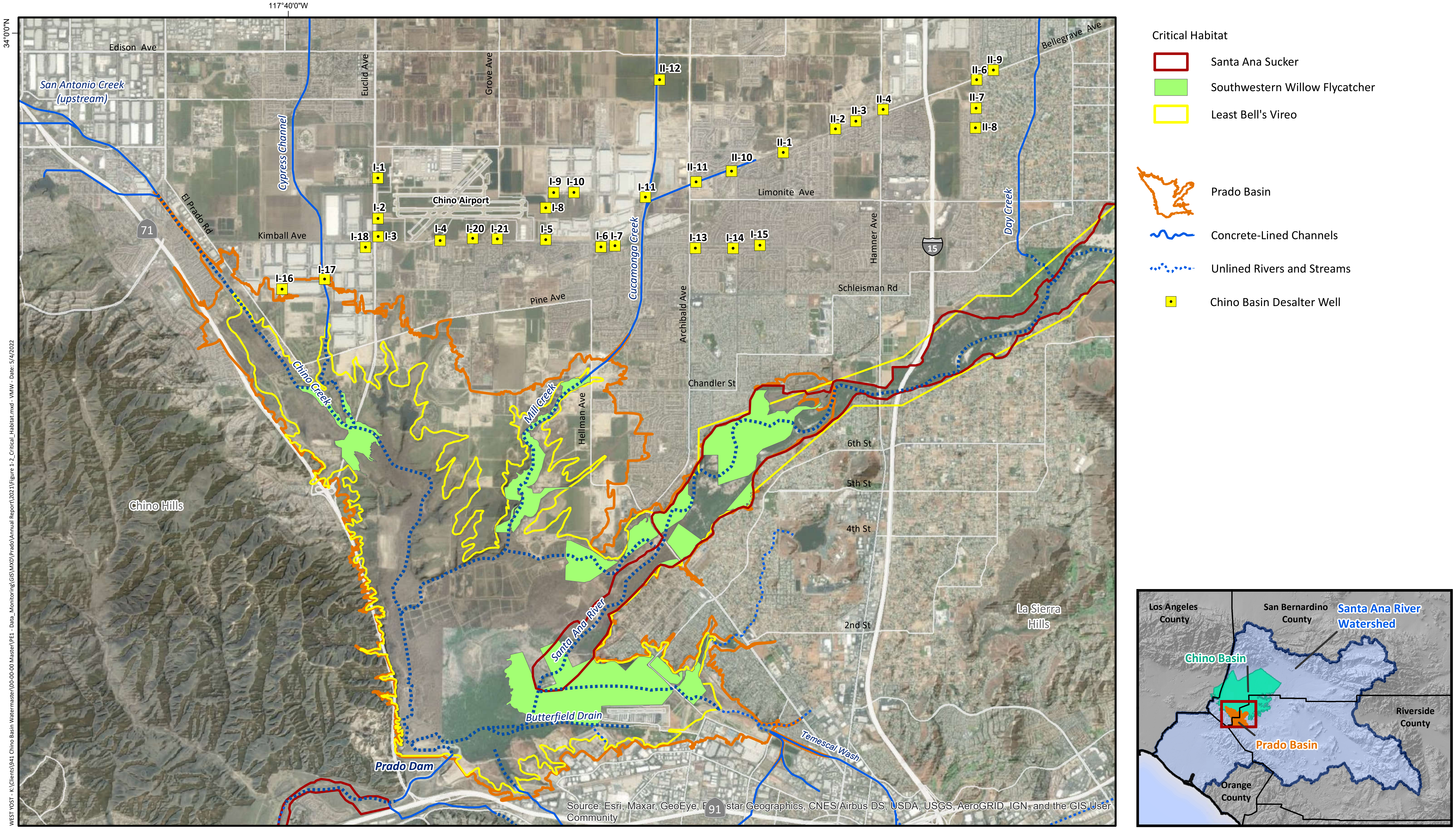
**Prado Basin Area**

**Figure 1-1**



WEST YOST - K:\Clients\941 Chino Basin Watermaster\00-00-00 Master\PE1 - Data_Monitoring\GIS\MXD\Prado\Annual Report\2021\Figure 1-2_Critical_Habitat.mxd - VMW - Date: 5/4/2022

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Critical Habitat for Endangered or Threatened
Species in the Prado Basin Area

**Figure 1-2**

The Prado Basin is a hydrologically complex region of the lower Chino Basin. Groundwater in the Chino Basin generally flows from the forebay regions in the north towards the Prado Basin in the south. Depth to groundwater is relatively shallow in the Prado Basin area, and the SAR and its tributaries are unlined across the Prado Basin, which allows for groundwater/surface-water interaction. Groundwater outflows in the Prado Basin occur via evapotranspiration by riparian vegetation and rising-groundwater discharge to the SAR and its tributaries.

To the north of the Prado Basin, the Chino Basin Desalter Authority (CDA) owns and operates the Chino Basin Desalter well field. Figure 1-1 shows the locations of Chino Basin Desalter wells. The well field pumps groundwater with high concentrations of total dissolved solids (TDS), nitrate, and volatile organic compounds (VOCs). The CDA treats the groundwater at two regional facilities using reverse osmosis, ion exchange, and blending to produce a potable water supply for the region. VOCs are currently treated through blending, and new treatment processes are being added to increase their removal. CDA operations are fundamental to achieving many of the management goals outlined in the OBMP and both Peace Agreements, which are discussed below.

## 1.2 Chino Basin Judgment, OBMP, and Peace Agreement

A 1978 Judgment entered in the Superior Court of the State of California for the County of San Bernardino (Chino Basin Municipal Water District vs. City of Chino et al.) established pumping and storage rights in the Chino Basin. The Judgment established Watermaster to oversee the implementation of the Judgment and provided Watermaster with the discretionary authority to develop an OBMP to maximize the beneficial use of the Chino Basin. The OBMP was developed by Watermaster and the parties to the Judgment (Parties) in the late 1990s (WEI, 1999). The OBMP maps a strategy to enhance the yield of the Chino Basin and provide reliable high-quality water supplies for the development expected to occur in the region. The goals of the OBMP are: to enhance basin water supplies, to protect and enhance water quality, to enhance the management of the Basin, and to equitably finance the OBMP.

In 2000, the Parties executed the Peace Agreement (Watermaster, 2000), which documented their intent to implement the OBMP. The Peace Agreement included an OBMP Implementation Plan which outlined the time frame for implementing tasks and projects in accordance with the Peace Agreement and the OBMP. The OBMP Implementation Plan is a comprehensive, long-range water-management plan for the Chino Basin and includes: the use of recycled water for direct reuse and artificial recharge, the capture of increased quantities of high-quality storm-water runoff, the recharge of imported water when TDS concentrations are low, the desalting of poor-quality groundwater in impaired areas of the basin via the Chino Basin Desalters, the support of regulatory efforts to improve water quality in the basin, subsidence management, storage management, and the implementation of management activities to reduce the discharge of high-TDS/high-nitrate groundwater to the SAR, thus ensuring the protection of downstream beneficial uses in the Orange County GMZ.

The Chino Basin Municipal Water District (CBMWD) was the plaintiff in the legal action that resulted in the Judgment. The CBMWD was formed in 1950 to supply supplemental, imported water purchased from the Metropolitan Water District of Southern California (MWD) to the Chino Basin. On July 1, 1998, the CBMWD changed its name to the IEUA and expanded its role to become the regional supplier of recycled water for most of the Chino Basin. For OBMP implementation, the IEUA has served as the lead agency for compliance with the California Environmental Quality Act (CEQA). A Program Environmental Impact Report for the OBMP (SCH#2000041047) was certified by the IEUA in July 2000 (Tom Dodson, 2000).

## 1.3 The Peace II Agreement and its Subsequent EIR

To further implement the goals and objectives of the OBMP, the Parties executed the Peace II Agreement in 2007, which modified the OBMP Implementation Plan (Watermaster, 2007). The two main activities of the Peace II Agreement are: (i) increasing the controlled overdraft of the Chino Basin, as defined in the Judgment,[2] by 400,000 acre-feet (af) through 2030 (re-operation), and (ii) refining the planned expansion facilities of the Chino Basin Desalters from about 30,000 to 40,000 acre-feet per year (afy) of groundwater production. Re-operation is allocated specifically to offset the production of the Chino Basin Desalters. Both re-operation and desalter expansion contribute to the attainment of "hydraulic control" of groundwater outflow from the Chino Basin to the SAR. The attainment and maintenance of hydraulic control is a requirement of Watermaster and the IEUA, as defined in the Water Quality Control Plan for the Santa Ana River Basin (California Regional Water Quality Control Board, Santa Ana Region, 2008). Hydraulic control ensures that the water management activities in the Chino Basin will not impair the beneficial uses designated for SAR water quality downstream of Prado Dam.

The expansion of the Chino Basin Desalters, described in the Peace II Agreement, was accomplished, in part, by the construction and operation of the Chino Creek Well Field (CCWF) in the southwest portion of Chino Basin (see Figure 1-3). During Peace II Agreement planning, the estimated capacity of the CCWF was about 5,000 to 7,700 afy (WEI, 2007). The CCWF wells were constructed in 2011-2012, and their actual capacity is about 1,500 afy.

In 2010, the IEUA certified the Peace II SEIR (Tom Dodson, 2010) to evaluate the environmental impacts that could result from implementing the Peace II Agreement. One of the potential impacts evaluated was the possible lowering of groundwater levels (drawdown) in the Prado Basin area, which could impact riparian vegetation that is dependent upon shallow groundwater. Watermaster performed modeling studies to predict the extent and magnitude of the drawdown associated with the implementation of the Peace II Agreement, using the planned capacity of 7,700 afy of the CCWF (WEI, 2007). Figure 1-3 (modified from Figure 4.4-10 from the Peace II SEIR) shows the model-predicted drawdown in the Prado Basin area for the period of 2005 to 2030. The drawdown throughout most of the Prado Basin area was predicted to be less than five feet by 2030.

Although the available modeling work indicated that implementing the Peace II Agreement would not cause significant adverse effects on Prado Basin riparian habitat, a contingency measure to address the potential for drawdown of groundwater levels and its impact on riparian vegetation was included in the Peace II SEIR as Mitigation Measure 4.4-3 (Biological Resources/Land Use & Planning section of the Mitigation Monitoring and Reporting Program).

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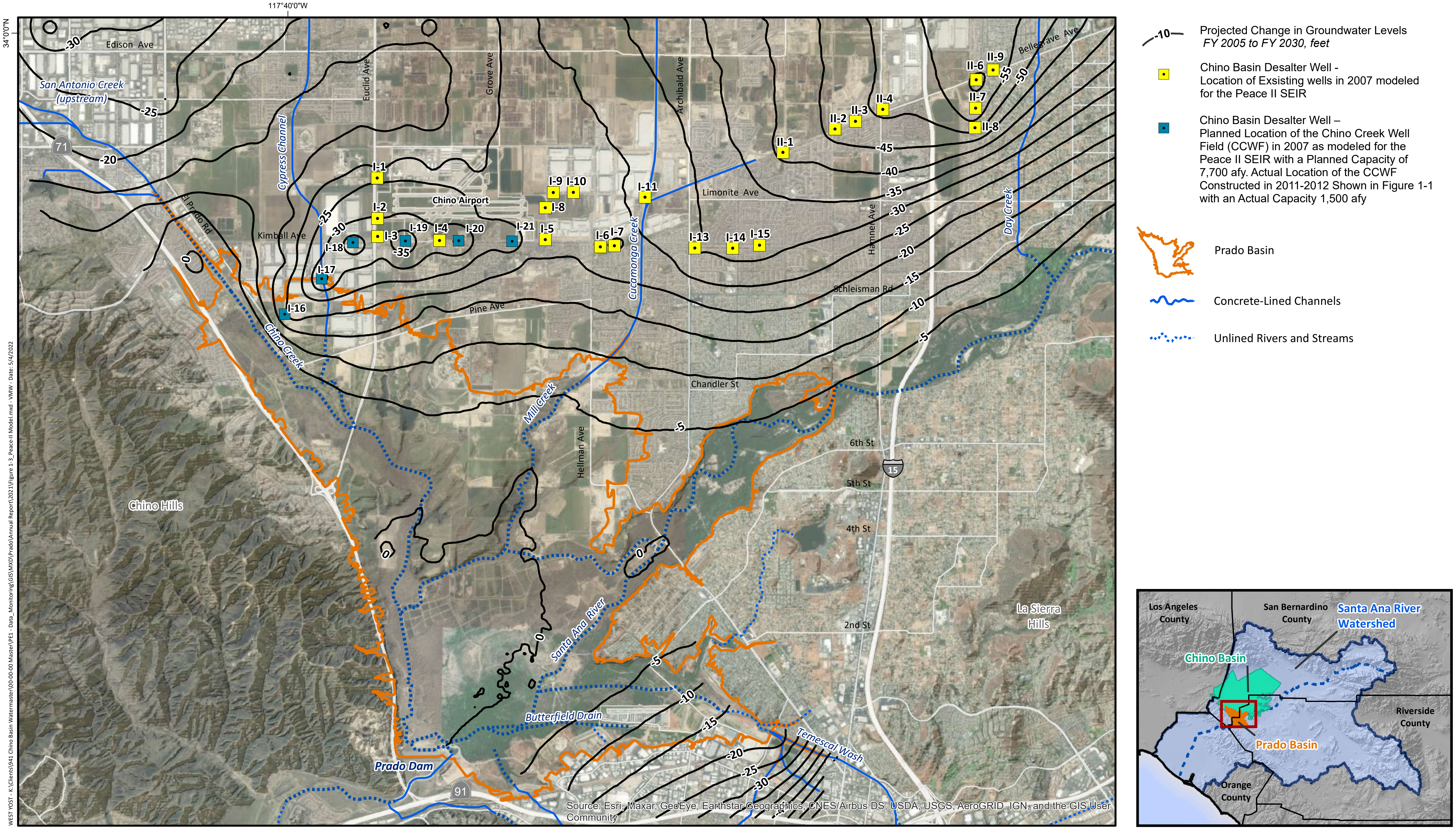
[2] The Judgment established 200,000 af of controlled overdraft over the period of 1978 to 2017. Re-operation increases the controlled overdraft to 600,000 af through 2030.



-10 Projected Change in Groundwater Levels *FY 2005 to FY 2030, feet*

🟨 Chino Basin Desalter Well - Location of Exsisting wells in 2007 modeled for the Peace II SEIR

🟦 Chino Basin Desalter Well – Planned Location of the Chino Creek Well Field (CCWF) in 2007 as modeled for the Peace II SEIR with a Planned Capacity of 7,700 afy. Actual Location of the CCWF Constructed in 2011-2012 Shown in Figure 1-1 with an Actual Capacity 1,500 afy

Prado Basin

Concrete-Lined Channels

Unlined Rivers and Streams

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**Projected Change in Groundwater Levels**
*FY 2005 to 2030 - Peace II Alternative*

**Figure 1-3**

Mitigation Measure 4.4-3 was developed to ensure that the riparian habitat will not incur unforeseeable significant adverse effects from the Peace II implementation and to contribute to the long-term sustainability of the riparian habitat. Mitigation Measure 4.4-3 calls for:

- Watermaster, the IEUA, the OCWD, and other stakeholders that choose to participate to jointly fund the development of an adaptive management program to monitor the extent and quality of the Prado Basin riparian habitat and investigate and identify essential factors to its long-term sustainability.
- Watermaster and the IEUA to convene the PBHSC, comprised of representatives from all interested parties to implement the adaptive management program.
- The PBHSC to prepare annual reports pursuant the adaptive management program. Annual reports are to include recommendations for ongoing monitoring and any adaptive management actions required to mitigate any measured or prospective loss of riparian habitat resulting from Peace II activities.

## 1.4 Adaptive Management Plan for the PBHSP

Pursuant to Mitigation Measure 4.4-3 in the SEIR, Watermaster and the IEUA convened four meetings of the PBHSC, starting in late-2012, to develop the adaptive management plan for the PBHSP and facilitate its implementation. Watermaster and the IEUA adopted the final *2016 Adaptive Management Plan for the Prado Basin Habitat Sustainability Program* (AMP) in August 2016 (WEI, 2016).

- The AMP was designed to answer the following questions to satisfy the monitoring and mitigation requirements of the Peace II SEIR:
- What are the factors that potentially can affect the extent and quality of the riparian habitat?
- What is a consistent, quantifiable definition of “riparian habitat quality,” including metrics and measurement criteria?
- What has been the historical extent and quality of the riparian habitat in the Prado Basin?
- How has the extent and quality of the riparian habitat changed during implementation of Peace II?
- How have groundwater levels and quality, surface-water discharge, weather, and climate changed over time? What were the causes of the changes? And, did those changes result in an adverse impact to riparian habitat in the Prado Basin?
- Are there other factors besides groundwater levels, surface-water discharge, weather, and climate that affect riparian habitat in the Prado Basin? What are those factors? And, did they (or do they) result in an adverse impact to riparian habitat in the Prado Basin?
- Are the factors that result in an adverse impact to riparian habitat in the Prado Basin related to Peace II implementation?
- Are there areas of prospective loss of riparian habitat that may be attributable to the Peace II Agreement?
- What are the potential mitigation actions that can be implemented if Peace II implementation results in an adverse impact to the riparian habitat?

The AMP outlines a process for monitoring, modeling, and annual reporting to answer and address the questions listed above. Appendix A to the AMP is the initial monitoring program: *2016 Monitoring Program for the Prado Basin Habitat Sustainability Program*. Annual reports are intended to document monitoring and modeling activities, the analysis and interpretation of the monitoring and modeling results, and recommendations for changes to the PBHSP, which may include monitoring, modeling, and/or mitigation, if deemed necessary. Any future mitigation measures that are deemed necessary will be developed jointly by Watermaster and the IEUA.

## 1.5 Annual Report Organization

This Annual Report for water year (WY) 2021 is the sixth annual report of the PBHSC. It documents the collection, analysis, and interpretations of the data and information generated by the PSHSP through September 30, 2021. The remainder of this report is organized as follows:

**Section 2.0 – Monitoring, Data Collection, and Methods**. This section describes the collection of historical information and recent monitoring data and describes the groundwater-modeling activities performed during WY 2021 for the PBHSP.

**Section 3.0 – Results and Interpretations**. This section describes the results and interpretations that were derived from the information, data, and groundwater-modeling.

**Section 4.0 – Conclusions and Recommendations**. This section summarizes the main conclusions derived from the PBHSP through the prior water year and describes the recommended activities for the subsequent fiscal year as a proposed scope-of-work, schedule, and budget.

**Section 5.0 – References**. This section lists the publications cited in the report.

# 2.0 MONITORING, DATA COLLECTION, AND METHODS

The PBHSP was designed, in part, to answer Question 1 from the AMP:

- What are the factors that potentially can affect the extent and quality of the riparian habitat?

The main hydrologic factors that can potentially affect the extent and quality of the riparian habitat in the Prado Basin include, but are not limited to, groundwater levels, surface-water discharge, weather events, and long-term climate. As such, the PBHSP includes integrated monitoring and analysis programs for riparian habitat, groundwater, surface water, climate, and other potential factors (e.g. wildfire, pests, etc.).

Since the implementation of the AMP in WY 2016, data collection efforts included the compilation of historical data through present. The period of data available for each data type varies, but all span both pre- and post-Peace II implementation. Data collection efforts for historical data were described in the first two annual reports for WY 2016 and WY 2017. Data collection efforts for subsequent water years have focused on recent water year monitoring data. All data collected and compiled for this effort were uploaded to Watermaster's centralized relational database, HydroDaVE$^{SM}$, and used in the analyses.

This section describes the collection of recent monitoring data and the groundwater-modeling activities performed for the PBHSP during WY 2021.

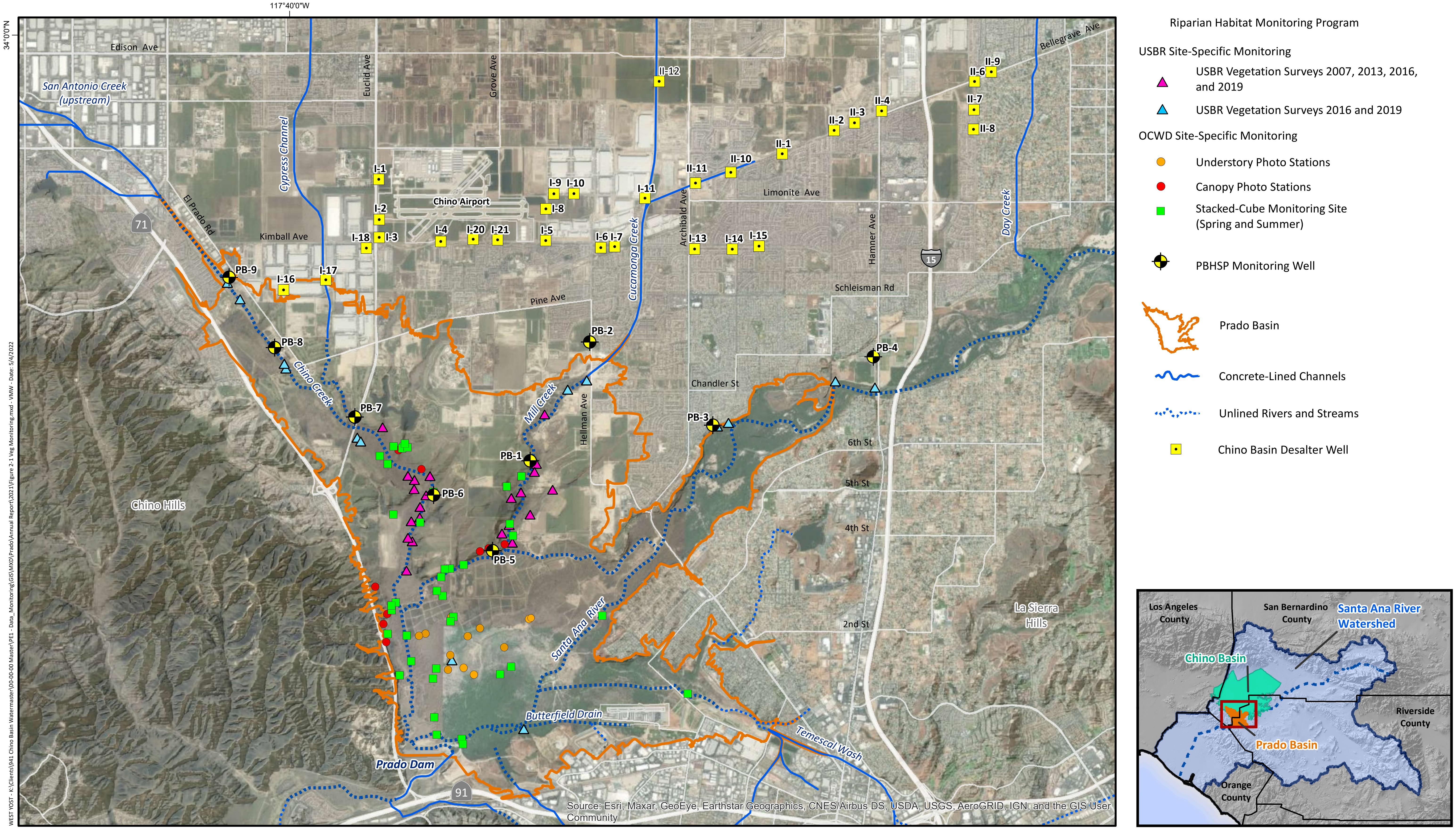
## 2.1 Riparian Habitat Monitoring

The objective of the Riparian Habitat Monitoring Program (RHMP) is to collect data to help answer questions 2, 3, and 4 from the AMP:

- What is a consistent quantifiable definition of "riparian habitat quality," including metrics and measurement criteria?
- What has been the historical extent and quality of the riparian habitat in the Prado Basin?
- How has the extent and quality of the riparian habitat changed during the implementation of Peace II?

To answer these questions, the RHMP includes time series data and information on the extent and quality of riparian habitat in the Prado Basin over a historical period, including both pre- and post-Peace II implementation.

Figure 2-1 displays the features of the RHMP. Two types of monitoring and assessment are performed: regional and site-specific. Regional monitoring and assessment is appropriate because the main potential stress to the riparian habitat associated with Peace II activities is the regional drawdown of groundwater levels. The intent of site-specific monitoring and assessment is to verify and complement the results of regional monitoring.



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**Riparian Habitat Monitoring Program**

**Figure 2-1**

### *2.1.1 Regional Monitoring of Riparian Habitat*

Regional monitoring and assessment of the riparian habitat is performed by mapping the extent and quality of riparian habitat over time using: (i) multi-spectral remote-sensing data and (ii) air photos.

#### 2.1.1.1 Multi-Spectral Remote Sensing Data

The Normalized Difference Vegetation Index (NDVI), derived from remote sensing measurements by Landsat Program satellites, is used to assess the extent and quality of the riparian vegetation in the Prado Basin over a long-term historical period. NDVI is a commonly used numerical indicator of vegetation health that can be calculated from satellite remote-sensing measurements (Ke et al., 2015; Xue, J. and Su, B., 2017). NDVI is calculated from visible and near-infrared radiation reflected by vegetation, is an index of greenness correlated with photosynthesis, and can be used to assess spatial and temporal changes in the distribution and productivity of vegetation (Pettorelli, 2013). Appendix A provides background information on NDVI, explains why NDVI was chosen as an analytical tool for the PBHSP, discusses its advantages and limitations, and describes how NDVI estimates were used for the PBHSP.

For the current reporting period, NDVI estimates were collected from the United States Geological Survey (USGS) using the Earth Resources Observation and Science (EROS) Center Science Processing Architecture (ESPA) On Demand Interface[3] (USGS, 2017b) over the period November 2019 through October 2020 to span the entire growing-season period (March-October 2020). To obtain complete spatial coverage of the Prado Basin area, NDVI estimates were requested for all Landsat scenes for Path 040, Rows 036 and 037 from the Landsat 7 and Landsat 8 satellites. The NDVI were processed and uploaded to Watermaster's centralized relational database, HydroDaVE$^{SM}$, which includes tools to manage, review, and extract NDVI estimates. The frequency of NDVI estimates from the Landsat 7 and 8 satellites is about every eight days. However, not all NDVI estimates are useable due to disturbances that can be caused by cloud cover, unfavorable atmospheric conditions, or satellite equipment malfunction. NDVI estimates were reviewed for these disturbances and excluded from analysis if they were determined erroneous due to these disturbances. Appendix A describes the how the NDVI estimates were collected, reviewed, and assembled for the PBHSP.

#### 2.1.1.2 Collection and Analysis of Air Photos

Georeferenced air photos are used to visually characterize the spatial extent and quality of the riparian habitat in the Prado Basin. The air photos also serve as an independent check on interpretations of NDVI, which involves visual comparison of the extent and density of the riparian habitat, as shown in the air photos, to the NDVI maps. For ongoing monitoring, a high-resolution (3-inch pixel) image of the visible spectrum for the entire Prado Basin is acquired during the middle of the growing season, typically in July.

For the current reporting period, the acquisition of the 2021 air photo included a custom flight that was performed by Tetra Tech on June 26, 2021. The cost to acquire the 2021 air photo was shared with the OCWD. This was the fifth annual high-resolution air photo acquired for the PBHSP and cost shared with the OCWD.

### *2.1.2 Site-Specific Monitoring of Riparian Habitat*

The objective of the site-specific monitoring of riparian habitat is to collect data that can be used to ground-truth the interpretations derived from the regional monitoring and assessment of the riparian

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[3] ESPA USGS

habitat (Pettorelli, 2013). Prior to the implementation of the AMP, site-specific monitoring performed in the Prado Basin included vegetation surveys performed by the United States Bureau of Reclamation (USBR) in 2007 and 2013 (USBR, 2008b; 2015). Since the implementation of the AMP, the USBR conducted vegetation surveys for the PBHSP in 2016 and 2019. The USBR vegetation surveys performed for the PBHSP in 2016 and 2019 consist of 37 sites in the Prado Basin: 24 previously established USBR sites during the 2007 and 2013 sampling and 14 new sites established in 2016 that are primarily located near the PBHSP monitoring wells. The OCWD performs site-specific monitoring in the southern portion of Prado Basin to monitor for effects of the operation of Prado Dam on riparian habitat. OCWD site-specific monitoring includes: seasonal monitoring at nine canopy photo stations located along the edge of Prado Basin, seasonal monitoring at 11 understory photo stations within different surface elevations of the inundation zone behind the dam, 40 stacked-cube monitoring sites monitored in the spring and summer throughout different surface elevation ranges of the inundation zone, and 40 stacked-cube monitoring sites in Least Bell's Vireo nesting and territory locations in the riparian habitat. The most recent OCWD results performed during this reporting period are described in the *Prado Basin Water Conservation and Habitat Assessment 2020-2021* report (OCWD, 2022).

Figure 2-1 shows the locations of the USBR vegetation surveys and the OCWD photo and stacked-cube monitoring sites.

## 2.2 Factors that Potentially Affect the Riparian Habitat

The main factors that can potentially affect riparian habitat in Prado Basin include, but are not limited to: groundwater levels, surface-water discharge, weather/climate, wildfires, and pests. This section describes the methods employed to collect and analyze information on these factors to help answer questions 5, 6, and 7 from the AMP:

- How have groundwater levels and quality, surface-water discharge, weather, and climate changed over time? What were the causes of the changes? And did those changes result in an adverse impact to riparian habitat in the Prado Basin?
- Are there other factors besides groundwater levels, surface-water discharge, weather, and climate that affect riparian habitat in the Prado Basin? What are those factors? And did they (or do they) result in an adverse impact to riparian habitat in the Prado Basin?
- Are the factors that result in an adverse impact to riparian habitat in the Prado Basin related to Peace II implementation?

### *2.2.1 Groundwater Monitoring Program*

A primary result of implementation of the Peace II Agreement is the lowering of groundwater levels (drawdown) in the southern portion of Chino Basin. Hence, drawdown is a factor that is potentially related to Peace II implementation and could adversely impact riparian habitat.

The Groundwater Monitoring Program (GMP) includes the collection of three types of data: groundwater production, groundwater level, and groundwater quality. Watermaster has been implementing a groundwater monitoring program across the entire Chino Basin to support various basin management initiatives and activities, and all data within Watermaster's centralized relational database are available to the GMP.

Watermaster's groundwater monitoring network was expanded in 2015 specifically for the PBHSP with the construction of 16 new monitoring wells at nine sites located along the fringes of the riparian habitat and between the riparian habitat and the CDA well field. These wells, along with two existing monitoring wells, HCMP-5/1 and RP2-MW3, are specifically monitored for the PBHSP and are called the "PBHSP monitoring wells."

Figure 2-2 shows the extent of the study area for which the GMP data are compiled and used for the PBHSP. The area covers the Prado Basin and the upgradient areas to the north that encompass the Chino Basin Desalter well field. Figure 2-2 also shows the wells in the study area where groundwater data were available in WY 2021.

#### 2.2.1.1 Groundwater Production

Groundwater production influences groundwater levels and groundwater-flow patterns. Groundwater-production data are analyzed together with groundwater-level data to characterize the influence of groundwater production on groundwater levels. Groundwater-production data are also used as an input to the Chino Basin groundwater-flow model to evaluate past and future conditions in the Chino Basin, which, for the PBHSP, supports the analysis of prospective losses of riparian habitat (see Section 2.3).

Watermaster collects quarterly groundwater-production data for all active production wells within the Chino Basin. The data are checked for quality assurance and quality control (QA/QC) and uploaded to Watermaster's centralized relational database. The active production wells within the study area include CDA wells and privately owned wells used for agricultural, dairy, or domestic purposes.

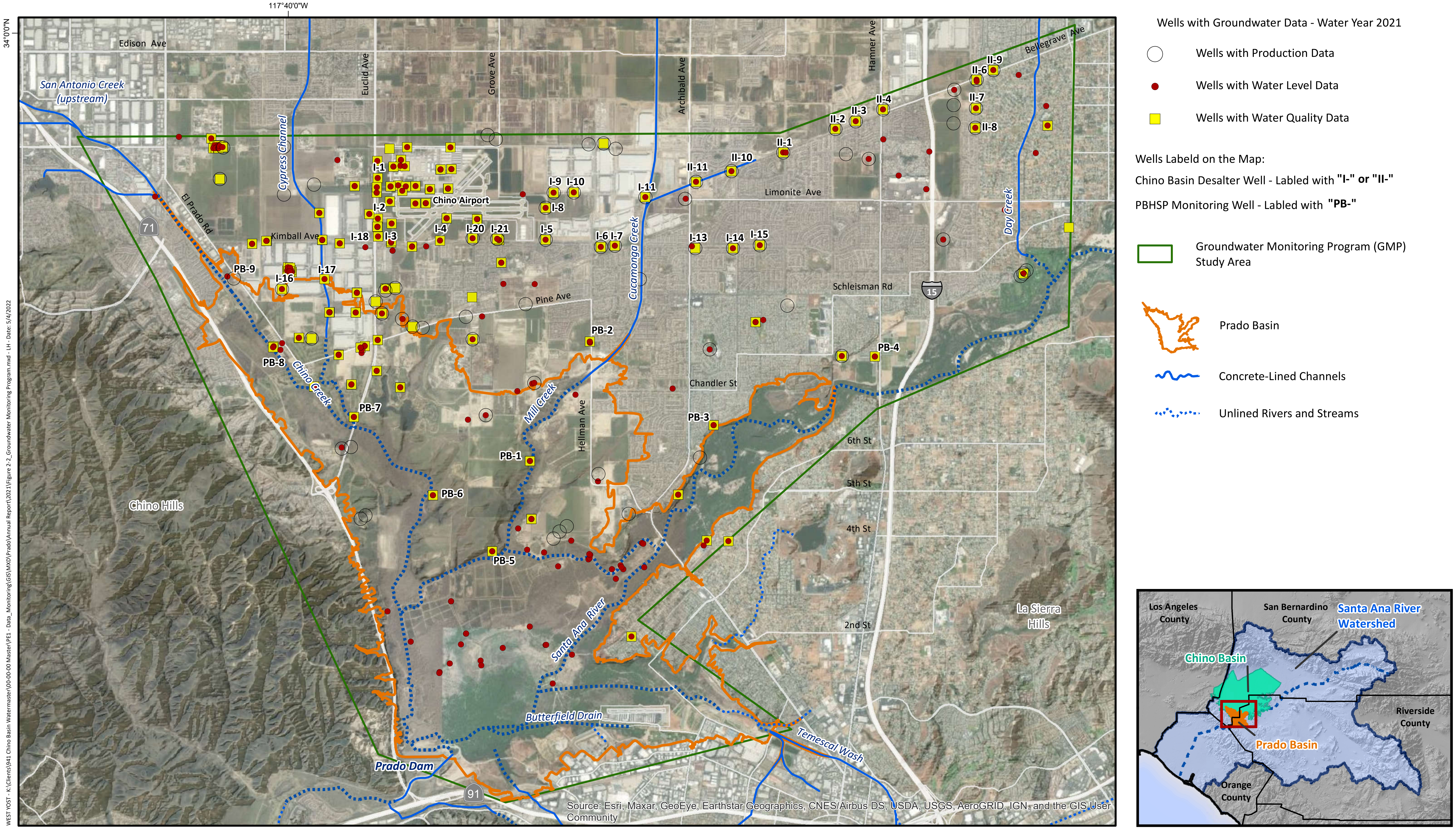
During WY 2021, Watermaster collected groundwater-production data at about 70 wells in the GMP study area.

#### 2.2.1.2 Groundwater Level

Monitoring groundwater levels in the Prado Basin is a key component of the PBHSP, as the potential for declining groundwater levels related to Peace II implementation could be a factor that adversely impacts riparian habitat. Groundwater-level data are analyzed together with production data to characterize how groundwater levels have changed over time in the GMP study area and to explore the relationship(s) to any observed changes that occurred in the extent and quality of the riparian habitat. Groundwater-level and production data are also used as input to the Chino Basin groundwater flow model to evaluate past and future conditions in the Chino Basin, which, for the PBHSP, supports the analysis of prospective losses of riparian habitat (see Section 2.3).

Watermaster collects groundwater-level data at various frequencies at wells in the GMP study area to support various groundwater-management initiatives. The data are checked for QA/QC and uploaded to Watermaster's centralized relational database.

During WY 2021, Watermaster collected groundwater-level data from 260 wells in the study area (see Figure 2-2). At 170 of these wells, water levels were measured by well owners at varying frequencies and provided to Watermaster. The remaining 90 wells are CDA wells, dedicated monitoring wells, or private wells that are monitored by Watermaster using manual methods once per month or with pressure transducers that record water levels once every 15 minutes. Groundwater-levels at the 18 PBHSP monitoring wells have been measured with pressure transducers since May 2015.



Wells with Groundwater Data - Water Year 2021

○ Wells with Production Data

● Wells with Water Level Data

🟨 Wells with Water Quality Data

Wells Labeld on the Map:

Chino Basin Desalter Well - Labled with **"I-" or "II-"**

PBHSP Monitoring Well - Labled with **"PB-"**

🟩 Groundwater Monitoring Program (GMP) Study Area

Prado Basin

Concrete-Lined Channels

Unlined Rivers and Streams

WEST YOST - K:\Clients\941 Chino Basin Watermaster\00-00-00 Master\PE1 - Data_Monitoring\GIS\MXD\Prado\Annual Report\2021\Figure 2-2_Groundwater Monitoring Program.mxd - LH - Date: 5/4/2022

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**Groundwater Monitoring Program**

**Figure 2-2**

### 2.2.1.3 Groundwater Quality

Water-quality data can be used to understand the various potential sources of shallow groundwater in the Prado Basin. Groundwater-quality data are compared to surface-water-quality data to characterize groundwater/surface-water interactions in the Prado Basin and assess the importance of those interactions to the extent and quality of the riparian habitat.

Watermaster collects groundwater-quality data from wells in the GMP study area to support various groundwater-management initiatives. These data are checked for QA/QC and uploaded to Watermaster's centralized relational database.

During WY 2021, groundwater-quality data were collected from 190 wells in the study area (see Figure 2-2). Of these wells, 145 were sampled by the well owners at varying frequencies. The remaining 45 wells are dedicated monitoring wells or private wells sampled by Watermaster either quarterly, annually, or triennially (every three years).

Watermaster has performed groundwater-quality monitoring at the PBHSP monitoring wells since they were constructed in 2015, and the monitoring program has been tailored to discern the groundwater/surface-water interactions important to the sustainability of the riparian habitat. During WY 2021, there was no sampling performed for the PBHSP. Watermaster conducted triennial monitoring at the 18 PBHSP monitoring wells as part of their basin-wide water quality monitoring to support various groundwater-management initiatives.

In July 2018, a pilot monitoring program was initiated at four monitoring wells at two locations along Chino Creek (PB-7 and PB-8) where the data loggers that measure groundwater levels at 15-minute intervals were replaced with data loggers with probes to measure and record electrical conductivity (EC), temperature, and water levels at a 15-minute frequency. Samples of groundwater were collected and analyzed quarterly (fiscal year 2019 and 2020) or semiannually (fiscal year 2021) for EC, temperature, and the parameters listed in Table 2-1. No groundwater quality samples were collected during fiscal year 2022. The same monitoring methods and protocols were performed at nearby surface-water sites in Chino Creek for comparison with the groundwater data. During this reporting period, Watermaster conducted the quarterly download of the data loggers at the four PBHSP monitoring wells and collected the last semi-annual samples of groundwater quality at these wells in March 2021.

**Table 2-1. Parameter List for the Groundwater and Surface Water Quality Monitoring Program**

| Chemical Parameter | Method Detection Limit | Method |
|---|---|---|
| Alkalinity in CaCO3 units | 2 mgl | SM2320B |
| Ammonia Nitrogen | 0.05 mgl | EPA 350.1 |
| Bicarbonate as HCO3 *Calculated* | 2 mgl | SM2320B |
| Calcium Total ICAP | 1 mgl | EPA 200.7 |
| Carbonate as CO3 *Calculated* | 2 mgl | SM2320B |
| Chloride | 1 mgl | EPA 300.0 |
| Hydroxide as OH *Calculated* | 2 mgl | SM2320B |
| Magnesium Total ICAP | 0.1 mgl | EPA 200.7 |
| Nitrate as Nitrogen by IC | 0.1 mgl | EPA 300.0 |
| Nitrate as NO3 *Calculated* | 0.44 mgl | EPA 300.0 |
| Nitrite as Nitrogen by IC | 0.05 mgl | EPA 300.0 |
| Nitrate plus Nitrite as Nitrogen *Calculated* | 0.1 mgl | EPA 300.0 |
| PH (H3=past HT not compliant) | 0.1 units | SM4500-HB |
| Potassium Total ICAP | 1 mgl | EPA 200.7 |
| Silica | 0.5 mgl | EPA 200.7 |
| Sodium Total ICAP | 1 mgl | EPA 200.7 |
| Specific Conductance, 25 C | 2 µmhos/cm | SM2510B |
| Sulfate | 0.5 mgl | EPA 300.0 |
| Total Dissolved Solids (TDS) | 10 mgl | E160.1/SM2540C |
| Total Hardness as CaCO3 by ICP *Calculated* | 3 mgl | SM 2340B |
| Total Organic Carbon | 0.3 mgl | SM5310C/E415.3 |
| Turbidity | 0.05 NTU | EPA 180.1 |

Notes:
mgl – milligrams per liter
NTU – nephelometric turbidity units
µmhos/cm – micromhos per centimeter

### *2.2.2 Surface-Water Monitoring Program*

Surface-water discharge in the Prado Basin is another factor that can influence the extent and quality of riparian habitat and can influence groundwater levels. Surface-water discharge data are evaluated for the PBHSP to characterize historical and current trends in the discharge of the SAR and its tributaries in the Prado Basin and to explore the relationship(s) to any observed changes that occurred in the extent and quality of the riparian habitat. Surface-water discharge data are also used as input to the Chino Basin groundwater-flow model to evaluate past and future conditions in the Chino Basin, which for the PBHSP, supports the analysis of prospective losses of riparian habitat (see Section 2.3). Surface-water quality is compared to groundwater-quality data to characterize groundwater/surface-water interactions in the Prado Basin and the importance of those interactions to the extent and quality of the riparian habitat.

The surface-water monitoring program (SWMP) for the PBHSP involves collecting existing, publicly available, surface-water discharge and quality data from sites within or tributary to the Prado Basin. Figure 2-3 shows the location of the surface-water monitoring sites used in the PBHSP. These sites include discharge locations for publicly owned treatment works (POTWs), USGS stream gaging stations, Watermaster and the IEUA Maximum-Benefit Monitoring Program surface-water-quality monitoring sites, ACOE's storage levels and inflow to Prado Dam, and the OCWD's discharge of untreated imported water from the OC-59 turnout tributary to Prado Basin. All surface-water discharge and quality data were collected for WY 2021, checked for QA/QC, and uploaded to Watermaster's relational database.

As noted in Section 2.2.1.3 above, a pilot monitoring program was initiated in July 2018 at two locations along Chino Creek near monitoring wells PB-7 and PB-8 to help characterize groundwater/surface-water interactions. Data loggers with probes were installed in Chino Creek adjacent to PB-7 and PB-8 to measure and record EC, temperature, and stage at a 15-minute frequency. Surface-water samples were collected and analyzed quarterly (fiscal year 2019 and 2020) or semiannually (fiscal year 2021) for EC, temperature, and the parameters listed in Table 2-1. During this reporting period, Watermaster conducted the quarterly download of the data loggers at the two PBHSP surface water sites in Chino Creek and collected the last semi-annual sample of surface water quality at these sites in March 2021.

### *2.2.3 Climatic Monitoring Program*

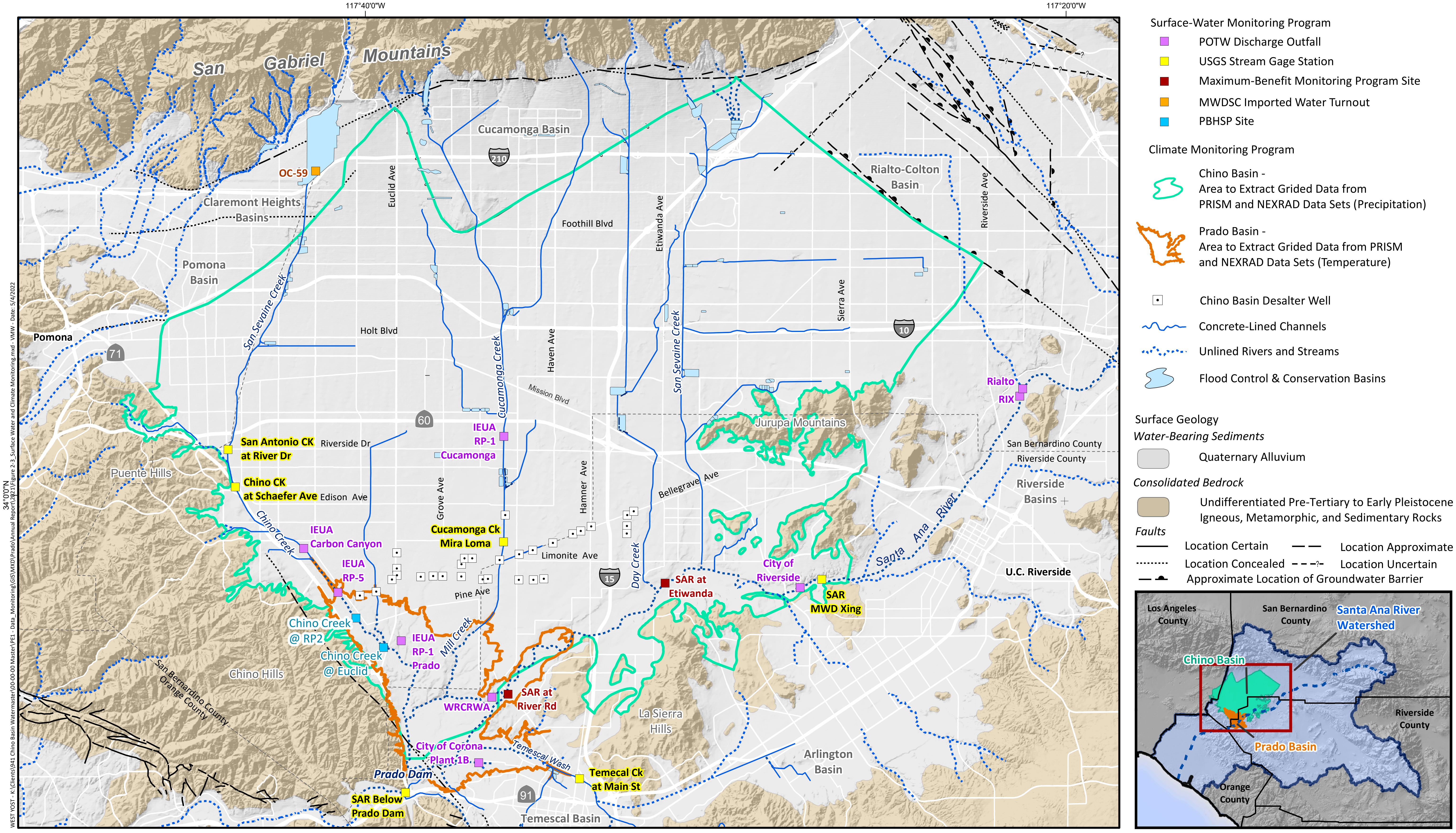
Climatic data are used to characterize how the climate has changed over time in the study area and to explore the relationship(s) to any observed changes that occurred in the extent and quality of the riparian habitat. Climatic data are also used for the Chino Basin groundwater-flow model to evaluate past and future conditions in the Chino Basin, which for the PBHSP, supports the analysis of prospective losses of riparian habitat (see Section 2.3).

The climatic monitoring program for the PBHSP involves collecting existing, publicly available spatially gridded climate datasets for precipitation and temperature in the vicinity of the Prado Basin. These climate datasets include Next-Generation Radar (NEXRAD) and the PRISM Climate Group. Figure 2-3 shows the location of the areas where the grided climate data is extracted from PRISM and NEXRAD to estimate a spatial average precipitation and temperature for the PBHSP analysis. The Chino Basin boundary is used to extract the spatially gridded data for precipitation, and the Prado Basin boundary is used to extract the spatially gridded data for maximum and minimum temperature. Climatic data are collected annually and uploaded to Watermaster's relational database.

### *2.2.4 Other Factors That Can Affect Riparian Habitat*

The AMP recognizes that there are potential factors other than groundwater, surface water, and climate that can affect riparian habitat in the Prado Basin. These factors include, but are not limited to: wildfire, disease, pests, and invasive species. To the extent necessary, data and information on these factors are collected and analyzed to explore for relationships to changes in the extent and quality of the riparian habitat.

In WY 2016, during the analysis for the first Annual Report, two specific factors were identified as potential impacts to the Prado Basin riparian habitat: wildfires and an invasive pest known as the Polyphagous Shot-Hole Borer (*Euwallacea fornicates*; PSHB hereafter). In WY 2018, the removal of the non-native invasive weed *Arundo donax* (Arundo) was identified as another factor to impact riparian habitat in the Prado Basin. The following describes the information that was collected for these three factors and how they are used to explore for relationships to changes that have occurred in the extent and quality of riparian habitat.



WEST YOST - K:\Clients\941 Chino Basin Watermaster\00-00-00 Master\PE1 - Data_Monitoring\GIS\MXD\Prado\Annual Report\2021\Figure 2-3_Surface Water and Climate Monitoring.mxd - VWW - Date: 5/4/2022

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**Surface Water and Climate**
*Monitoring Programs*

**Figure 2-3**

### 2.2.4.1 Wildfires

Wildfires occur periodically in the Prado Basin and can reduce the extent and quality of riparian habitat. For the PBHSP, the occurrence and locations of wildfires are used to help understand and explain the trends observed in the extent and quality of the riparian vegetation.

To map the extent of any wildfires that have occurred in the study area, fire-perimeter data were collected from the Fire and Resource Assessment Program (FRAP) of the California Department of Forestry and Fire Protection (CAL FIRE).[4]

For the current reporting period, wildfire data were obtained from the FRAP database for the Prado Basin region for calendar year 2020.[5]

### 2.2.4.2 Polyphagous Shot-Hole Borer (PSHB)

The PSHB is a beetle that burrows into trees, introducing a fungus (*Fusarium euwallacea*) into the tree bark that spreads the disease Fusarium Dieback (FD).[6,7] FD destroys the food and water conducting systems of the tree, eventually causing stress and tree mortality. The PSHB was first discovered in Southern California in 2003 and has been recorded to have caused branch die-back and tree mortality for various tree specimens throughout the Southern California region (USDA, 2013). Since 2016, the PSHB is an identified pest within the Prado Basin that has the potential to negatively impact riparian habitat vegetation (USBR, 2016; Palenscar, K., personal communication, 2016; McPherson, D., personal communication, 2016).

Information on PSHB occurrence in the Prado Basin has been obtained during the USBR vegetation surveys of riparian habitat in the Prado Basin for the PBHSP during 2016 and 2019, and also from the University of California, United States Department of Agriculture (USDA) and Natural Resources' online PSHB/FD Distribution Map[8], and the OCWD's PSHB trap deployment and monitoring. For the PBHSP, the occurrences of the PSHB in the Prado Basin are used to help understand and explain the trends observed in the extent and quality of the riparian vegetation. There was no new information on the PSHB occurrence in the Prado Basin collected for the current reporting period.

### 2.2.4.3 Arundo Removal

Non-native Arundo is prominent throughout riparian habitat in the Prado Basin. Arundo consumes significantly more water than native plants, can out-compete native vegetation, and is flammable in nature increasing the risk of wildfire. There are several SAR watershed stakeholders that remove Arundo in the riparian habitat to restore native habitat to aid in the recovery of the threated and endangered species, such as the Least Bell's Vireo and Santa Ana Sucker. For the PBHSP, the occurrence and locations of habitat restoration activities that include the removal of Arundo can help understand and explain trends in the extent and quality of the riparian habitat. The OCWD and Santa Ana Watershed Association (SAWA) in

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[4] Frap.fire.ca.gov

[5] Data for the previous year is available each year in April.

[6] UCANR.edu

[7] Cisr.Ucr.Edu

[8] Ucanr.edu

coordination with others, are the main entities in the watershed that implement habitat restoration programs that include removing Arundo.

In WY 2021, information on Arundo removal and management activities that have occurred recently in the Prado Basin were obtained to track these programs and explore if there is a connection between these activities and trends observed in the extent and quality of riparian habitat. This effort involved coordinating with the OCWD and SAWA to obtain information on the location and timing of these programs.

## 2.3 Prospective Loss of Riparian Habitat

Monitoring and mitigation requirement 4.4-3 in the Peace II SEIR calls for annual reporting for the PBHSP, that will include recommendations for ongoing monitoring and any adaptive management actions required to mitigate any measured loss or **prospective loss** of riparian habitat that may be attributable to the Peace II Agreement (emphasis added). The meaning of “prospective loss” in this context is “future potential losses” of riparian habitat. Predictive modeling of groundwater levels can be used to answer question 8 from the AMP:

- Are there areas of prospective loss of riparian habitat that may be attributable to the Peace II Agreement?

Watermaster’s most recent groundwater-modeling results can be used to evaluate forecasted groundwater-level changes within the Prado Basin under current and projected future conditions in the Basin, including, but not limited to, plans for pumping, storm-water recharge, and supplemental water recharge. To perform this evaluation, the predictive model results are mapped and analyzed to identify areas (if any) where groundwater levels are projected to decline to depths that may negatively impact riparian habitat in the Prado Basin.

For this Annual Report, Watermaster’s most recent groundwater model projections were used to characterize future groundwater-level conditions in the PBHSP study area. This model projection was the simulation of planning scenario “2020 SYR1” for the 2020 recalculation of Safe Yield using the updated Chino Basin groundwater-flow model (WEI, 2020)

# 3.0 RESULTS AND INTERPRETATIONS

## 3.1 Trends in Riparian Habitat Extent and Quality

This section describes the analysis and interpretation of the monitoring data and groundwater-modeling results for the PBHSP. Analyzed data span various historical periods, based on data availability, and include both pre- and post-Peace II implementation (2007).

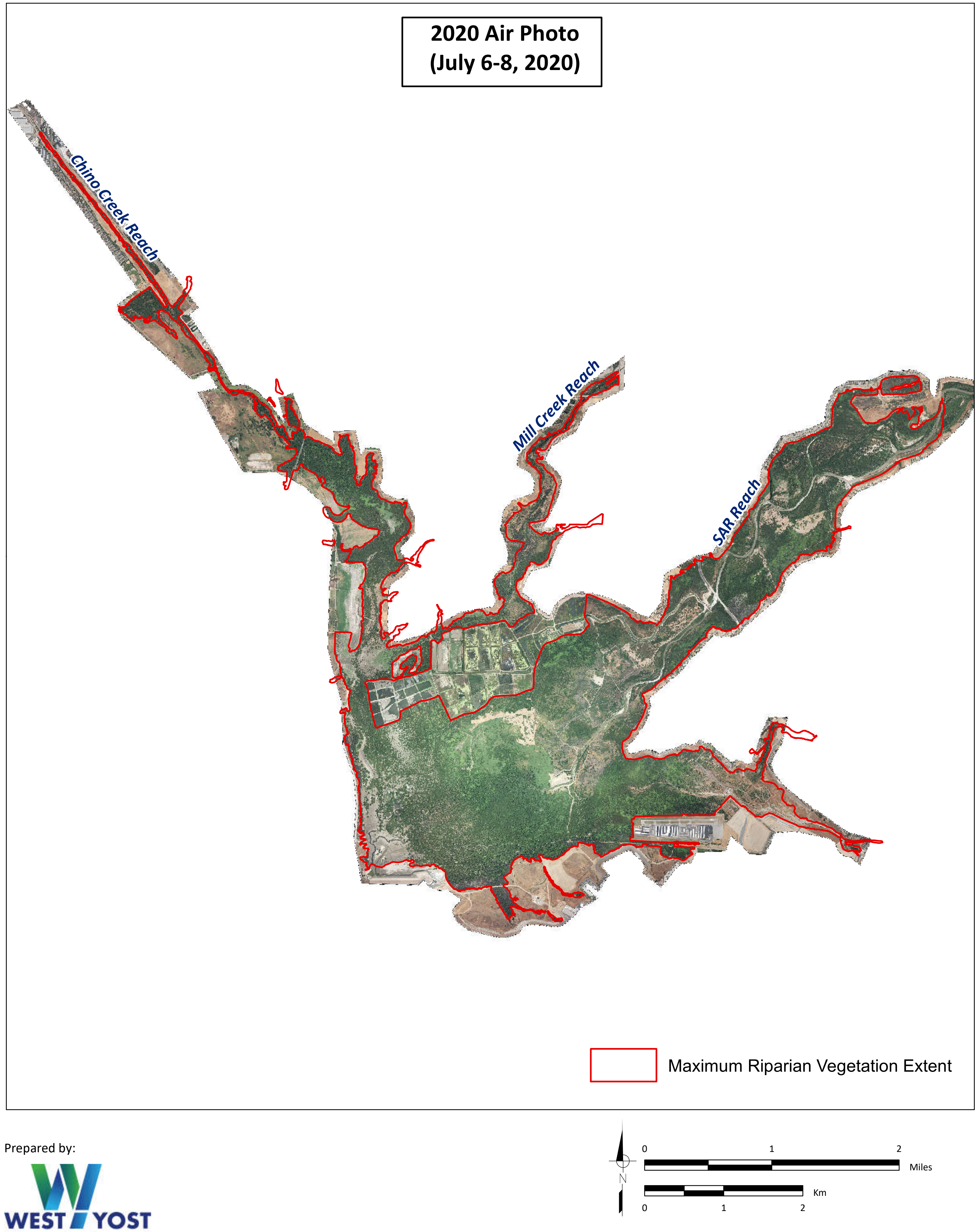
More specifically, this section describes the trends in the extent and quality of the riparian habitat, describes the trends in factors that can impact the riparian habitat, and evaluates potential cause-and-effect relationships—particularly any cause-and-effect relationships that may be associated with Peace II implementation. The factors that can potentially impact the extent and quality of the riparian habitat include changes in groundwater levels, surface-water discharge, climate, and other factors, such as pests, wildfires, and habitat management activities. Declining groundwater levels is the primary factor that is potentially related to Peace II implementation and could adversely impact the riparian habitat.

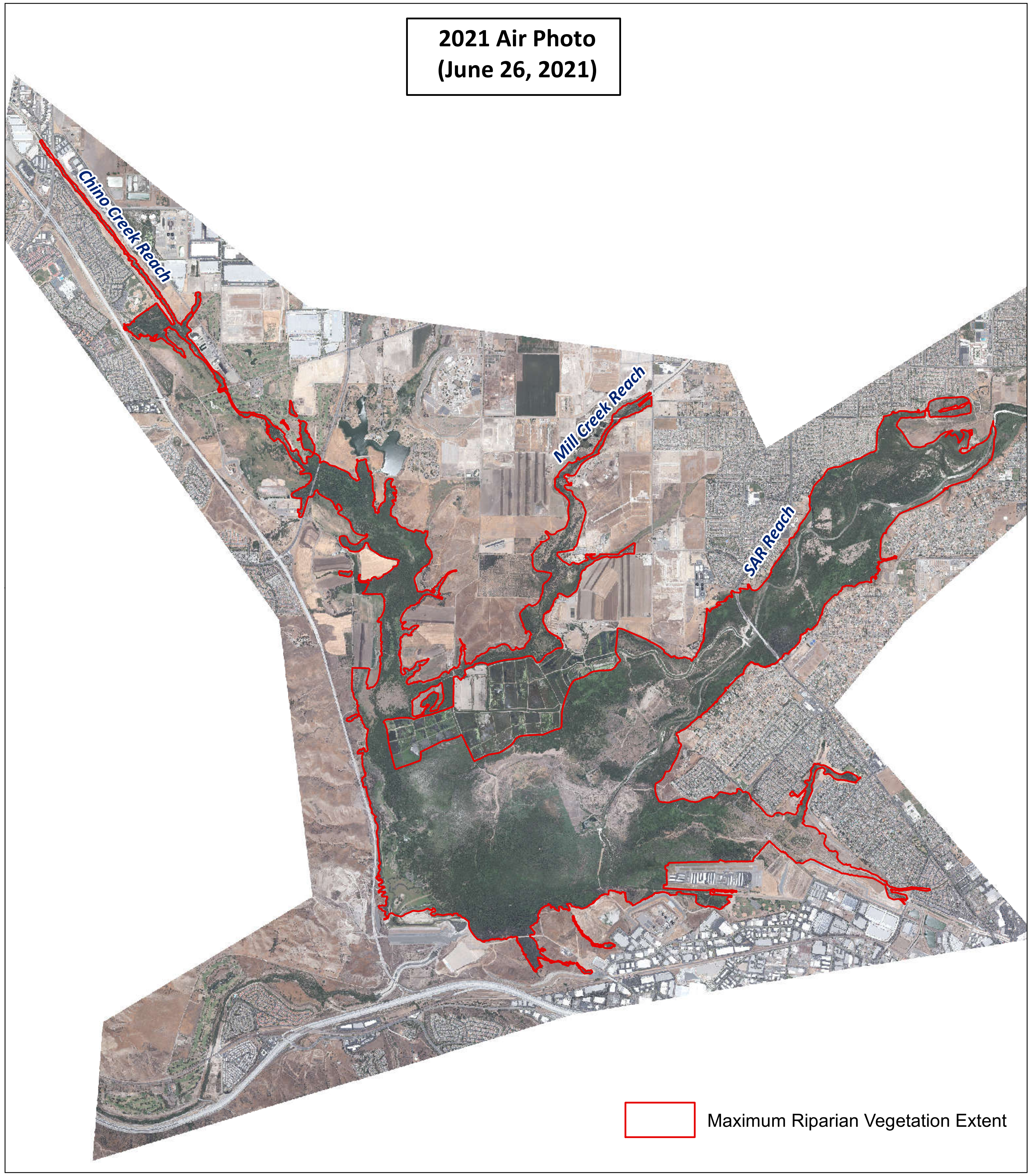
This section also includes a review of Watermaster's most recent predictive Chino Basin groundwater modeling results to identify areas of potential future declines in groundwater levels that could impact the riparian habitat.

### *3.1.1 Extent of the Riparian Habitat*

Previous annual reports include an analysis of the riparian vegetation using historical air photos to map the density and extent of the vegetation in the Prado Basin (WEI, 2017; 2018; 2019; 2020). In general, these analyses concluded that from 1960 to 1999 the mapped extent of the riparian habitat increased from about 1.8 to 6.7 square miles ($mi^2$) and its vegetated density increased. Since 1999, the extent and vegetated density of the riparian habitat has remained relatively constant.

Figure 3-1a compares air photos that were acquired for the PBHSP in July 2020 and June 2021. Both air photos are high resolution (3-inch pixels) which allow for a side-by-side visual comparison of riparian vegetation extent and quality in July 2020 and June 2021. There are no significant differences in these air photos that justify an adjustment to the mapped extent of the riparian habitat.





WEST YOST - K:\Clients\941 Chino Basin Watermaster\00-00-00 Master\PE1 - Data_Monitoring\GIS\MXD\Prado\Annual Report\2021\Figure 3-1a_2020_2021 AirPhoto.mxd - LH - Date: 5/4/2022

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**Air Photos and Extent of the Riparian Vegetation**
*2020 and 2021*

**Figure 3-1a**

Figure 3-1b compares the 2021 air photo and the mapped extent of the riparian habitat to the NDVI estimates for the Prado Basin area on a date that corresponds to the maximum of the spatial average of NDVI during the growing season for 2021.[9] Generally, the following ranges in NDVI during the growing season correspond to these land cover types:

- < 0: Water
- 0 - 0.2: Non-vegetated surfaces, such as urbanized land cover and barren land
- 0.3 - 1.0: Vegetated land cover: higher NDVI values indicate greater photosynthetic activity

Three main observations and interpretations are derived from this figure:

- Prado Basin riparian vegetation areas have NDVI estimates of about 0.3 to 0.9 during the growing season. Active agricultural lands in the Prado Basin region can also have NDVI values of a similar range during the growing season.
- The NDVI estimates support the delineation of the extent of the riparian habitat as drawn from the air photos.
- The consistency of NDVI values to land cover observed in the air photo indicates that the processing of NDVI estimates for this study were performed accurately, which supports subsequent analyses and interpretations.

### *3.1.2 Quality of the Riparian Habitat*

As discussed, and referenced in Section 2.0, NDVI is an indicator of the photosynthetic activity of vegetation and therefore can be used to interpret the health or "quality" of the riparian vegetation. In this section, NDVI is spatially and temporally analyzed in maps and time-series charts for defined areas throughout Prado Basin to characterize changes in the quality of riparian habitat over the period 1984 to 2021.

#### 3.1.2.1 Spatial Analysis of NDVI

Figure 3-2 compares maps of NDVI across the entire Prado Basin area for 2020 and 2021 on the dates that correspond to the maximum growing-season NDVI as a spatial average across the entire extent of the riparian vegetation. Figure 3-3 is a map of change in NDVI from 2020 to 2021 that was prepared by subtracting the 2020 NDVI map from the 2021 NDVI map on Figure 3-2. These figures identify areas that may have experienced a change in the quality of riparian habitat from 2020 to 2021:

- About half of the riparian vegetation extent area showed no change in NDVI from 2020 to 2021.
- NDVI decreased in small patches along Mill Creek.
- NDVI decreased in large patches along the SAR and below the OCWD wetlands. Inspection of the air photos in Figure 3-1a corroborates these observations, showing a decrease in green land cover in these same areas from 2020 to 2021.

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[9] The growing season for the Prado Basin riparian vegetation is from March through October (Merkel, 2007; USBR, 2008). The maximum NDVI for the 2019 growing season occurred on July 10, 2019.

- NDVI decreased in the southern portion of Chino Creek above and below the OCWD wetlands Inspection of the air photos in Figure 3-1a corroborates these observations, showing a decrease in green land cover in these same areas from 2020 to 2021.
- NDVI increased in the small and large patches along the SAR.

These spatial changes in NDVI will be analyzed along with the factors that can impact riparian habitat in Sections 3.2 through 3.6 of this report.

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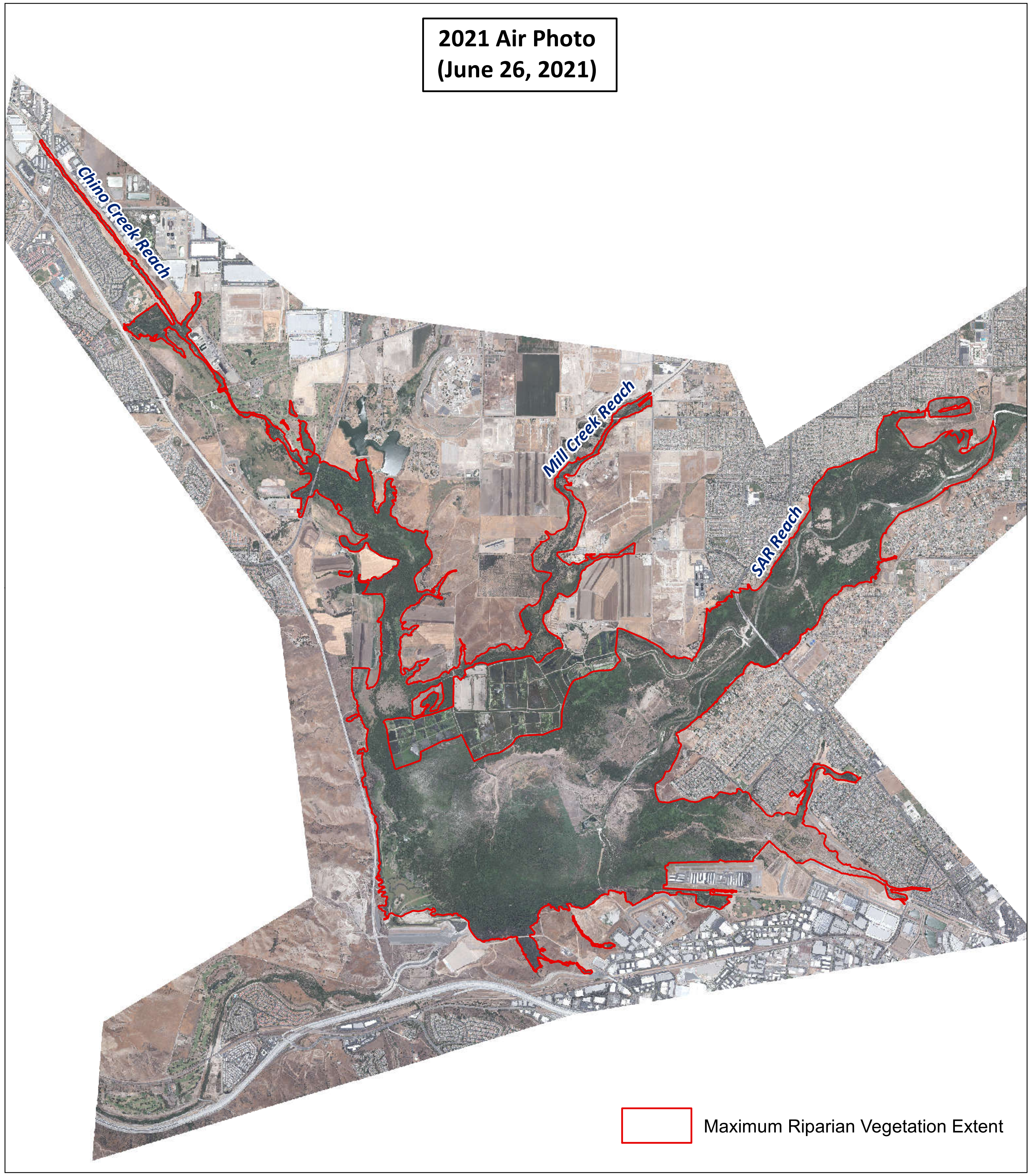

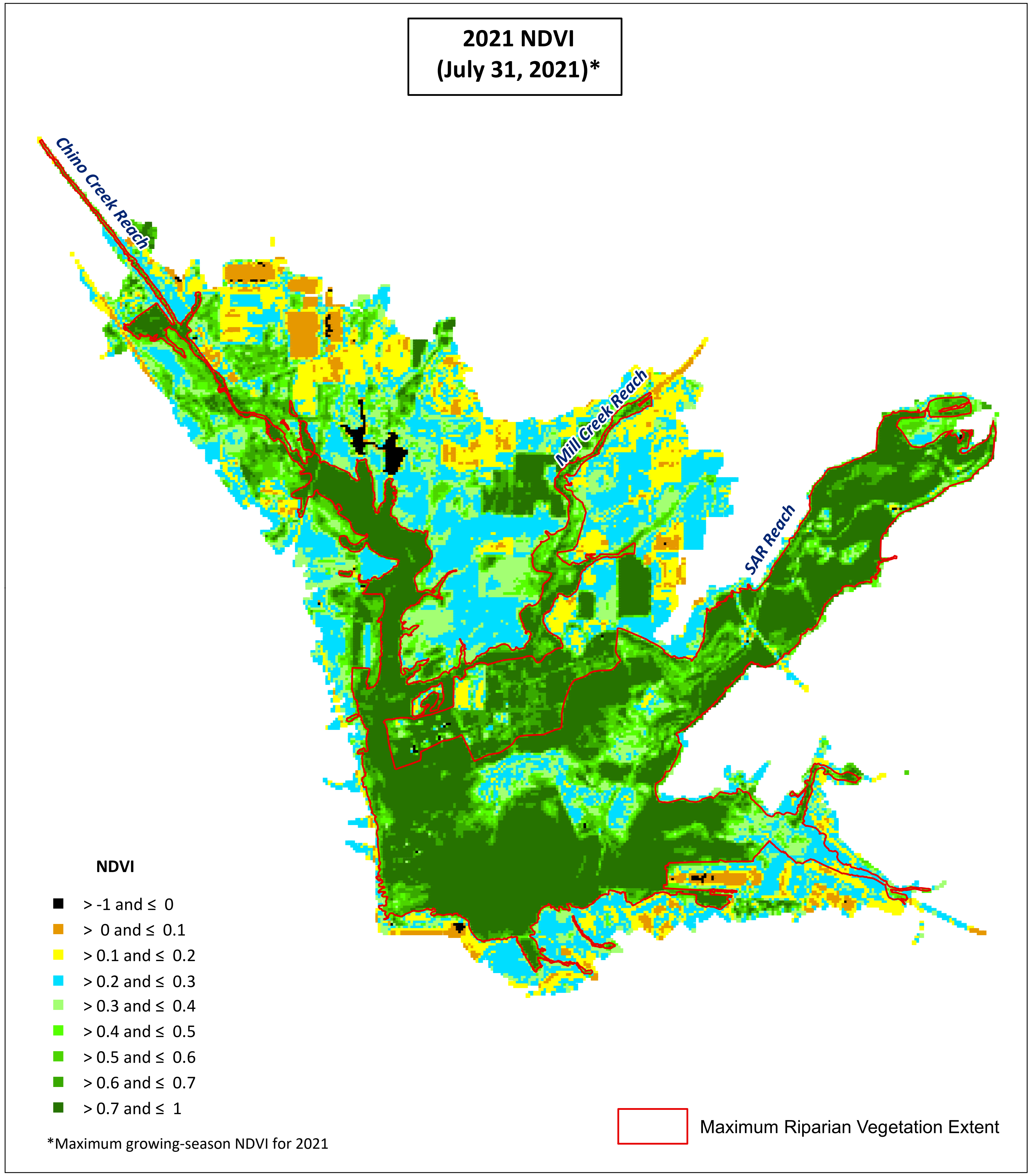

*Maximum growing-season NDVI for 2021

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**Air Photo and Spatial NDVI for the Prado Basin**
*2021*

**Figure 3-1b**

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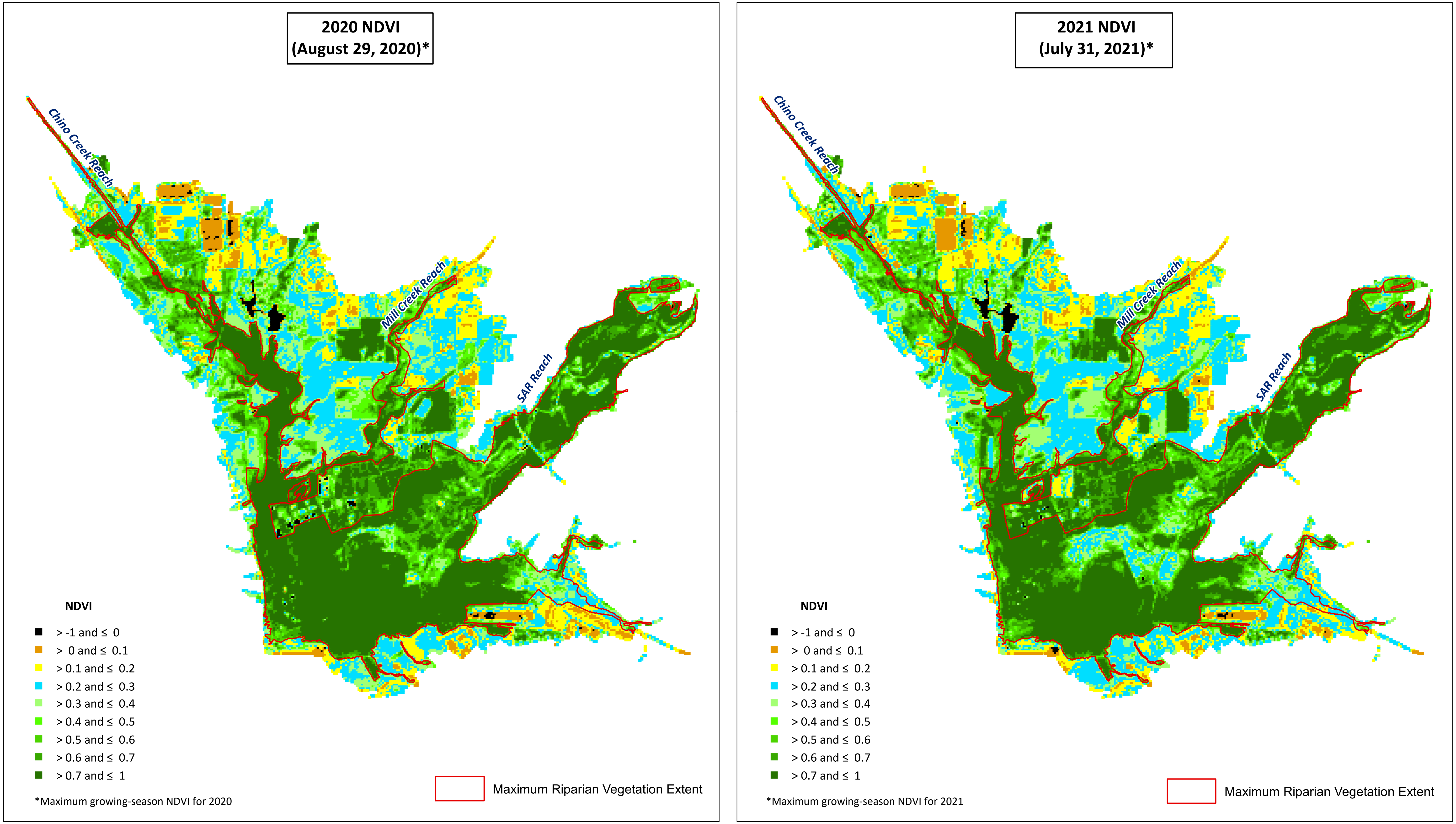

**2020 NDVI (August 29, 2020)***

**2021 NDVI (July 31, 2021)***

*Maximum growing-season NDVI for 2020

*Maximum growing-season NDVI for 2021

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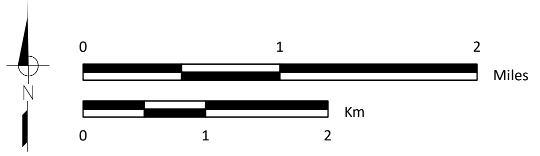

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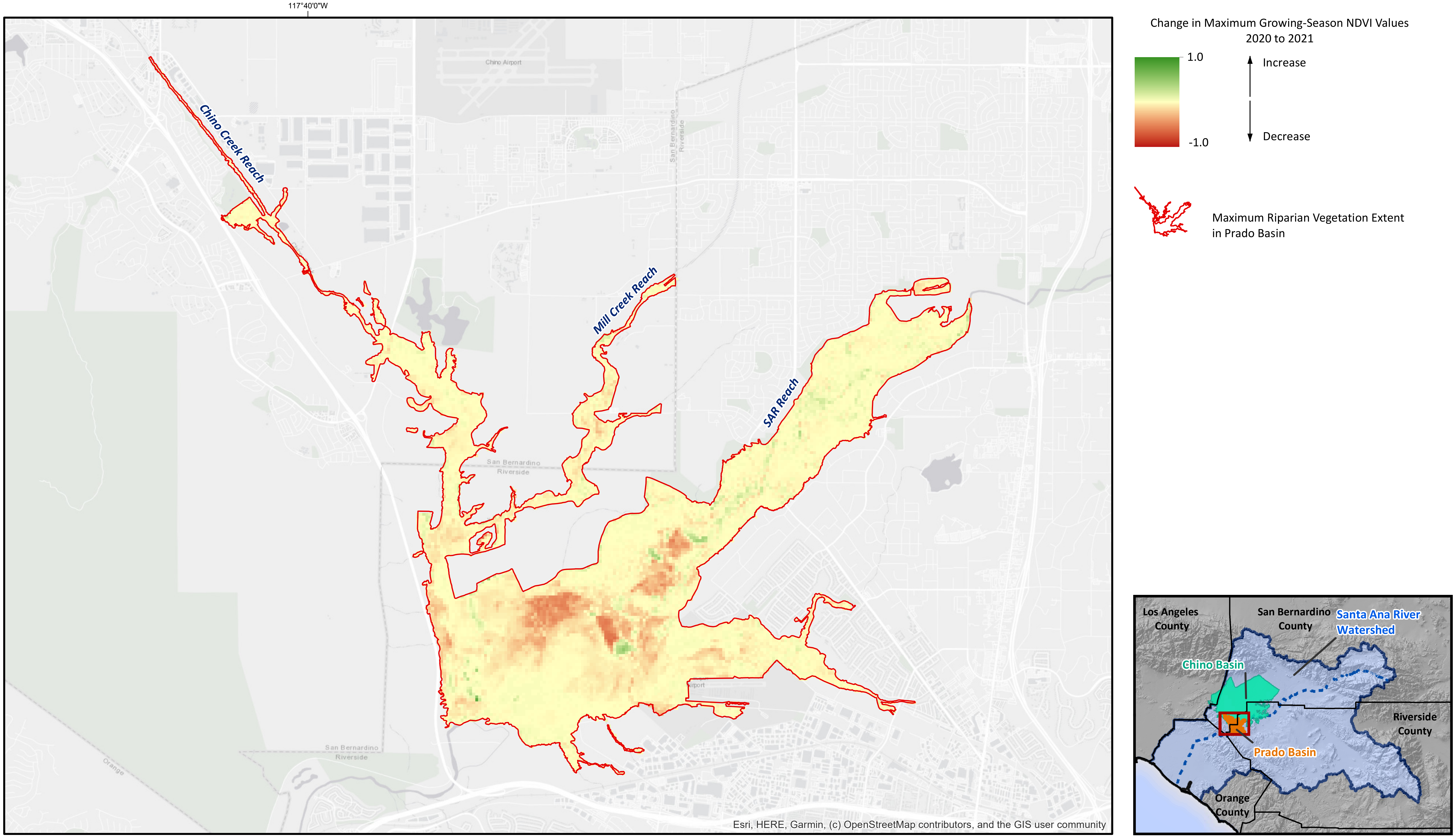
**Spatial NDVI for the Prado Basin**
*2020 and 2021*

**Figure 3-2**



WEST YOST - K:\Clients\941 Chino Basin Watermaster\00-00-00 Master\PE1 - Data_Monitoring\GIS\MXD\Prado\Annual Report\2021\Figure 3-3_Change NDVI_2020-2021.mxd - EM and LH - Date: 5/4/2022

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**Spatial Change in NDVI for the Prado Basin**
*2020 and 2021*

**Figure 3-3**

### 3.1.2.2 Temporal Analysis of NDVI

NDVI pixels[10] within defined areas throughout the Prado Basin were spatially averaged and temporally analyzed in time-series charts. The defined areas include large and small areas within Prado Basin and are shown in Figure 3-4. The large areas include the entire extent of the riparian habitat (6.8 mi$^2$ –- 19,520 NDVI pixels), the extent of the riparian habitat along the upper portion of Chino Creek (0.74 mi$^2$ – 2,134 NDVI pixels), and the extent of the riparian habitat along Mill Creek (0.26 mi$^2$ –- 759 NDVI pixels). The small areas are located along the northern reaches of the Prado Basin riparian habitat near the PBHSP monitoring wells and a location of a USBR vegetation survey site (10-meter radius plot). All the small areas are one NDVI pixel (30 x 30-meter pixel – 900 square meters).[11]

Figures 3-5, 3-6, 3-7, and 3-8a through 3-8l are time-series charts of the NDVI for each of the defined areas that indicate changes in the quality of riparian habitat over time. These figures are used to characterize long- and short-term changes in NDVI in specific areas, which provide context for interpreting the trends and changes in NDVI that have been occurring during Peace II implementation. Each figure shows three datasets that illustrate trends in the NDVI estimates:

- **Spatial Average NDVI** (green dots). Spatial Average NDVI are the spatial average of the NDVI pixels within the defined area. These data characterize the seasonal and long-term trends in NDVI for each defined area. The NDVI exhibit an oscillatory pattern caused by seasonal changes in the riparian habitat. The NDVI time-series are typical for a deciduous forest, where NDVI values are higher in the growing season from March through October and lower in the dormant season from November through February when plants and trees shed their leaves.
- **Average Growing-Season NDVI (black squares and black curve).** The Average Growing-Season NDVI is the annual average of the Spatial Average NDVI for each growing season from March through October. This curve shows the annual changes and long-term trends in the NDVI for the growing season. This metric is used to analyze year-to-year changes and long-term trends in NDVI.
- **Maximum Growing-Season NDVI (red squares and red curve).** The Maximum Growing-Season NDVI is the annual maximum of the Spatial Average NDVI for each growing season from March through October. Maximum Growing-Season NDVI typically occurs during summer months. This curve shows the annual changes and long-term trends in the maximum NDVI.

NDVI maps or air photos are included on the time-series charts for spatial reference and as a visual check on the interpretations derived from the time-series charts. These air photos are for 2018, 2019, 2020, and 2021— showing the last four years using the high-resolution air photos collected for the PBHSP.

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[10] Each NDVI pixel is 30 x 30 meters.

[11] In previous annual reports these small areas were four NDVI pixels in this same general area. During WY 2020, these areas were modified to one NDVI pixel that aligned with the USBR vegetation survey to that the field vegetation survey data can better correlate with the NDVI time-series data.

- To statistically characterize long-term trends in NDVI, the Mann-Kendall statistical trend test (Mann-Kendall test) was performed on the Average Growing-Season NDVI for all defined areas over the following three periods:
- 1984 to 2021: the entire period of record
- 1984 to 2006: period prior to Peace II Agreement implementation
- 2007 to 2021: period subsequent to Peace II Agreement implementation

The Mann-Kendall test utilizes a ranking formula to statistically analyze if there is an increasing trend, decreasing trend, or no trend in the NDVI time-series. Appendix B describes the Mann-Kendall test methods and results. The final Mann-Kendall test results for the Average Growing-Season NDVI are shown on each time-series chart and are summarized in Table 3-1.

**Table 3-1. Mann-Kendall Test Results of the Average-Growing Season NDVI Trends for Defined Areas in the Prado Basin**

| Defined Area | Figure Number | Mann Kendal Test Result[(a)] Period of Record 1984 - 2021 | Prior to Peace II 1984 - 2006 | Post Peace II 2007 - 2021 |
|---|---|---|---|---|
| Riparian Vegetation Extent | 3-5 | No Trend | No Trend | No Trend |
| Chino Creek Area | 3-6 | Increasing | Increasing | No Trend |
| Mill Creek Area | 3-7 | No Trend | Decreasing | No Trend |
| CC-1 | 3-8a | Increasing | No Trend | No Trend |
| CC-2 | 3-8b | Increasing | Increasing | Increasing |
| CC-3 | 3-8c | Increasing | Increasing | Increasing |
| CC-4 | 3-8d | Increasing | No Trend | Increasing |
| MC-1 | 3-8e | Increasing | No Trend | Increasing |
| MC-2 | 3-8f | No Trend | No Trend | Increasing |
| MC-3 | 3-8g | No Trend | No Trend | Increasing |
| MC-4 | 3-8h | Increasing | No Trend | No Trend |
| SAR-1 | 3-8i | No Trend | No Trend | Increasing |
| SAR-2 | 3-8j | No Trend | Decreasing | Increasing |
| SAR-3 | 3-8k | Increasing | No Trend | Increasing |
| LP | 3-8l | Increasing | No Trend | No Trend |

(a) See Appendix B for a description of the Mann-Kendall statistical trend test and results.

To characterize the short-term trends in NDVI, Table 3-2 summarizes the one-year change in the Average Growing-Season NDVI from 2020 to 2021 at the 15 defined areas and compares to the changes and variability in Average Growing-Season NDVI over the historical period of 1984 to 2021 at each area. During WY 2021, there were decreasing trends in the NDVI from 2020 to 2021 at most of the areas: 12 areas decreased; two areas showed no trend; and one area increased. These one-year changes in the Average

Growing-Season NDVI are within the range of long-term annual variability of the NDVI at each area, except for the LP area in the lower portion of Prado Basin.

**Table 3-2. Characterization of Variability in the Average-Growing Season NDVI for Defined Areas in the Prado Basin**

| Defined Area | Figure Number | Historical NDVI Statistics 1984 - 2020 | | One-Year Change in NDVI1 from 2020-2021 |
|---|---|---|---|---|
| | | Average Annual Change in NDVI (Absolute Value) | Maximum One-Year Change in NDVI (Absolute Value) | |
| Riparian Vegetation Extent | 3-5 | 0.03 | 0.10 | -0.04 |
| Chino Creek Area | 3-6 | 0.02 | 0.09 | -0.01 |
| Mill Creek Area | 3-7 | 0.07 | 0.57 | -0.05 |
| CC-1 | 3-8a | 0.03 | 0.11 | 0.01 |
| CC-2 | 3-8b | 0.03 | 0.13 | -0.03 |
| CC-3 | 3-8c | 0.03 | 0.13 | -0.04 |
| CC-4 | 3-8d | 0.03 | 0.12 | -0.04 |
| MC-1 | 3-8e | 0.04 | 0.31 | -0.02 |
| MC-2 | 3-8f | 0.05 | 0.14 | -0.09 |
| MC-3 | 3-8g | 0.03 | 0.12 | 0.00 |
| MC-4 | 3-8h | 0.03 | 0.13 | 0.00 |
| SAR-1 | 3-8i | 0.06 | 0.44 | -0.13 |
| SAR-2 | 3-8j | 0.04 | 0.21 | -0.05 |
| SAR-3 | 3-8k | 0.03 | 0.10 | -0.03 |
| LP | 3-8l | 0.03 | 0.10 | -0.32 |

### 3.1.2.3 Temporal Analysis of NDVI in Prado Basin

Figure 3-5 is a time-series chart from 1984 to 2021 of the spatial average of all 19,520 NDVI pixels that are within the maximum delineated extent of the riparian habitat in the Prado Basin.[12] The intent of the time series is to characterize the trends in NDVI for the Prado Basin as a whole, which is used as a basis of comparison to the trends in the NDVI for each of the smaller defined areas shown in subsequent figures. Figure 3-5 also includes NDVI maps from, 2018, 2019, 2020, and 2021 to visually compare to the NDVI time-series.

Figure 3-5 and Tables 3-1 and 3-2 show that the Average Growing-Season NDVI varies from year-to-year by no more than 0.10 with no apparent long-term trends. The Mann-Kendall test result on the Average

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[12] The extent of the riparian habitat in the Prado Basin has been relatively stable since 1999, and has been verified by inspection of the 2017, 2018, 2019, and 2020 high-resolution air photos.

Growing-Season NDVI indicates "no trend" over the 1984 to 2021 period, "no trend" over the 1984 to 2006 period, and "no trend" over the 2007 to 2021 period.

From 2020 to 2021, the Average Growing-Season NDVI decreased by 0.04. This recent one-year decrease in Average Growing-Season NDVI is within the historical range of the annual Average Growing-Season NDVI variability for the extent of the riparian vegetation.

This time-series analysis of NDVI suggests that the riparian habitat in Prado Basin, analyzed as a whole, has not experienced statistically significant declines in NDVI in the recent water year, nor during the post-Peace II Agreement period from 2007 to 2021.

### 3.1.2.4 Temporal Analysis of NDVI within Large Areas along Chino Creek and Mill Creek

Figure 3-6 and Figure 3-7 are time-series charts from 1984-2021 of the spatial average for NDVI pixels within large areas of riparian habitat located along the reaches of Chino Creek and Mill Creek, respectively. These charts characterize trends and changes in NDVI for these northern reaches of the riparian habitat in the Prado Basin and provide a basis for comparison to the NDVI trends and changes for each of the smaller defined areas. These figures include a series of air photos for spatial reference and as a visual check on the interpretations derived from the NDVI time-series charts. The air photos are for 2018, 2019, 2020, and 2021—showing the last four years using the high-resolution air photos collected for the PBHSP.

***Chino Creek***

Figure 3-6 is an NDVI time-series chart for 1984-2021 of the spatial average of all 2,134 NDVI pixels along the northern reach of Chino Creek in the Prado Basin. This reach of Chino Creek is susceptible to impacts from declining groundwater levels associated with Peace II implementation.

Figure 3-6 and Tables 3-1 and 3-2 show that over the period of record, the Average Growing-Season NDVI varied from year-to-year by no more than 0.09 with no long-term declining trends. The Mann-Kendall test result on the Average Growing-Season NDVI indicates an "increasing trend" over the 1984 to 2021 period, an "increasing trend" over the 1984 to 2006 period, and "no trend" over the 2007 to 2021 period.

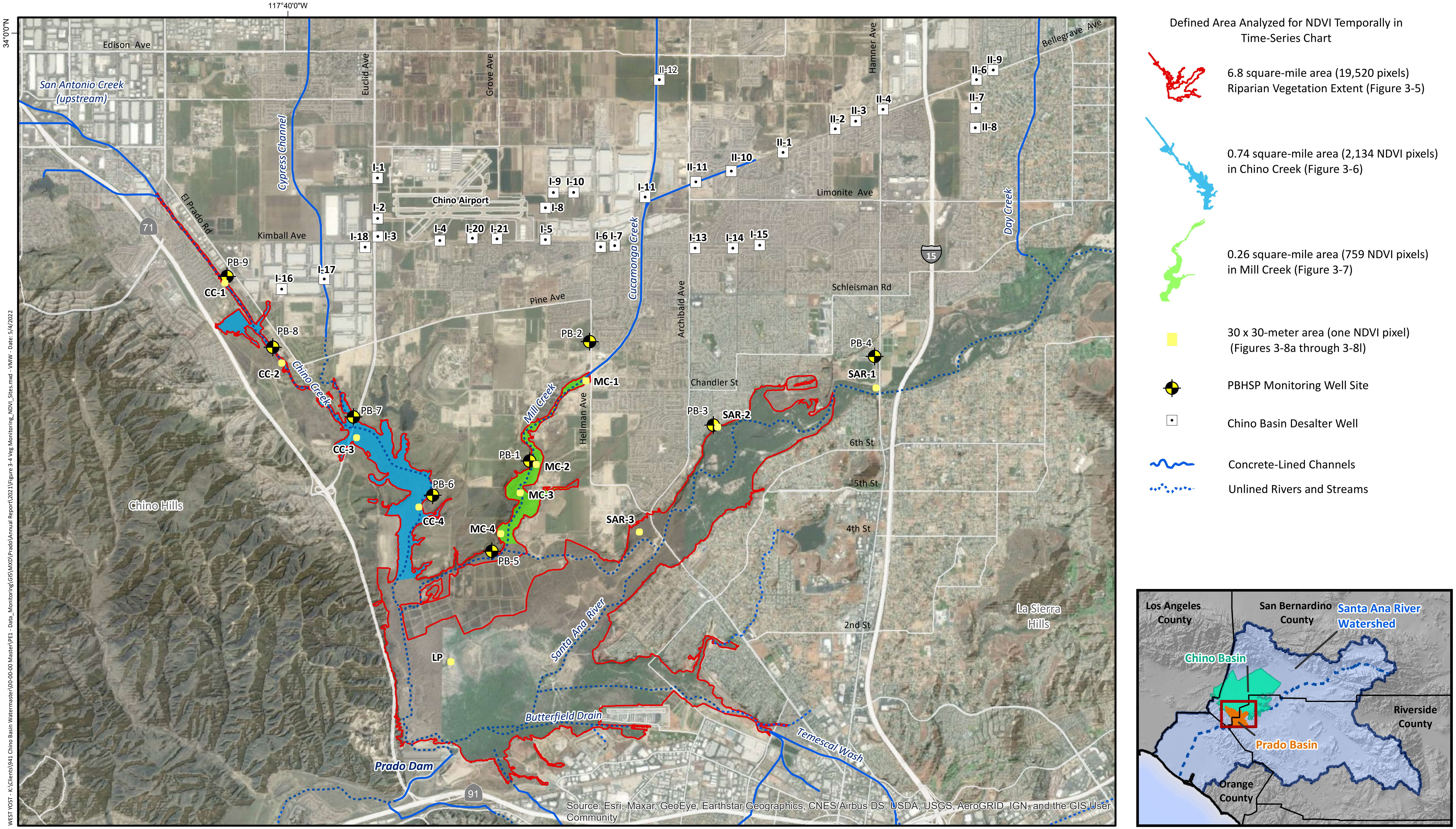
From 2020 to 2021, the Average Growing-Season NDVI decreased by 0.01, which is within the historical range of variability for the annual Average Growing-Season NDVI. Visual inspection of the 2020 and 2021 air photos show a slight decrease in greenness along the southern portion of Chino Creek.

***Mill Creek***

Figure 3-7 is a NDVI time-series chart for 1984-2021 of the spatial average of all 759 NDVI pixels along the northern reach of Mill Creek in the Prado Basin. This reach of Mill Creek is susceptible to impacts from declining groundwater levels associated with Peace II implementation.

Figure 3-7 and Tables 3-1 and 3-2 show that over the period of record, the Average Growing-Season NDVI varied from year-to-year by no more than 0.57. The Mann-Kendall test result on the Average Growing-Season NDVI indicates "no trend" over the 1984 to 2021 period, "decreasing trend" over the 1984 to 2006 period, and "no trend" over the 2007 to 2021 period.

From 2020 to 2021, the Average Growing-Season NDVI decreased by 0.05, which is within the historical range of variability for the annual Average Growing-Season NDVI. Visual inspection of the 2020 and 2021 air photos show a slight decrease in greenness within the central portion of Mill Creek.



Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

WEST YOST - K:\Clients\941 Chino Basin Watermaster\00-00-00 Master\PE1 - Data_Monitoring\GIS\MXD\Prado\Annual Report\2021\Figure 3-4 Veg Monitoring_NDVI_Sites.mxd - VMW - Date: 5/4/2022

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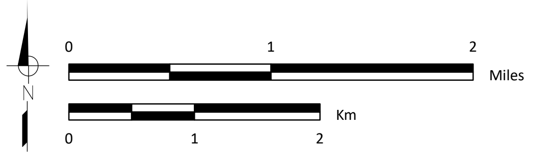

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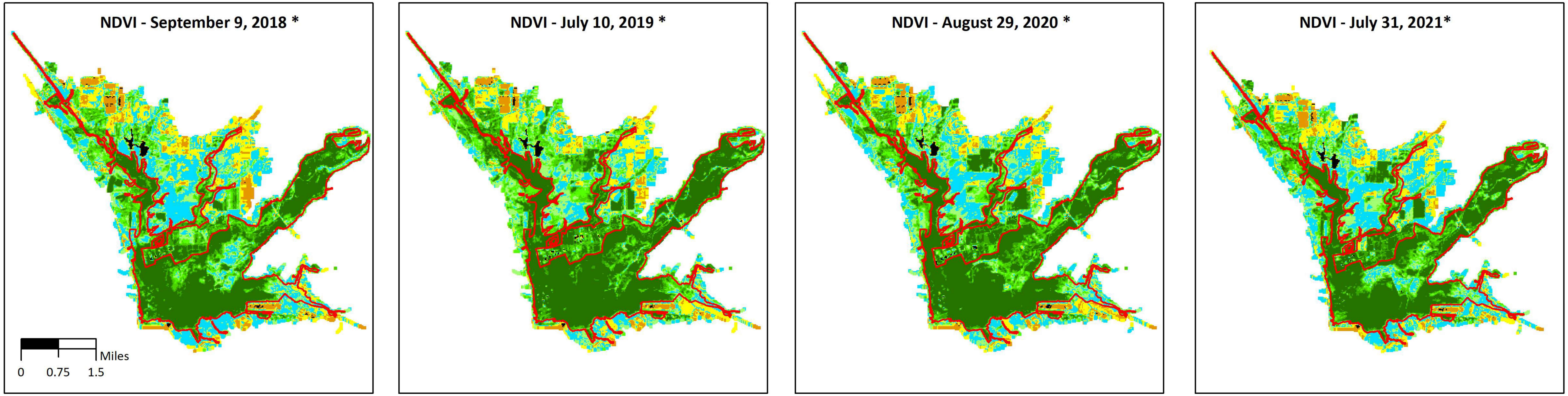
**Inland Empire Utilities Agency**
2021 Annual Report of the
Prado Basin Habitat Sustainability Committee

## Areas for Analysis of NDVI Time Series

**Figure 3-4**

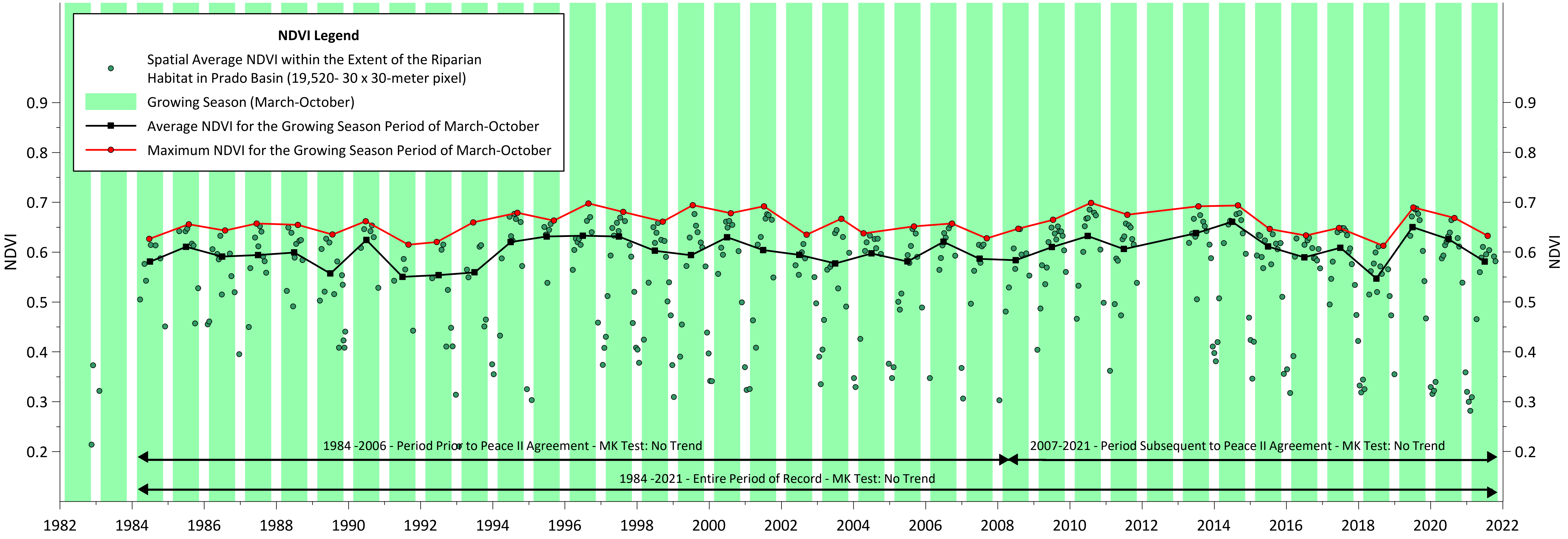


* Maximum Growing-Season NDVI

**Map Legend:**

NDVI

- ■ > -1 and ≤ 0
- 🟧 > 0 and ≤ 0.1
- 🟨 > 0.1 and ≤ 0.2
- 🟦 > 0.2 and ≤ 0.3
- 🟩 > 0.3 and ≤ 0.4
- 🟩 > 0.4 and ≤ 0.5
- 🟩 > 0.5 and ≤ 0.6
- 🟩 > 0.6 and ≤ 0.7
- 🟩 > 0.7 and ≤ 1
- □ Maximum Riparian Vegetation Extent



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WEST YOST - K:\Clients\941 Chino Basin Watermaster\00-00-00 Master\PE1 - Data_Monitoring\GRAPHER\GRF\Prado\AnnualR\Figure 3-5_NDVI_Regional.grf - lhedley - 5/3/2022

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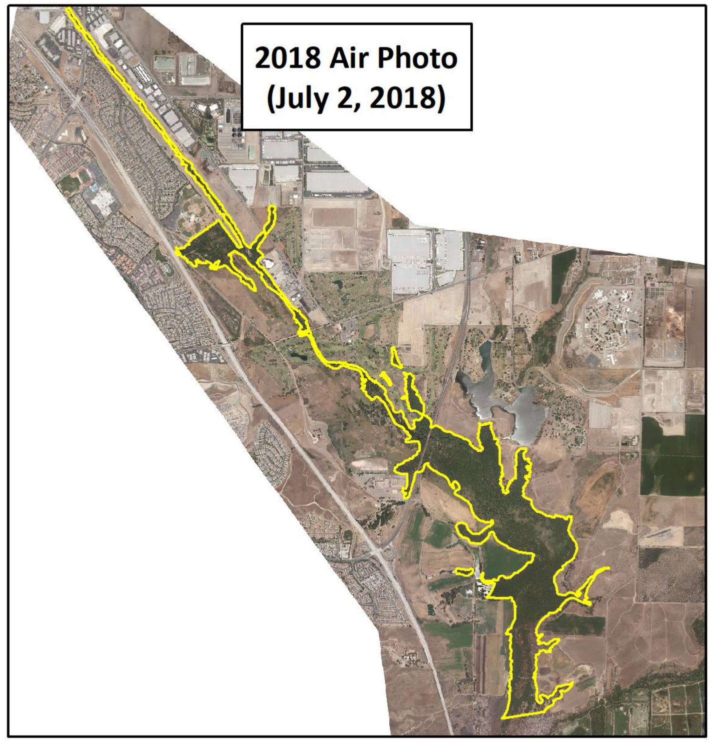
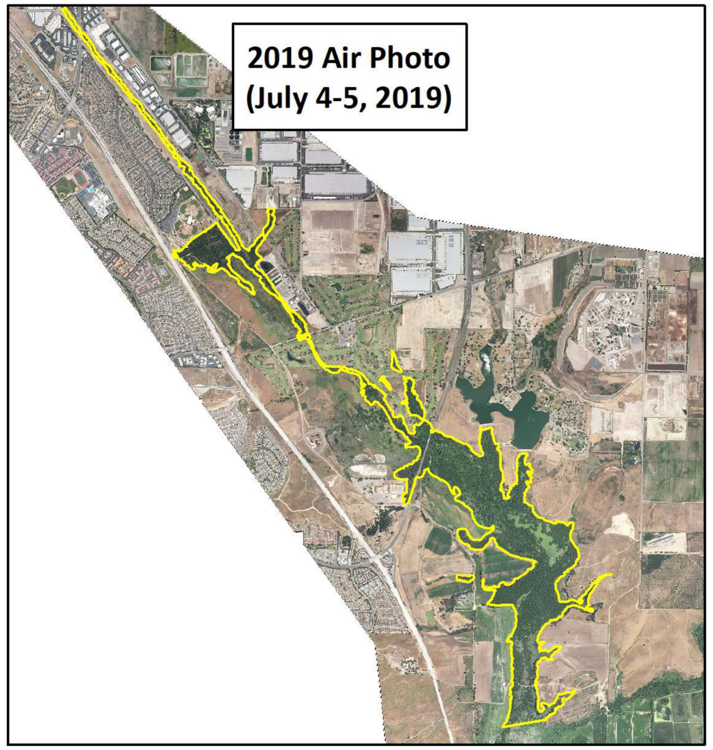
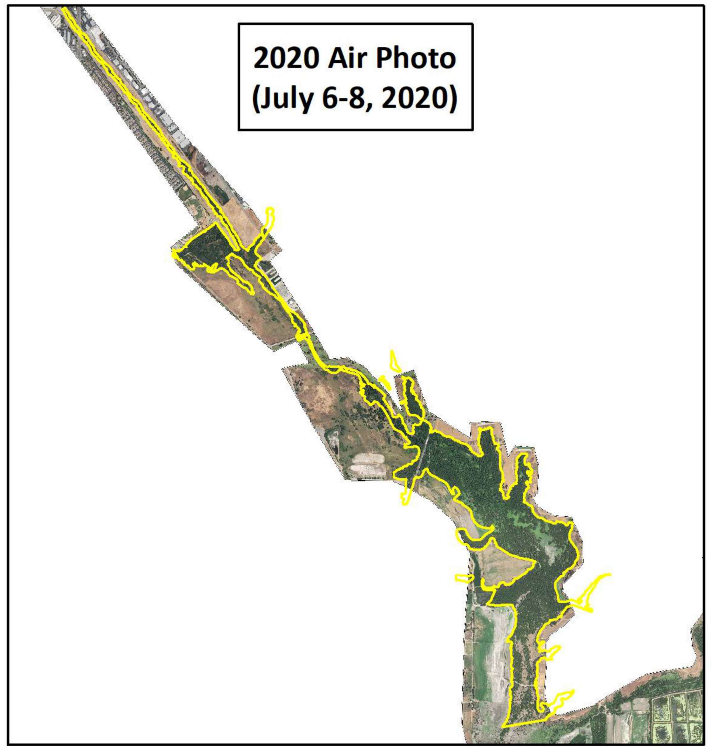
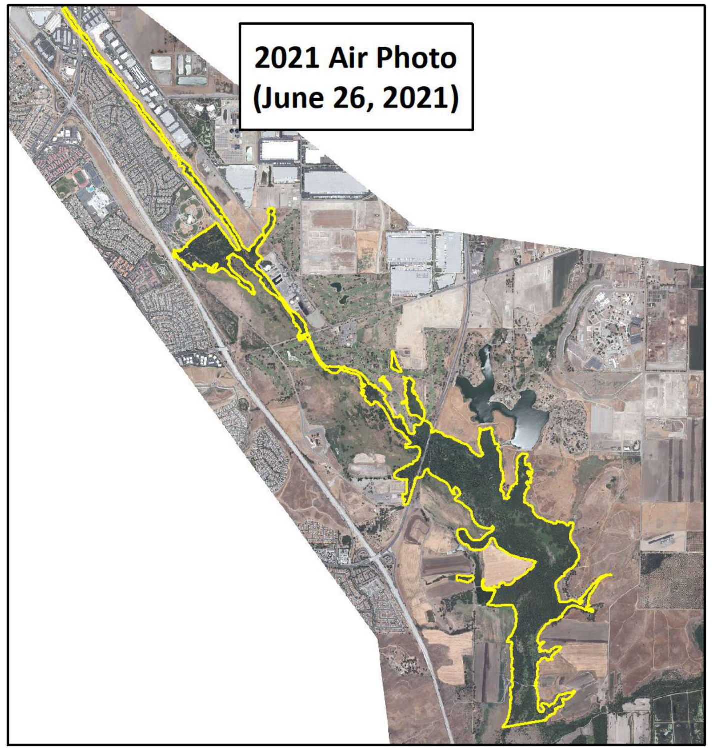
**Time Series of NDVI for the Riparian Vegetation Extent** - *1984 to 2021*

**Figure 3-5**


2018 Air Photo
(July 2, 2018)

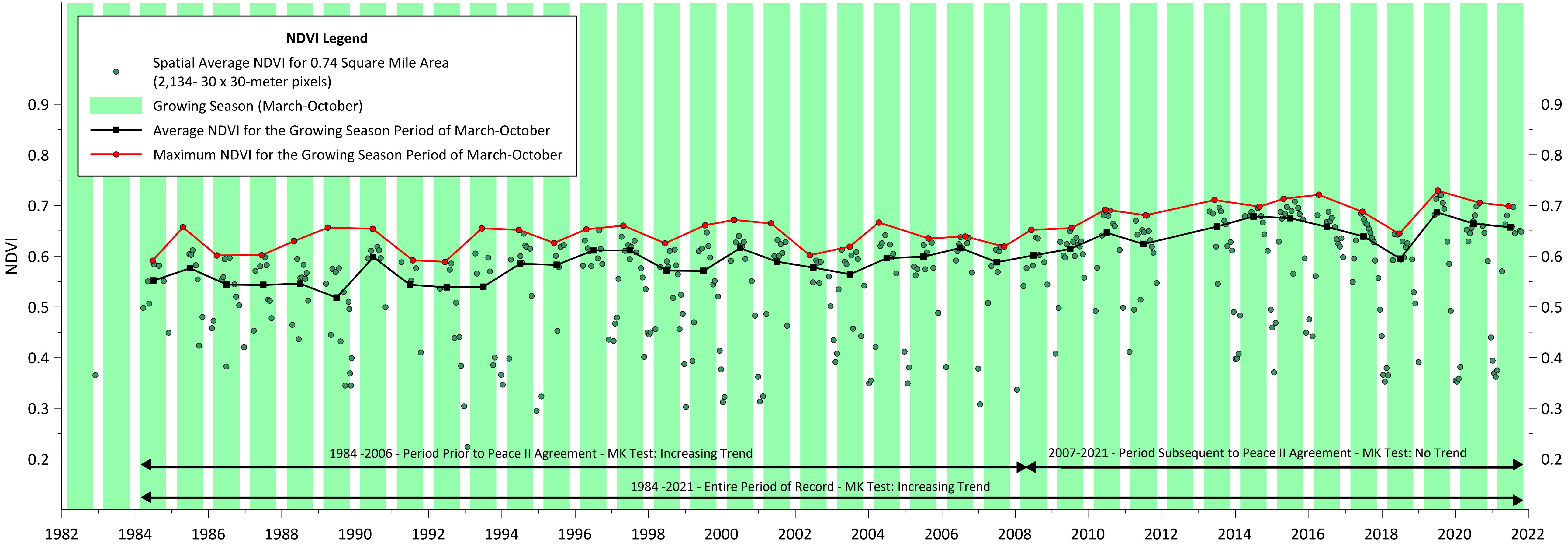

2019 Air Photo
(July 4-5, 2019)


2020 Air Photo
(July 6-8, 2020)

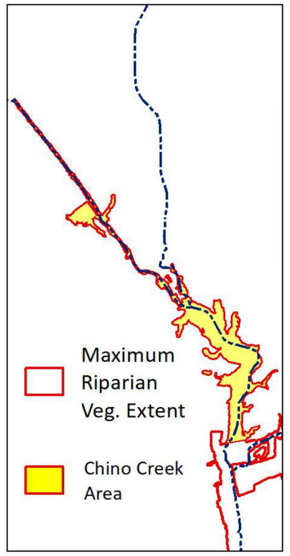

2021 Air Photo
(June 26, 2021)

Miles
0 0.5 1

🟨 0.74 Square Mile Area (2,134 30 x 30-meter pixels)



**Location of Chino Creek Area**



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WEST YOST - K:\Clients\941 Chino Basin Watermaster\00-00-00 Master\PE1 - Data_Monitoring\GRAPHER\GRF\Prado\AnnualR\Figure 3-6_NDVI_Chino Creek.grf - lhedley - 5/3/2022

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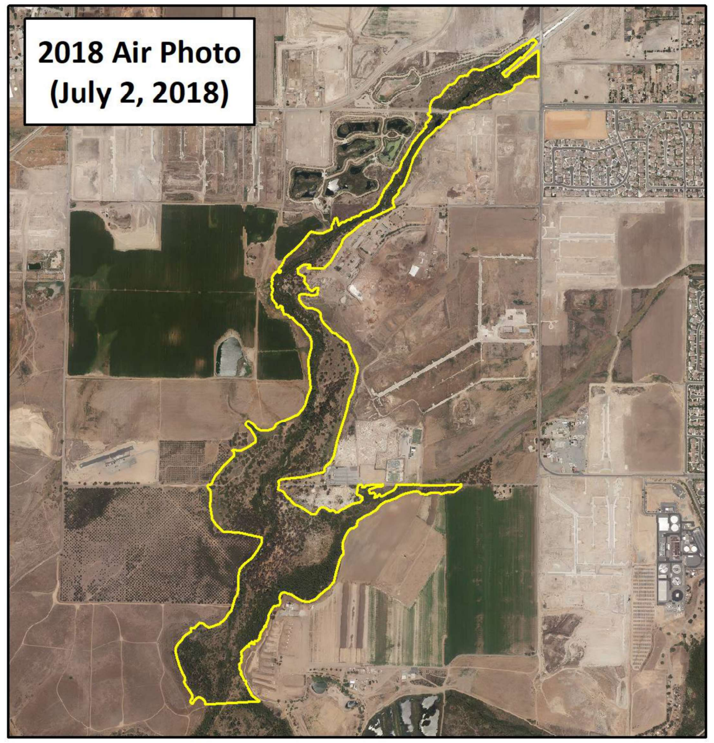
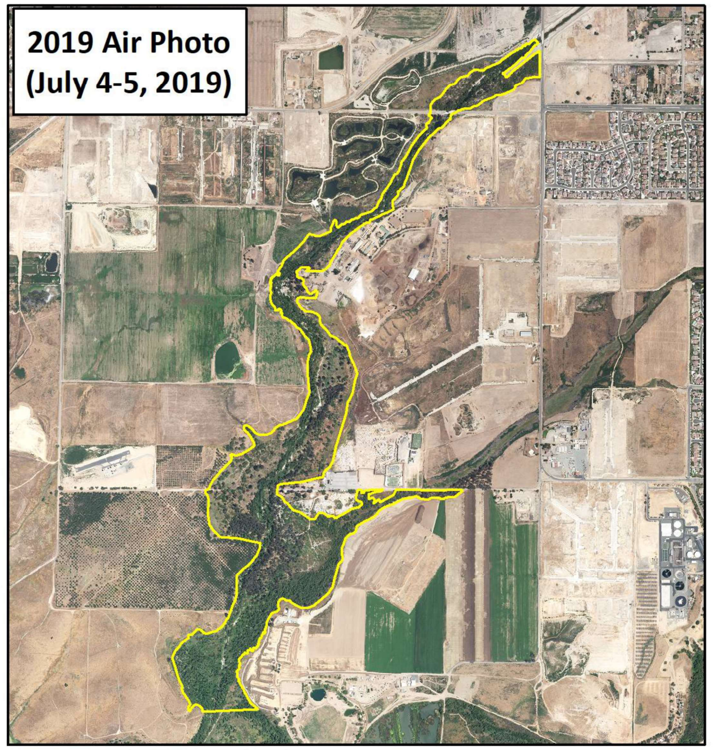
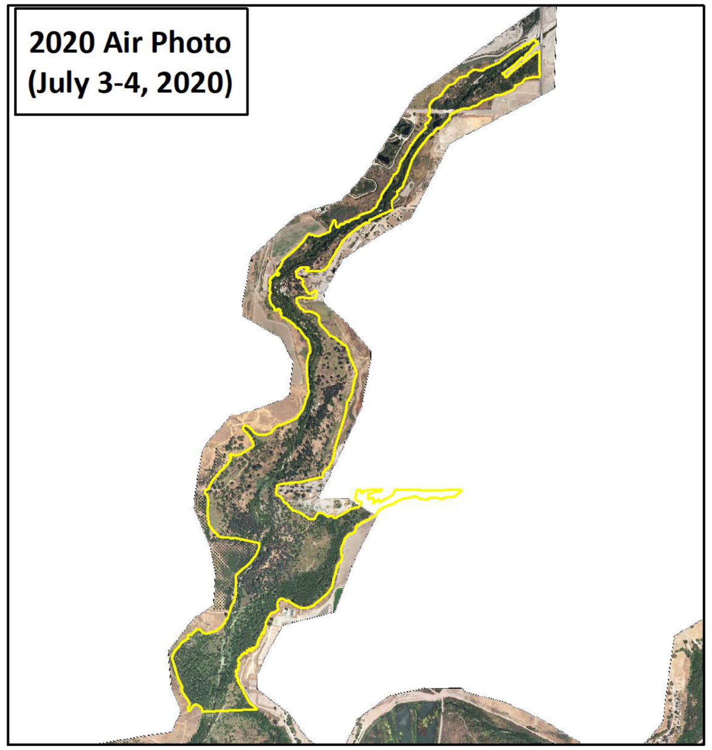
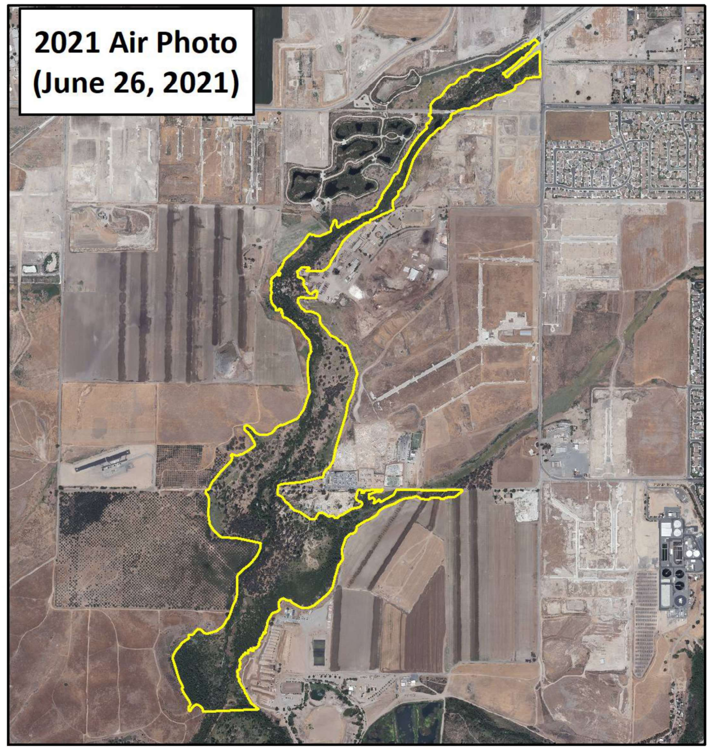
**Time Series of NDVI and Air Photos**
*Along Chino Creek Area for 1984 to 2021*

**Figure 3-6**


2018 Air Photo (July 2, 2018)


2019 Air Photo (July 4-5, 2019)

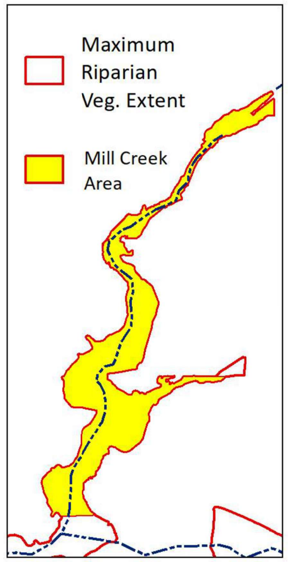

2020 Air Photo (July 3-4, 2020)

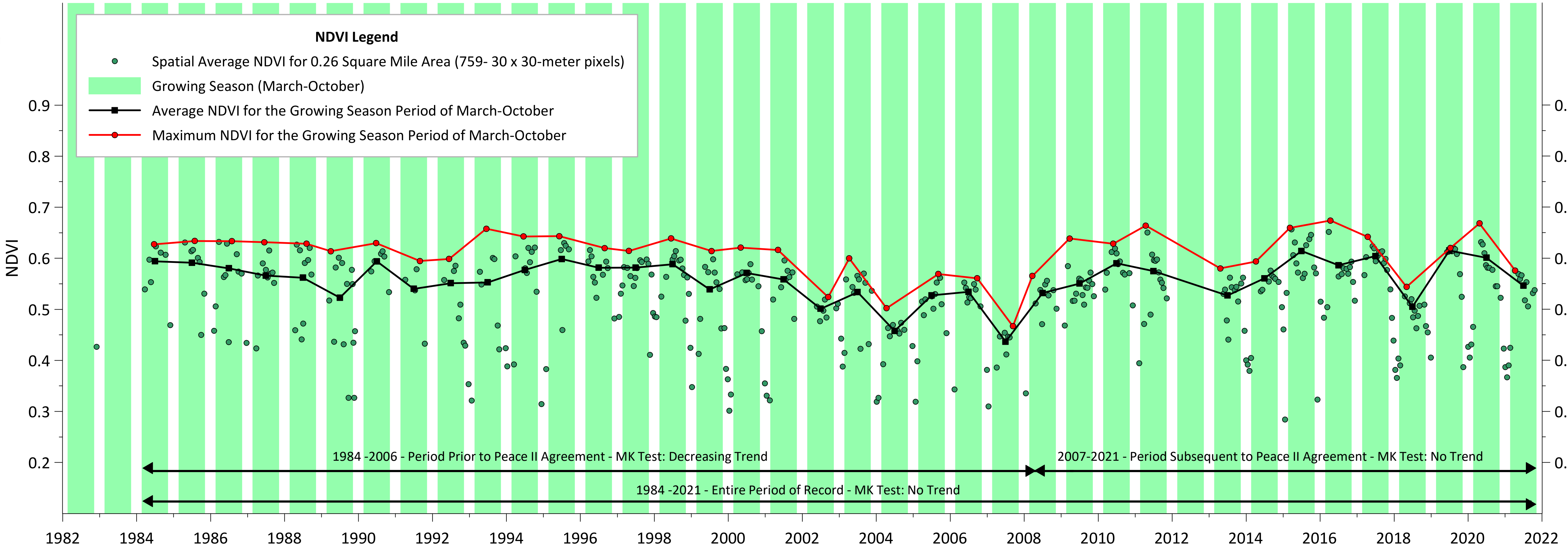

2021 Air Photo (June 26, 2021)

0 0.425 0.85 Miles

🟨 0.26 Square Mile Area (759 30 x 30-meter pixels)

**Location of Mill Creek Area**





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**Time Series of NDVI and Air Photos**
*Along Mill Creek Area for 1984 to 2021*

**Figure 3-7**

WEST YOST - K:\Clients\941 Chino Basin Watermaster\00-00-00 Master\PE1 - Data_Monitoring\GRAPHER\GRF\Prado\AnnualR\Figure 3-7_NDVI_Mill Creek.grf - lhedley - 5/3/2022

### *3.1.2.4.1 Temporal Analysis of NDVI within Small Areas along Chino Creek, Mill Creek, and the Santa Ana River*

Figures 3-8a through 3-8l are time-series charts of the NDVI for one NDVI pixel for small defined areas located along Chino Creek, Mill Creek, and the SAR near the PBHSP monitoring wells from 1984 to 2021. The areas are located near a PBHSP monitoring well to facilitate the comparison of changes in groundwater levels versus changes in the riparian habitat. These small areas also align with a location of a 10-meter radius plot where vegetation surveys are conducted by the USBR every three years so that the field measurements from the surveys can be compared to the NDVI.

The purpose of these charts is to characterize long-term trends and short-term changes in NDVI for smaller areas primarily located along the northern stream reaches of the Prado Basin riparian habitat—areas that are most susceptible to potential impacts from declining groundwater levels associated with Peace II implementation, and provide a basis for comparison to the NDVI trends and changes for each of the larger defined areas. Each figure includes a series of air photos for spatial reference and as a visual check on the interpretations derived from the NDVI time-series charts. The air photos are for 2018, 2019, 2020, and 2021—showing the last four years using the high-resolution air photos collected for the PBHSP.

***Chino Creek*** **(Figures 3-8a to 3-8d)**. Four vegetated areas were analyzed along Chino Creek:CC-1, CC-2, CC-3, and CC-4 (see Figure 3-4 for locations). These figures, and Tables 3-1 and 3-2, show that over the period of record the Average Growing-Season NDVI varied from year-to-year by up to 0.13 with no long-term declining trends. For all four areas, the Mann-Kendall test result on the Average Growing-Season NDVI indicates an “increasing trend” over the 1984 to 2021 period, “no trend” or “increasing trend” over the 1984 to 2006 period, and “no trend” or “increasing trend” over the 2007 to 2021 period.

For these four areas along Chino Creek, the Average Growing-Season NDVI from 2020 to 2021 decreased for three of the areas (CC-2, CC-3, CC-4) and increased for one of the areas (CC-1). At all of the areas, these one-year changes in the Average Growing-Season NDVI are relatively minor and within the historical ranges of one-year NDVI variability (see Table 3-2). Visual inspection of the 2020 and 2021 air photos do not show significant changes in the riparian vegetation at these four areas.

***Mill Creek*** **(Figures 3-8e to 3-8h).** Four vegetated areas were analyzed along Mill Creek just south of the CDA well field: MC-1, MC-2, MC-3, and MC-4 (see Figure 3-4 for locations). These figures, and Tables 3-1 and 3-2, show that over the period of record the Average Growing-Season NDVI varied year-to-year by up to 0.31 with no long-term declining trends. For all four areas, the Mann-Kendall test result on the Average Growing-Season NDVI indicates an “increasing trend” or “no trend” for the 1984 to 2021 period, “no trend” for the 1984 to 2006 period, and “increasing trend” or “no trend” for the 2007 to 2021 period.

For these four areas along Mill Creek, the Average Growing-Season NDVI from 2020 to 2021: decreased for two of the areas (MC-1, MC-2), and did not change for two of the areas (MC-3, MC-4). At all of the areas these recent changes in the Average Growing-Season NDVI are within their historical ranges of the one-year NDVI variability. Visual inspection of the 2020 and 2021 air photos for the MC-2 area, where NDVI decreased from 2020 to 2021, shows a noticeable decrease in green vegetated areas. In contrast, the 2020 to 2021 air photos show an increase in green vegetated areas at the MC-3 area, where NDVI did not change over this period, and the increase is following a decrease observed in the air photos from 2019 to 2020 (noted in the previous WY 2020 Annual Report, West Yost, 2021).

***Santa Ana River* (Figures 3-8i to 3-8l).** Four vegetated areas were analyzed along the floodplain of the SAR: SAR-1, SAR-2, SAR-3, and LP (see Figure 3-4 for locations). These figures, and Tables 3-1 and 3-2, show that over the period of record the Average Growing-Season NDVI varied by up to 0.44 from year-to-year. For all four areas, the Mann-Kendall test result on the Average Growing-Season NDVI indicates an “increasing trend” or “no trend” for the 1984 to 2021 period, “no trend” or “decreasing trend” for the 1984 to 2006 period, and an “increasing trend” or “no trend” for the 2007 to 2021 period.

At all four areas along the SAR, the Average Growing-Season NDVI from 2020 to 2021 decreased. At three of the areas, these one-year increases in the Average Growing-Season NDVI are relatively minor and within the historical ranges of one-year NDVI variability (see Table 3-2). At the LP area the Average Growing-Season NDVI decreased by 0.32 which is the maximum decrease observed historically. Visual inspection of the 2020 and 2021 air photos for both the SAR-1 and LP areas, where NDVI decreased, show a significant change in the riparian vegetation in 2021: the eastern edge of the vegetation at SAR-1 has been removed to create construction easements for expansion of the Hamner bridge over the SAR; and the LP area has significantly less green vegetation and was part of the 2020 wildfire in the lower Prado Basin (see section 3.6.1 of this report).

2018 Air Photo (July 2, 2018)

2019 Air Photo (July 4-5, 2019)

2020 Air Photo (July 6-8, 2020)

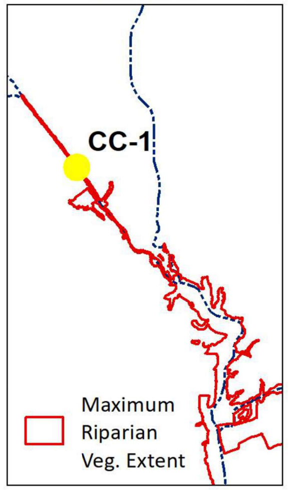
2021 Air Photo (June 26, 2021)

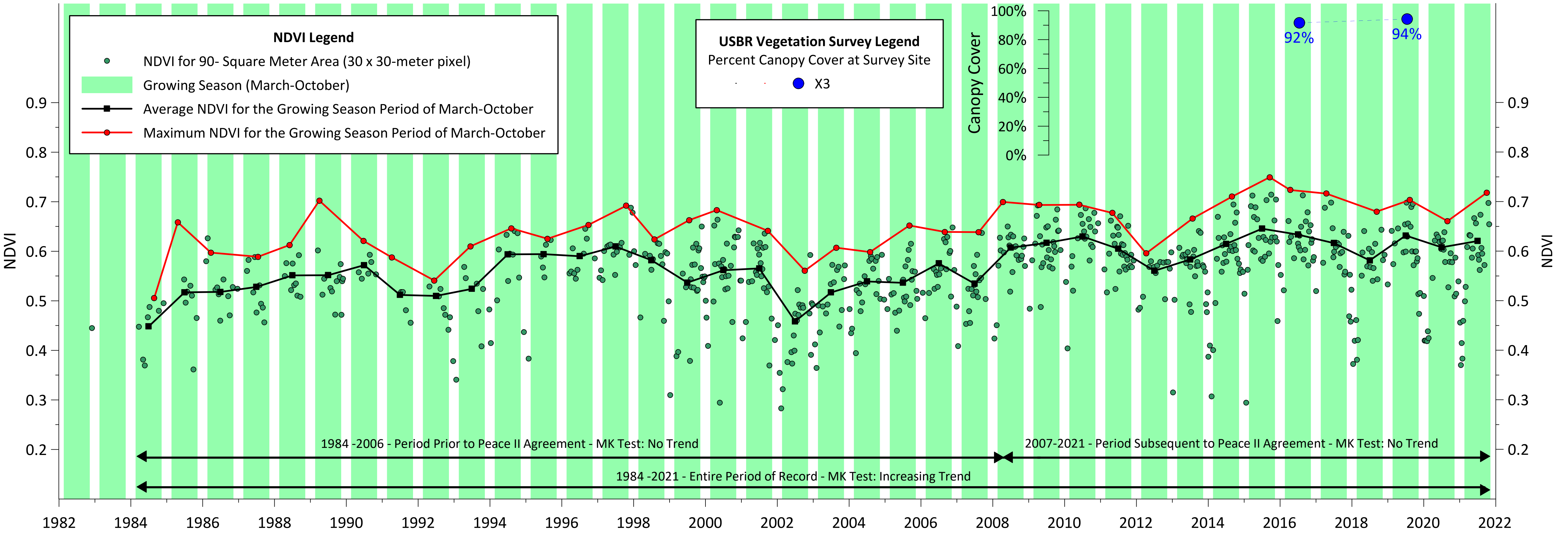
Meters
0 5 10

🟨 CC-1 Area for NDVI Analysis 30x30 meter pixel

○ Vegetation Survey Plot Location 10-meter radius

**Location Along Chino Creek**





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WEST YOST - K:\Clients\941 Chino Basin Watermaster\00-00-00 Master\PE1 - Data_Monitoring\GRAPHER\GRF\Prado\AnnualR\Figure 3-8a_NDVI_CC-1.grf - lhedley - 5/3/2022

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**Time Series of NDVI and Air Photos**
*CC-1 Area for 1984 to 2021*

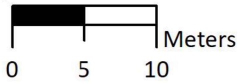
**Figure 3-8a**

**2018 Air Photo (July 2, 2018)**

**2019 Air Photo (July 4-5, 2019)**

**2020 Air Photo (July 6-8, 2020)**

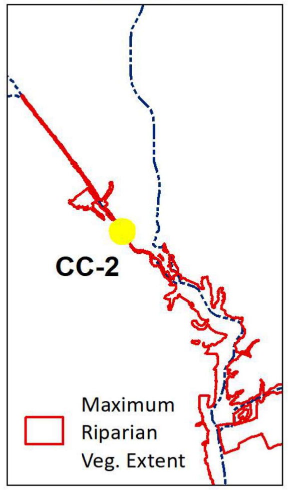
**2021 Air Photo (June 26, 2021)**

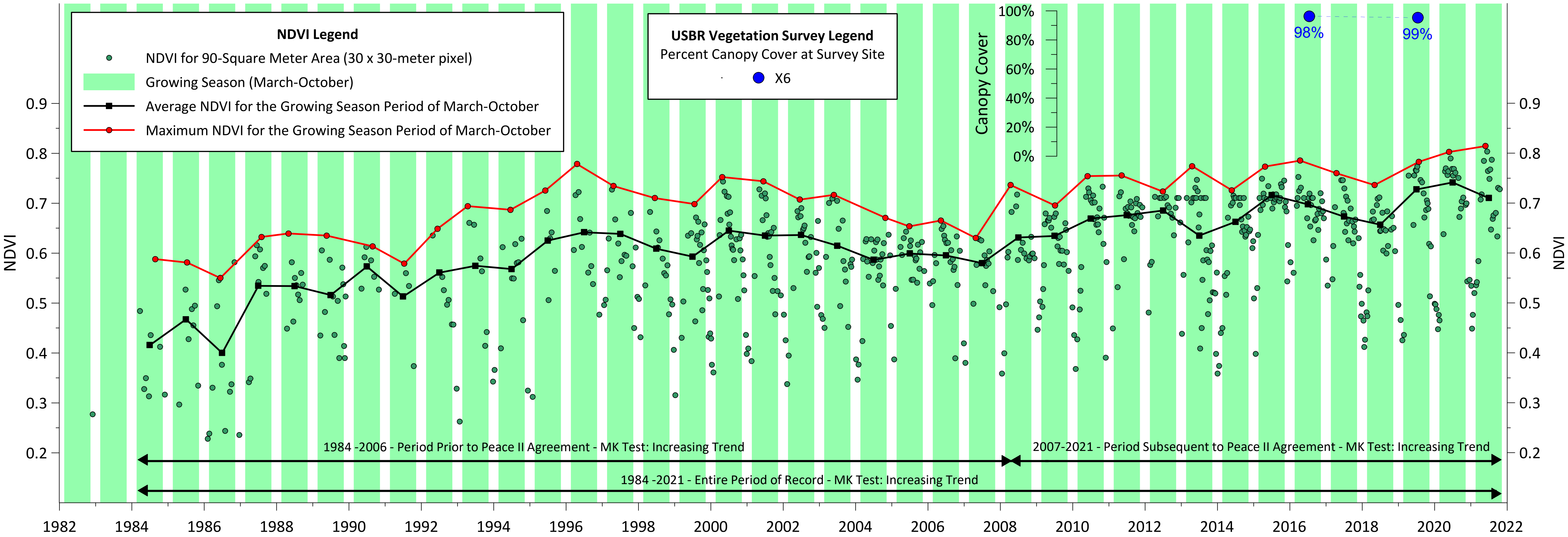


🟨 CC-2 Area for NDVI Analysis 30x30 meter pixel

○ Vegetation Survey Plot Location 10-meter radius

**Location Along Chino Creek**





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WEST YOST - K:\Clients\941 Chino Basin Watermaster\00-00-00 Master\PE1 - Data_Monitoring\GRAPHER\GRF\Prado\AnnualR\Figure 3-8b_NDVI_CC-2.grf - lhedley - 5/3/2022

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**Time Series of NDVI and Air Photos**
*CC-2 Area for 1984 to 2021*

**Figure 3-8b**

**2018 Air Photo (July 2, 2018)**

**2019 Air Photo (July 4-5, 2019)**

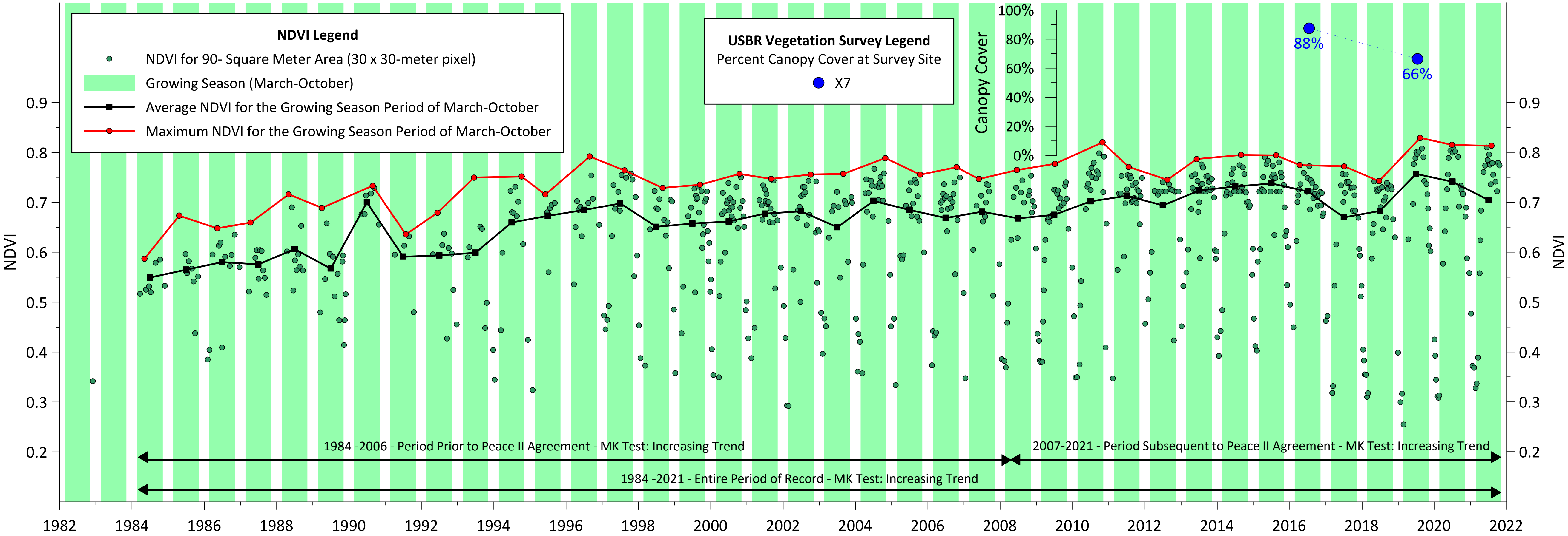
**2020 Air Photo (July 6-8, 2020)**

**2021 Air Photo (June 26, 2021)**

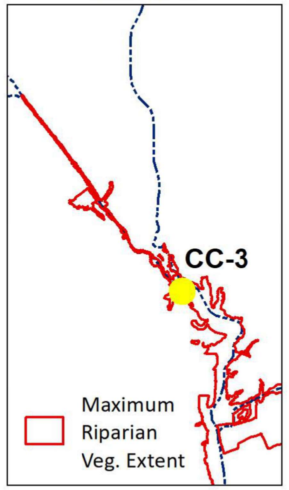
Meters
0 5 10

🟨 CC-3 Area for NDVI Analysis 30x30 meter pixel

○ Vegetation Survey Plot Location 10-meter radius



**Location Along Chino Creek**



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2021 Annual Report

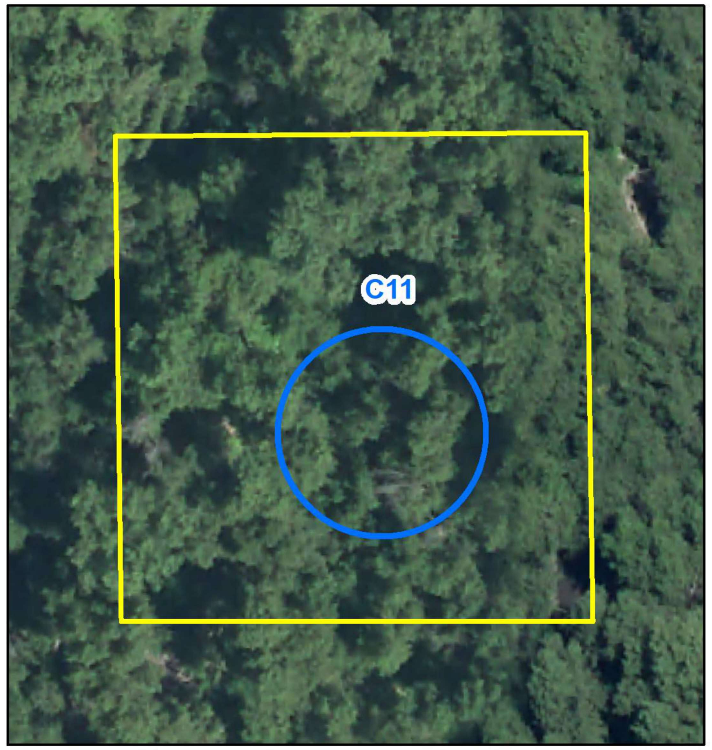
**Time Series of NDVI and Air Photos**
*CC-3 Area for 1984 to 2021*

**Figure 3-8c**

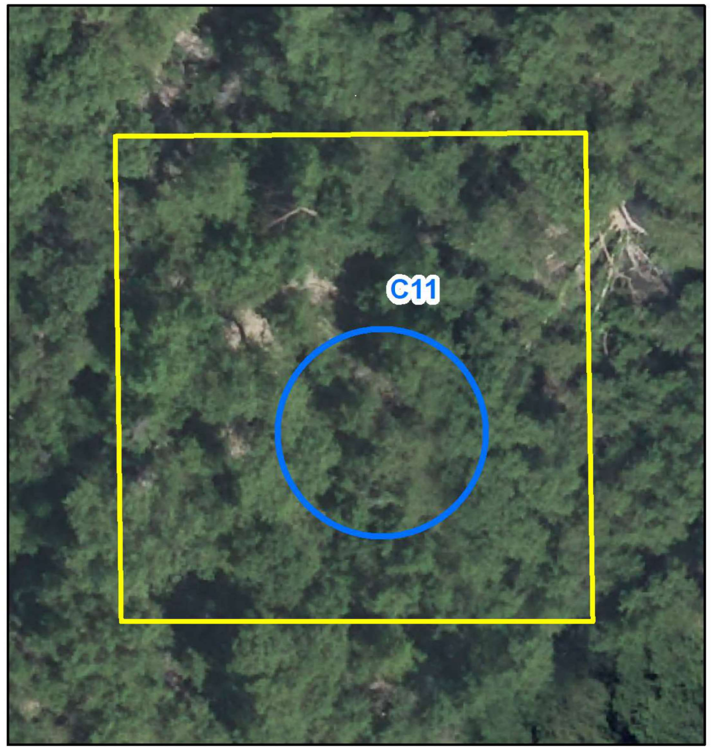
WEST YOST - K:\Clients\941 Chino Basin Watermaster\00-00-00 Master\PE1 - Data_Monitoring\GRAPHER\GRF\Prado\AnnualR\Figure 3-8c_NDVI_CC-3.grf - lhedley - 5/3/2022

2018 Air Photo (July 2, 2018)

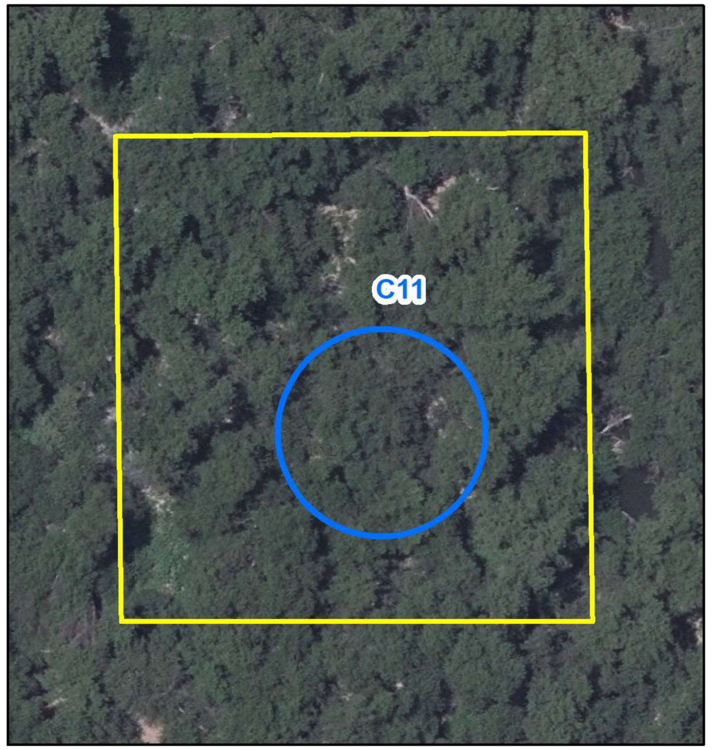
2019 Air Photo (July 4-5, 2019)



2020 Air Photo (July 6-8, 2020)



2021 Air Photo (June 26, 2021)

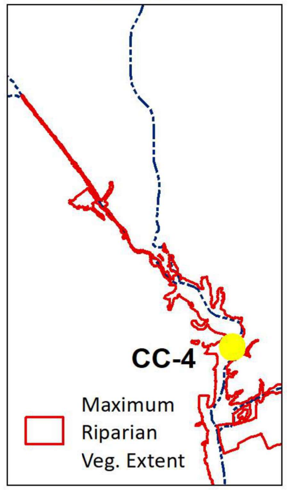


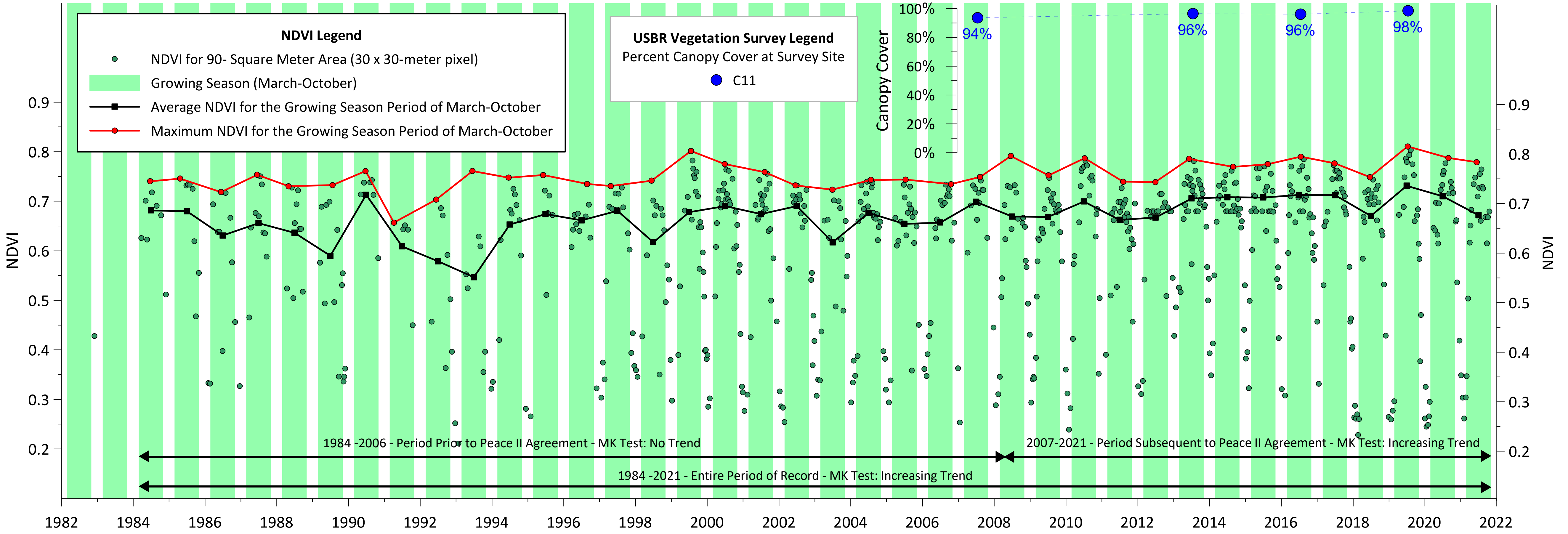
Meters
0 5 10

🟨 CC-4 Area for NDVI Analysis 30x30 meter pixel

○ Vegetation Survey Plot Location 10-meter radius

**Location Along Chino Creek**





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2021 Annual Report

**Time Series of NDVI and Air Photos**
*CC-4 Area for 1984 to 2021*

**Figure 3-8d**

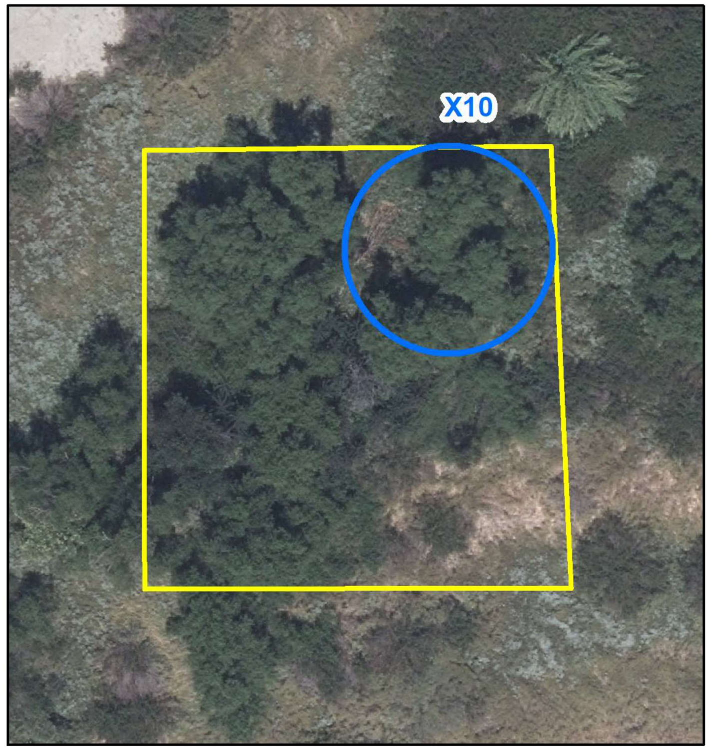
WEST YOST - K:\Clients\941 Chino Basin Watermaster\00-00-00 Master\PE1 - Data_Monitoring\GRAPHER\GRF\Prado\AnnualR\Figure 3-8d_NDVI_CC-4.grf - lhedley - 5/3/2022

2018 Air Photo (July 2, 2018)

2019 Air Photo (July 4-5, 2019)

2020 Air Photo (July 6-8, 2020)

2021 Air Photo (June 26, 2021)

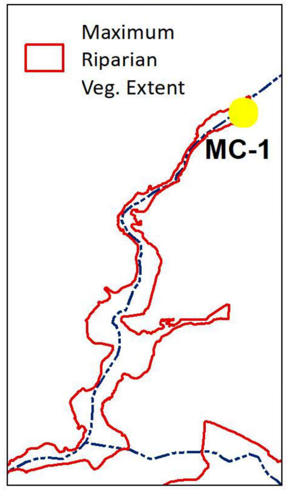


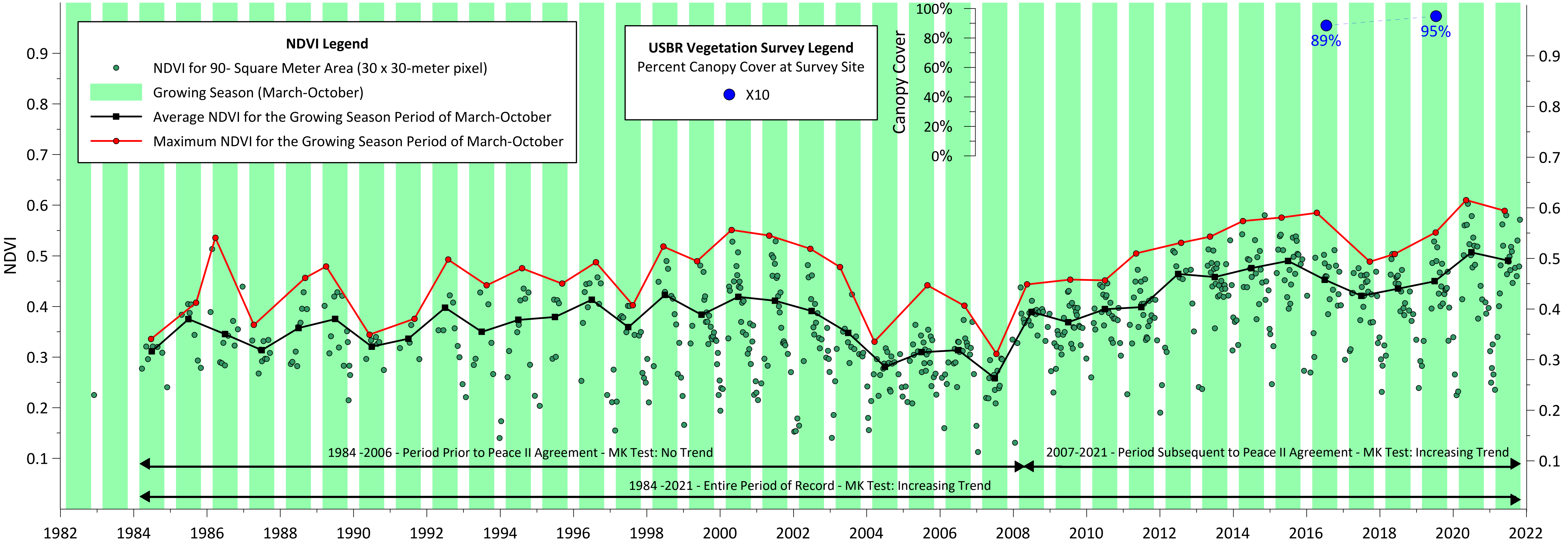
Meters
0 5 10

🟨 MC-1 Area for NDVI Analysis 30x30 meter pixel

○ Vegetation Survey Plot Location 10-meter radius

**Location Along Mill Creek**





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**Time Series of NDVI and Air Photos**
*MC-1 Area for 1984 to 2021*

**Figure 3-8e**

WEST YOST - K:\Clients\941 Chino Basin Watermaster\00-00-00 Master\PE1 - Data_Monitoring\GRAPHER\GRF\Prado\AnnualR\Figure 3-8e_NDVI_MC-1.grf - lhedley - 5/3/2022

2018 Air Photo (July 2, 2018)

2019 Air Photo (July 4-5, 2019)

2020 Air Photo (July 6-8, 2020)

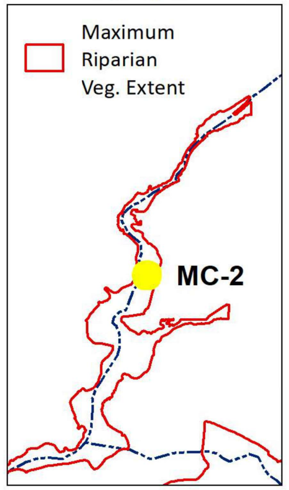
2021 Air Photo (June 26, 2021)

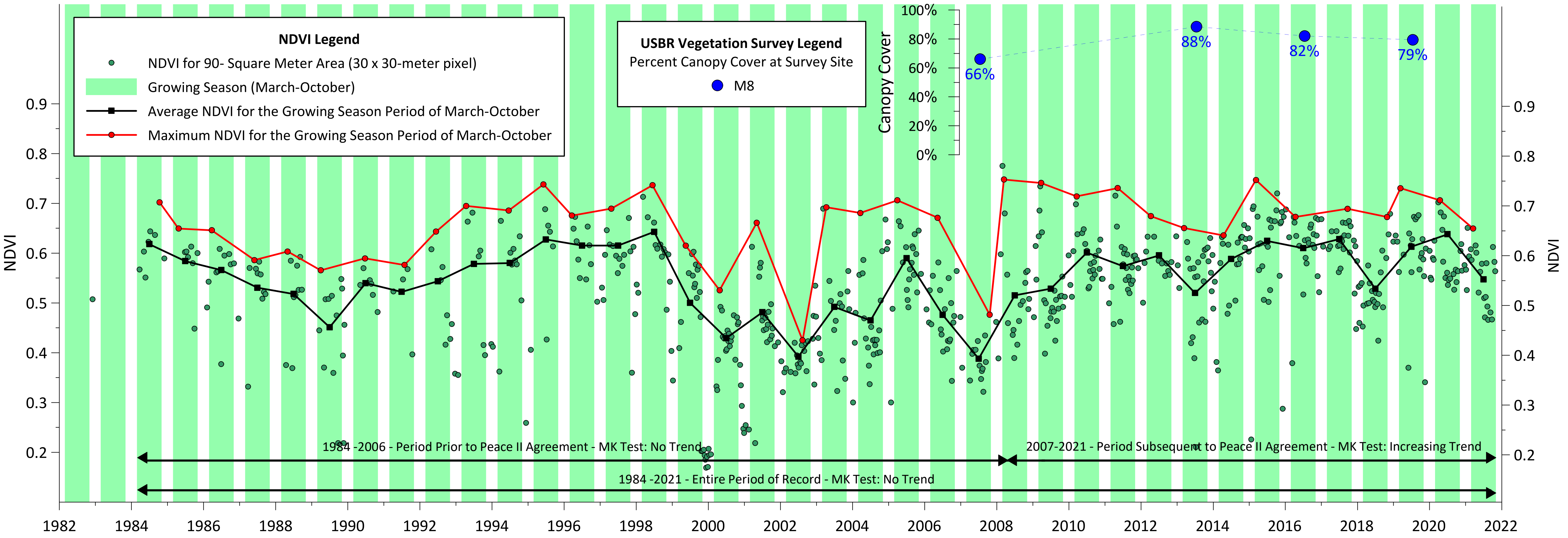
Meters
0 5 10

🟨 MC-2 Area for NDVI Analysis 30x30 meter pixel

○ Vegetation Survey Plot Location 10-meter radius

**Location Along Mill Creek**





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**Time Series of NDVI and Air Photos**
*MC-2 Area for 1984 to 2021*

**Figure 3-8f**

WEST YOST - K:\Clients\941 Chino Basin Watermaster\00-00-00 Master\PE1 - Data_Monitoring\GRAPHER\GRF\Prado\AnnualR\Figure 3-8f_NDVI_MC-2.grf - lhedley - 5/3/2022

**2018 Air Photo (July 2, 2018)**

**2019 Air Photo (July 4-5, 2019)**

**2020 Air Photo (July 6-8, 2020)**

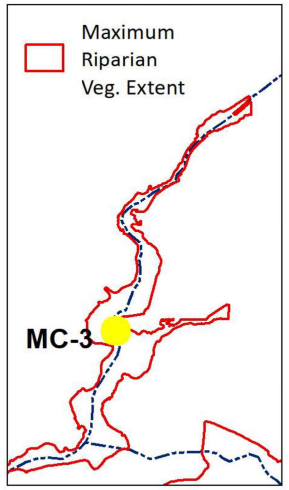
**2021 Air Photo (June 26, 2021)**

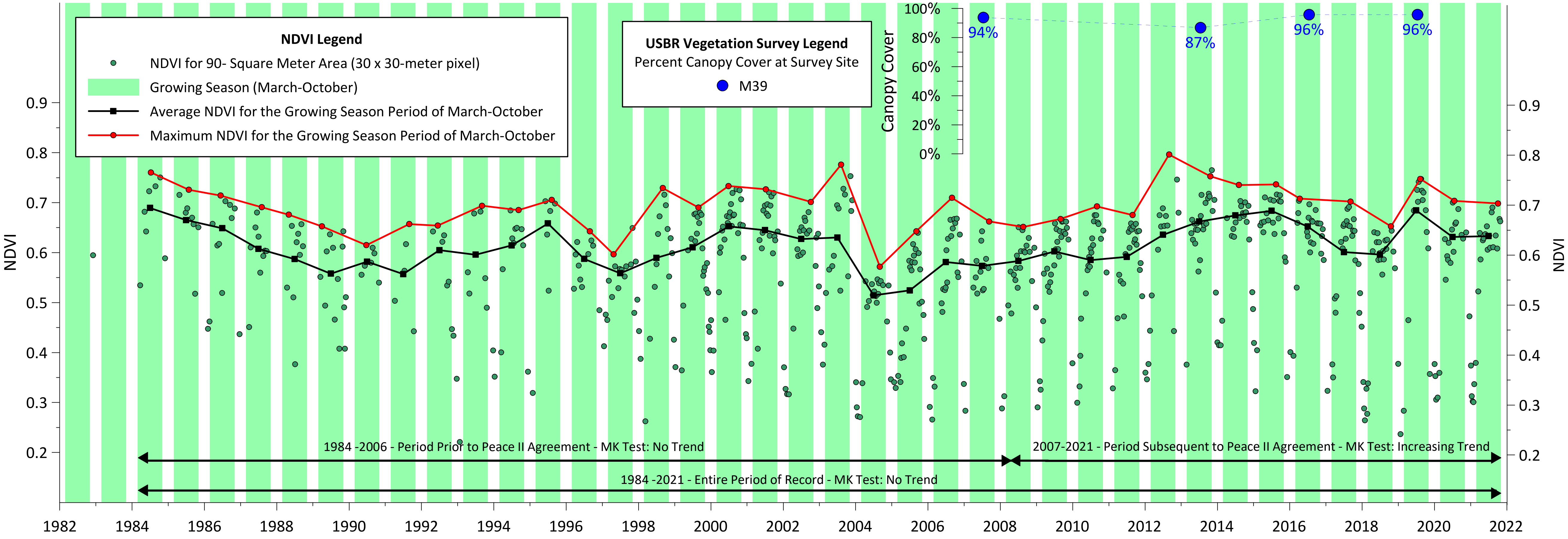
Meters
0 5 10

🟨 MC-3 Area for NDVI Analysis 30x30 meter pixel

○ Vegetation Survey Plot Location 10-meter radius

**Location Along Mill Creek**





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WEST YOST - K:\Clients\941 Chino Basin Watermaster\00-00-00 Master\PE1 - Data_Monitoring\GRAPHER\GRF\Prado\AnnualR\Figure 3-8g_NDVI_MC-3.grf - lhedley - 5/3/2022

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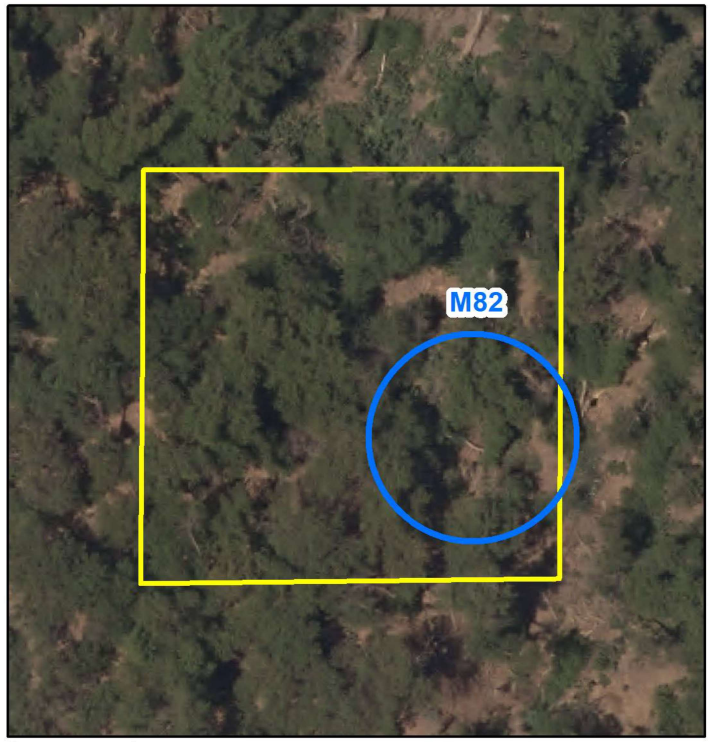
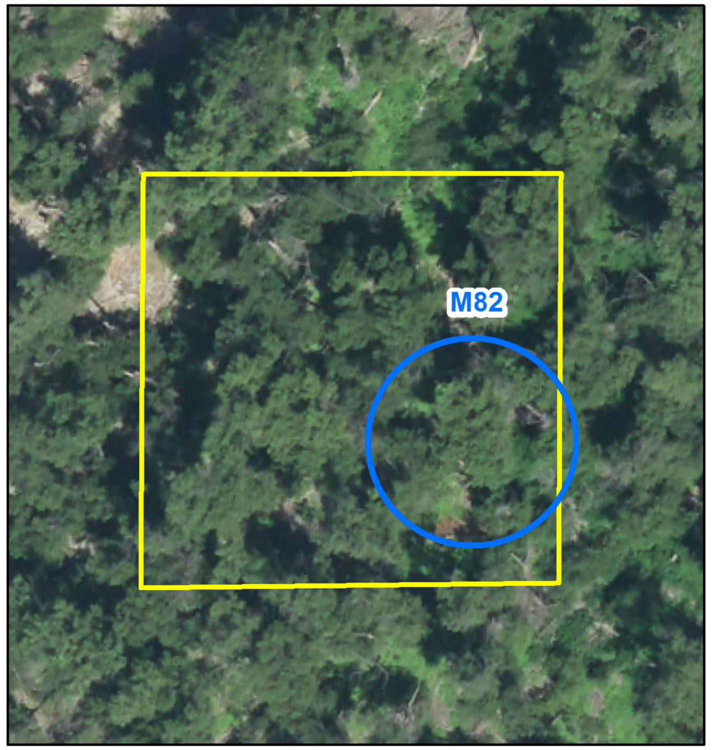
**Time Series of NDVI and Air Photos**
*MC-3 Area for 1984 to 2021*

**Figure 3-8g**

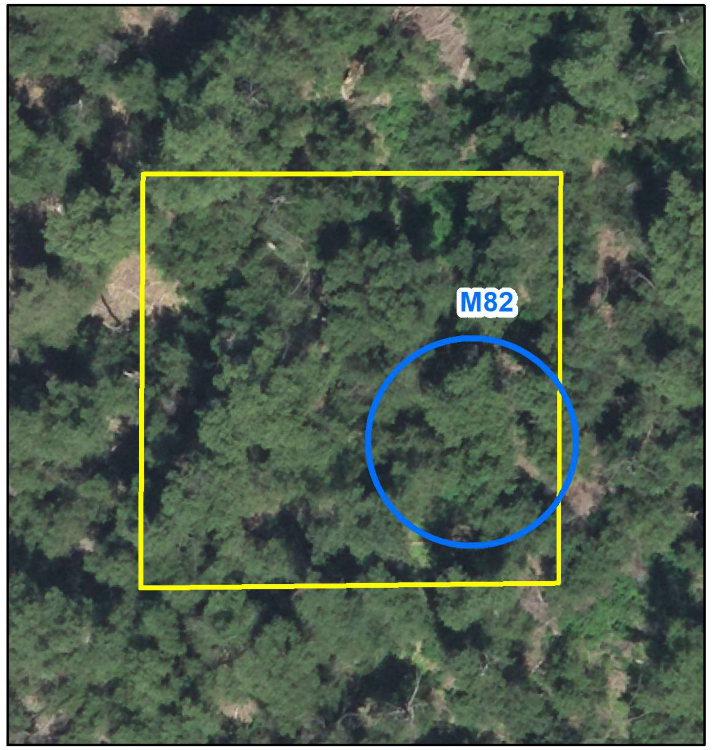
**2018 Air Photo (July 2, 2018)**



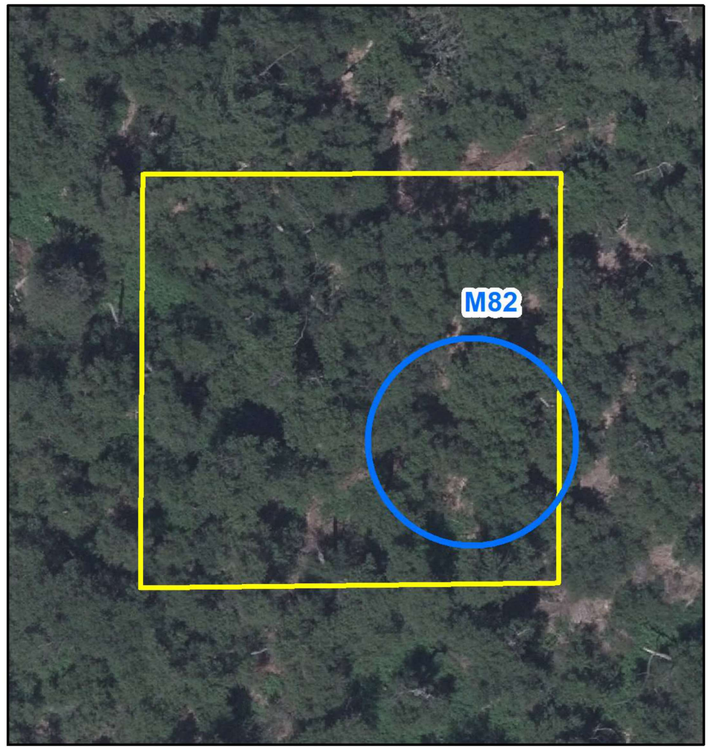
**2019 Air Photo (July 4-5, 2019)**

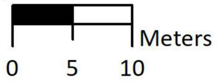


**2020 Air Photo (July 6-8, 2020)**



**2021 Air Photo (June 26, 2021)**

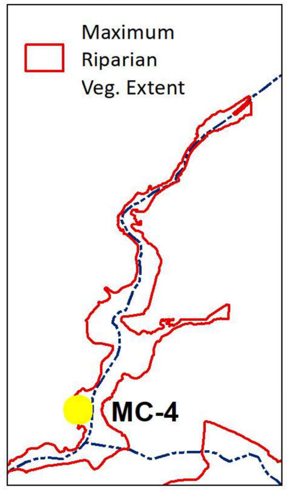


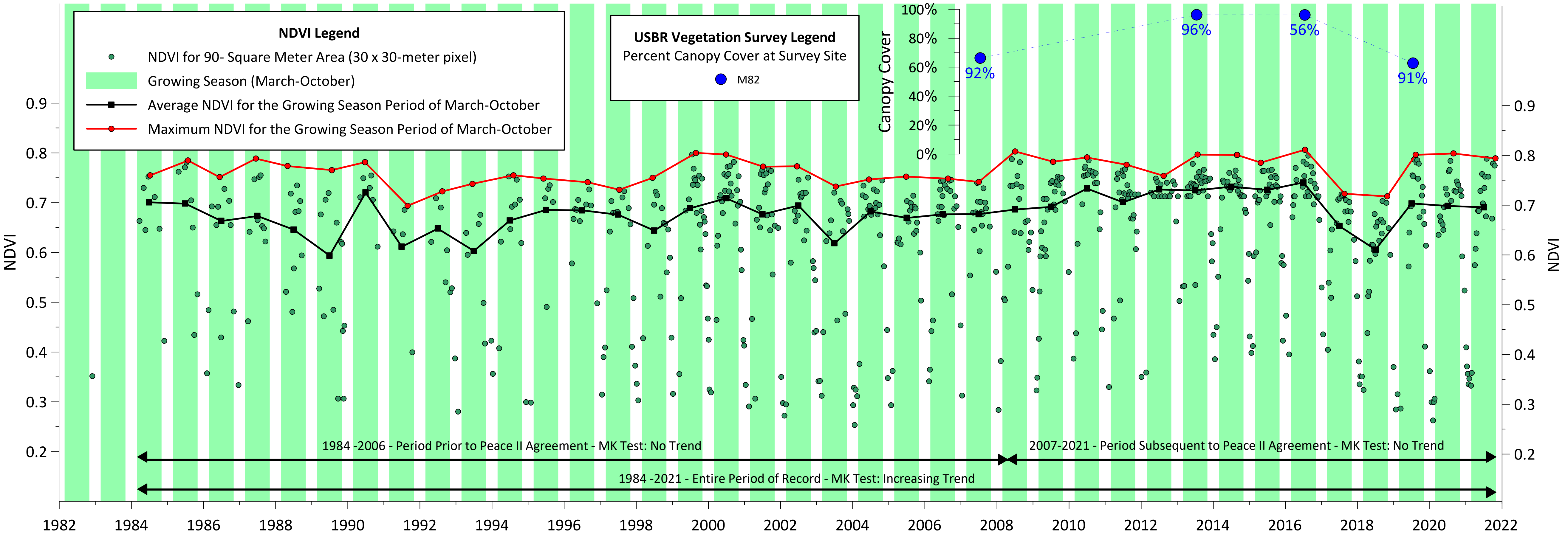


MC-4 Area for NDVI Analysis 30x30 meter pixel

Vegetation Survey Plot Location 10-meter radius

**Location Along Mill Creek**





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**Time Series of NDVI and Air Photos**
*MC-4 Area for 1984 to 2021*

**Figure 3-8h**

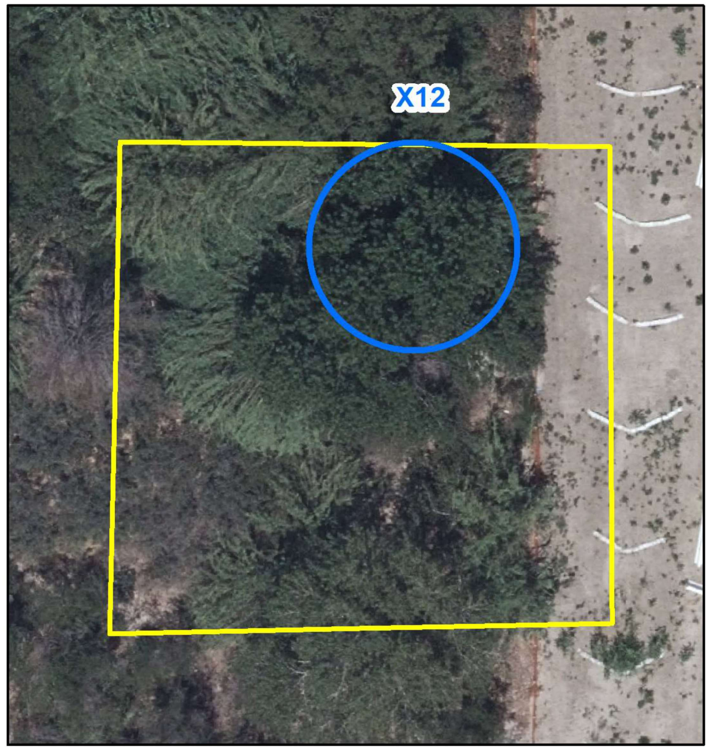
WEST YOST - K:\Clients\941 Chino Basin Watermaster\00-00-00 Master\PE1 - Data_Monitoring\GRAPHER\GRF\Prado\AnnualR\Figure 3-8h_NDVI_MC-4.grf - lhedley - 5/3/2022

**2018 Air Photo (July 2, 2018)**

**2019 Air Photo (July 4-5, 2019)**

**2020 Air Photo (July 6-8, 2020)**

**2021 Air Photo (June 26, 2021)**

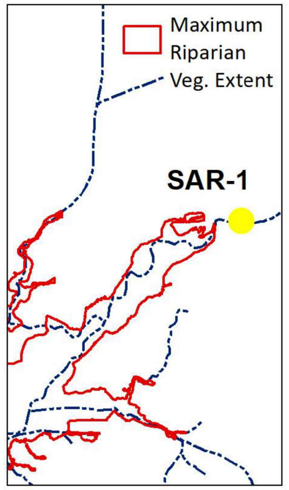


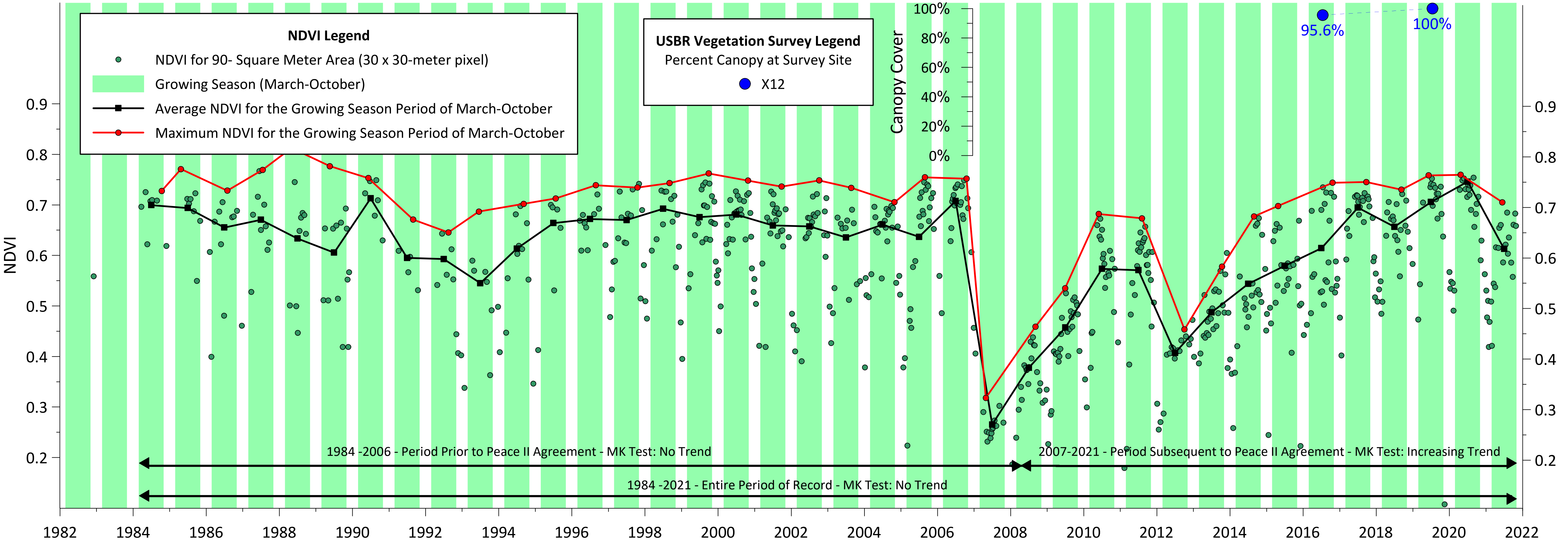
Meters
0 5 10

🟨 SAR-1 Area for NDVI Analysis 30x30 meter pixel

○ Vegetation Survey Plot Location 10-meter radius

**Location Along Santa Ana River**





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**Time Series of NDVI and Air Photos**
*SAR-1 Area for 1984 to 2021*

**Figure 3-8i**

WEST YOST - K:\Clients\941 Chino Basin Watermaster\00-00-00 Master\PE1 - Data_Monitoring\GRAPHER\GRF\Prado\AnnualR\Figure 3-8i_NDVI_SAR-1.grf - lhedley - 5/3/2022

**2018 Air Photo (July 2, 2018)**

**2019 Air Photo (July 4-5, 2019)**

**2020 Air Photo (July 6-8, 2020)**

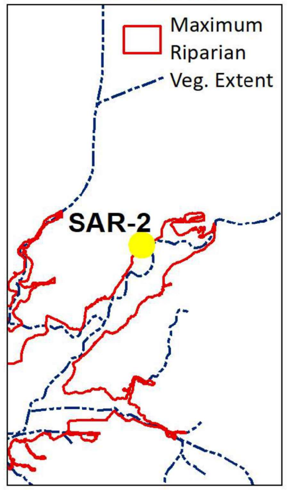
**2021 Air Photo (June 26, 2021)**

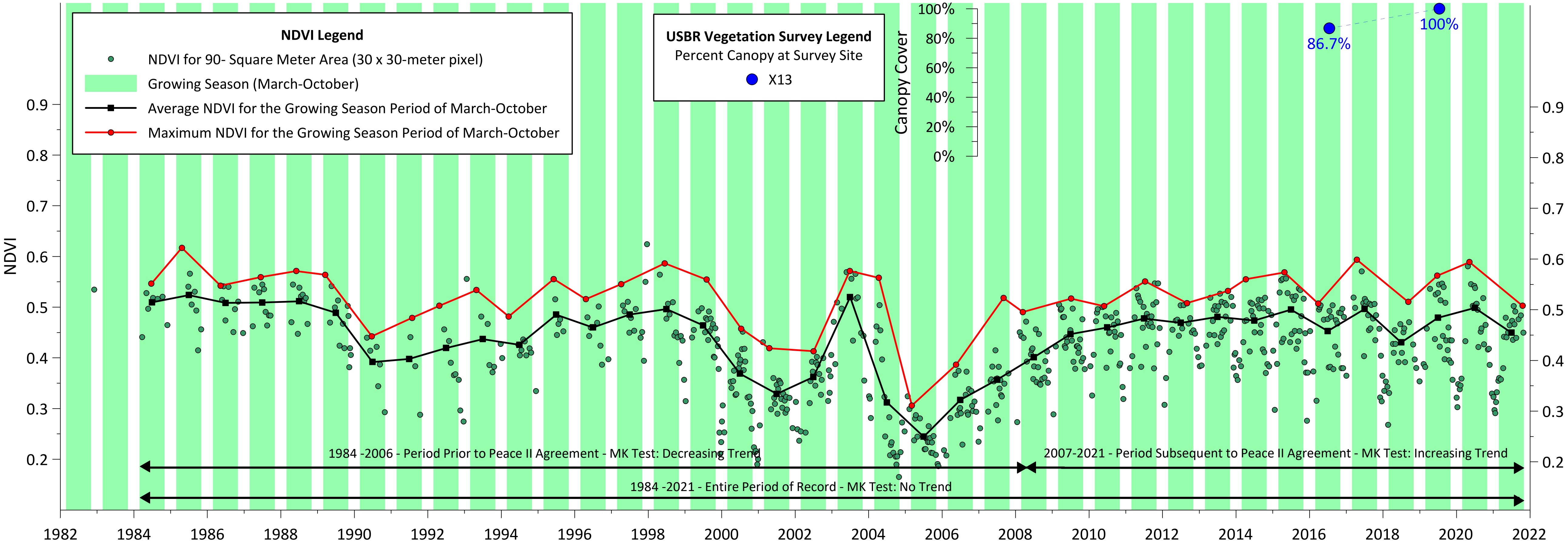
Meters
0 5 10

🟨 SAR-2 Area for NDVI Analysis 30x30 meter pixel

○ Vegetation Survey Plot Location 10-meter radius

**Location Along Santa Ana River**





Prepared by:

WEST YOST
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WEST YOST - K:\Clients\941 Chino Basin Watermaster\00-00-00 Master\PE1 - Data_Monitoring\GRAPHER\GRF\Prado\AnnualR\Figure 3-8j_NDVI_SAR-2.grf - lhedley - 5/3/2022

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2021 Annual Report

CHINO BASIN WATERMASTER
Partners in Basin Management

**Time Series of NDVI and Air Photos**
*SAR-2 Area for 1984 to 2021*

**Figure 3-8j**

**2018 Air Photo (July 2, 2018)**

**2019 Air Photo (July 4-5, 2019)**

**2020 Air Photo (July 6-8, 2020)**

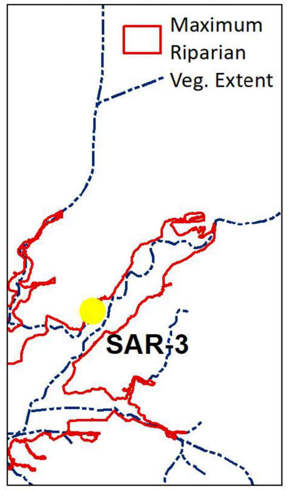
**2021 Air Photo (June 26, 2021)**

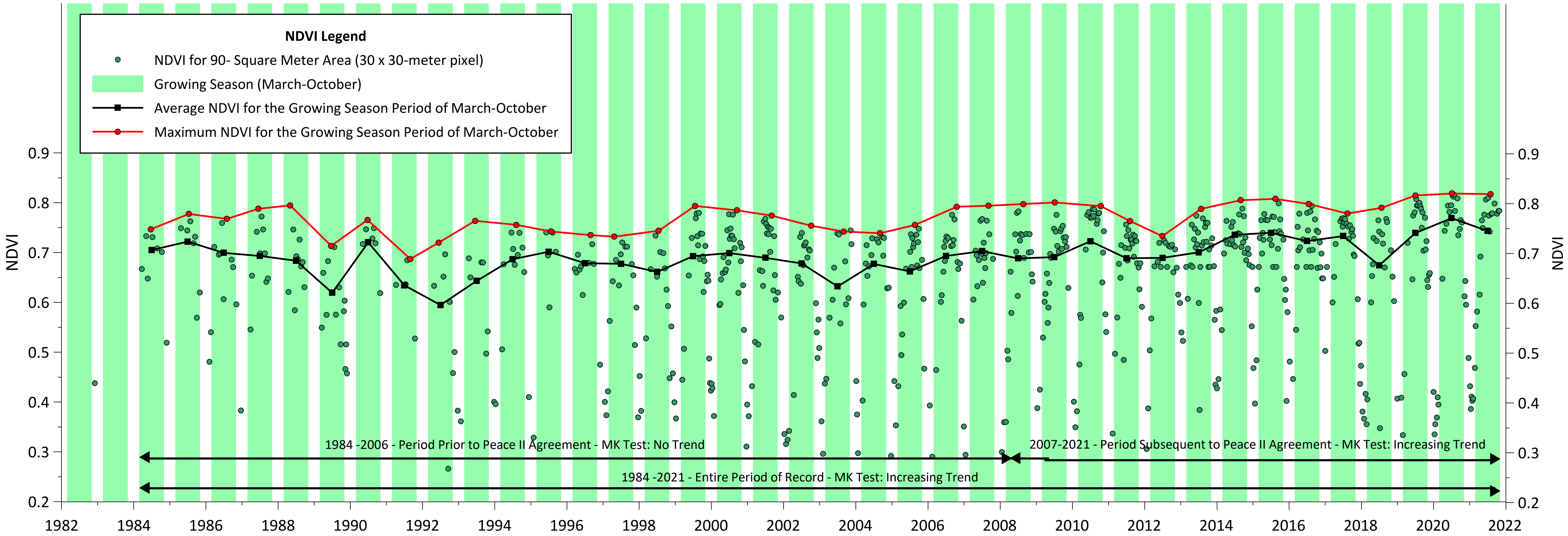
Meters
0 5 10

🟨 SAR-3 Area for NDVI Analysis 30x30 meter pixel

○ Vegetation Survey Plot Location 10-meter radius

**Location Along Santa Ana River**





Prepared by:

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WEST YOST - K:\Clients\941 Chino Basin Watermaster\00-00-00 Master\PE1 - Data_Monitoring\GRAPHER\GRF\Prado\AnnualR\Figure 3-8k_NDVI_SAR-3.grf - lhedley - 5/3/2022

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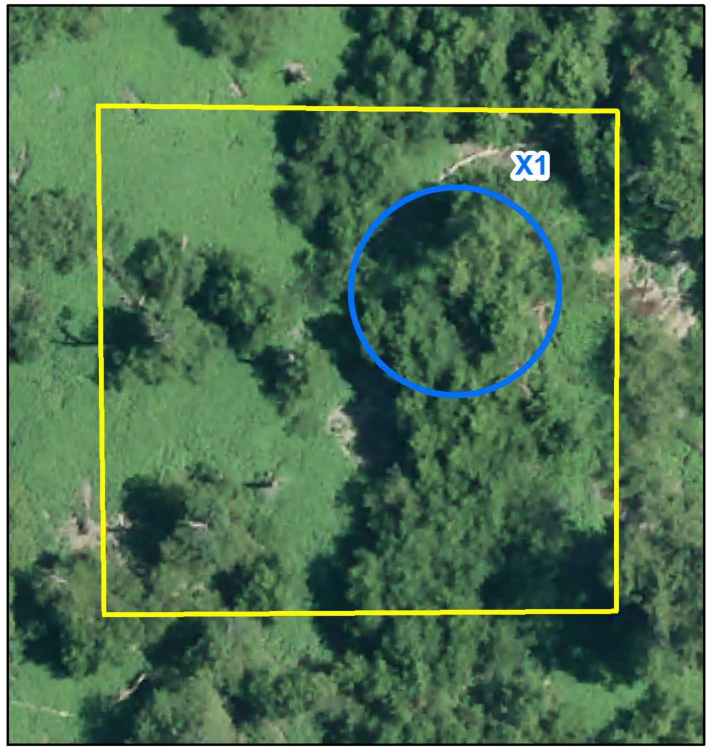
2021 Annual Report

**Time Series of NDVI and Air Photos**
*SAR-3 Area for 1984 to 2021*

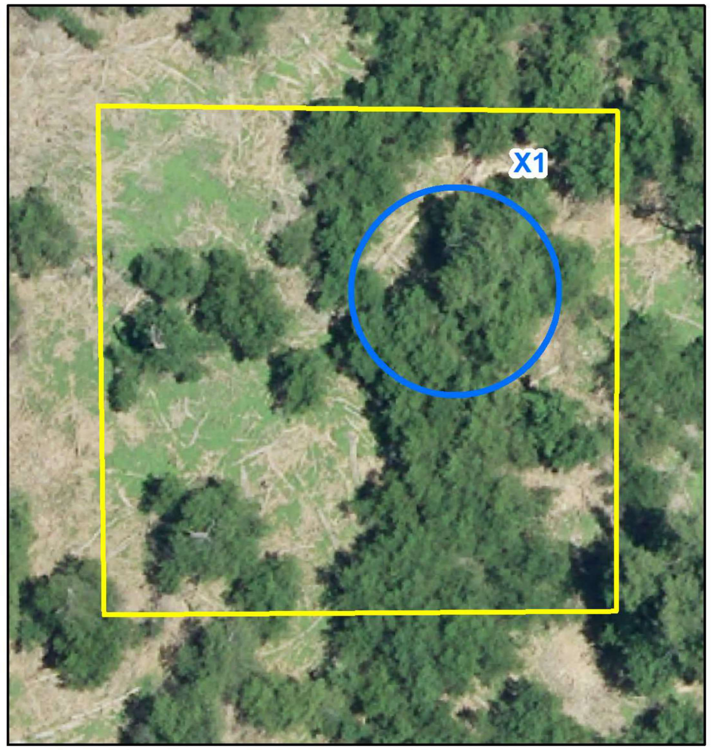
**Figure 3-8k**

## 2018 Air Photo (July 2, 2018)

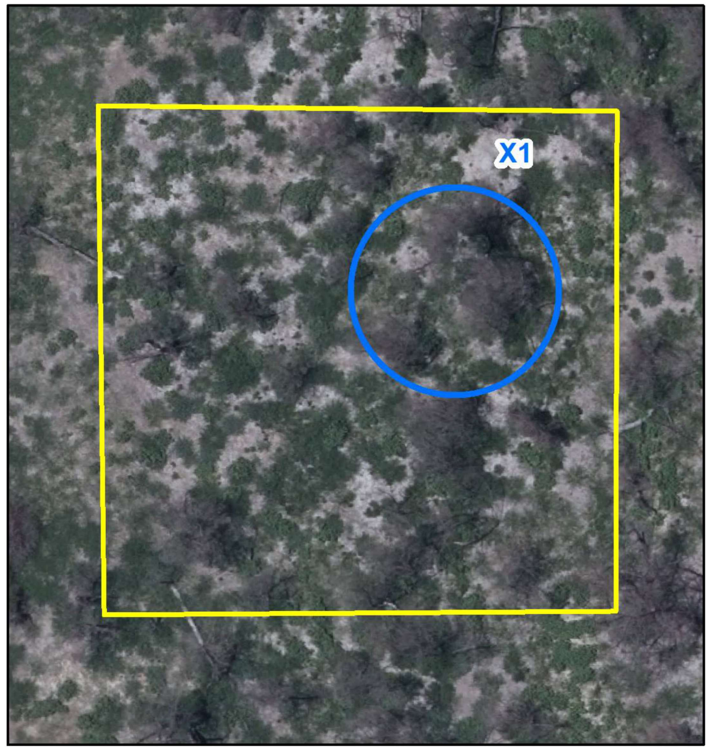
## 2019 Air Photo (July 4-5, 2019)



## 2020 Air Photo (July 6-8, 2020)



## 2021 Air Photo (June 26, 2021)

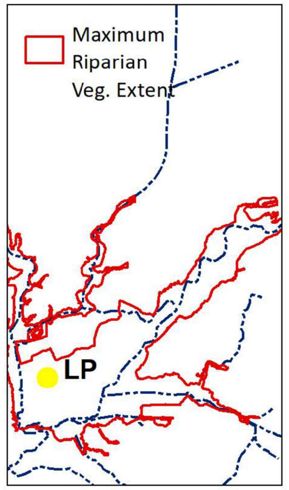


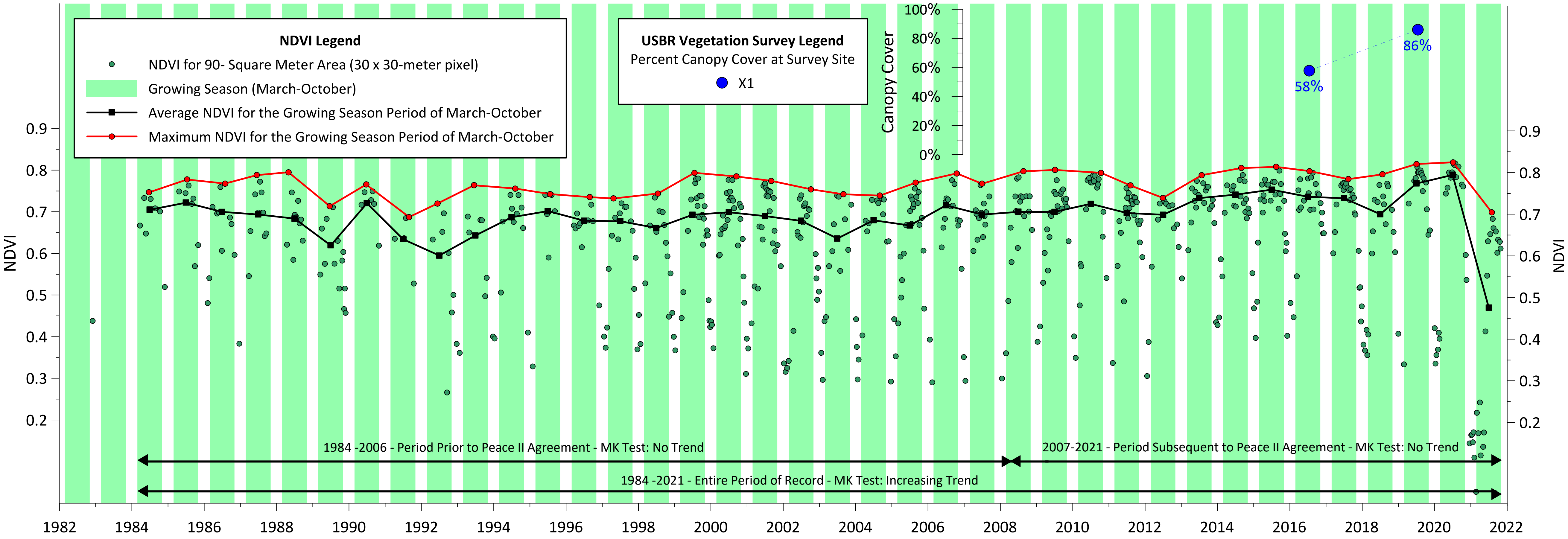
Meters
0 5 10

🟨 LP Area for NDVI Analysis 30x30 meter pixel

○ Vegetation Survey Plot Location 10-meter radius

**Location Along Santa Ana River**





Prepared by:

**WEST YOST**
Water. Engineered.

WEST YOST - K:\Clients\941 Chino Basin Watermaster\00-00-00 Master\PE1 - Data_Monitoring\GRAPHER\GRF\Prado\AnnualR\Figure 3-8l_NDVI_LP.grf - lhedley - 5/3/2022

**Prado Basin Habitat Sustainability Committee**
2021 Annual Report

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**Time Series of NDVI and Air Photos**
*Lower Prado Area for 1984 to 2021*

**Figure 3-8l**

### 3.1.3 Analysis of Vegetation Surveys

Vegetation surveys are performed for the PBHSP once every three years. The most recent vegetation survey was performed in 2019 by the USBR which was a continuation of the surveys performed in 2007, 2013, and 2016. Preliminary findings and results from the 2019 vegetation survey were published in the final report in June 2020 (USBR, 2020).

Table 3-3 summarizes some of the measured parameters for all areas surveyed in 2007, 2013, 2016, and 2019. The measurements of percent canopy cover from the USBR vegetation surveys are the most appropriate measured data for ground-truthing the NDVI. Percent canopy cover is a measurement of the percentage of the ground surface area that is directly covered by the vertical projections of tree crowns (USDA, 1999). Although there is no direct quantitative relationship between percent canopy cover and NDVI, percent canopy cover is a metric of the areal density of the vegetation that is reflecting visible and near-infrared light and therefore can be used for comparison with the NDVI analysis. The percent canopy cover at the survey location within the small areas of NDVI analysis in Figures 3-8a through 3-8l are charted with the NDVI time-series data. Where percent canopy cover measurements are available for more than one year, they typically show stable or increasing trends, consistent with the increasing trends in NDVI since 2007. Table 3-3 shows that overall the percent canopy cover for all surveyed areas each year has increased: the average percentages of canopy cover at all areas surveyed in 2007, 2013, 2016, and 2019 were 75-, 76-, 86-, and 82-percent, respectively.

## Table 3-3. Summary of USBR Vegetation Surveys in 2007, 2013, 2016, and 2019 in the Prado Basin - Canopy Cover, Tree Condition, and Occurrence of Polyphagous Shot-Hole Borer

| | Canopy Cover (%)[a] | | | | | Tree Condition (% trees surveyed per plot)[b] | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Not Stressed (Live) | | | | | Stressed | | | | | Dead | | | | | Polyphagous Shot-Hole Borer[c] | | | | |
| Site | 2007 | 2013 | 2016 | 2019 | Change Through 2019 | 2007 | 2013 | 2016 | 2019 | Change Through 2019 | 2007 | 2013 | 2016 | 2019 | Change Through 2019 | 2007 | 2013 | 2016 | 2019 | Change Through 2019 | Present in 2016 | % of Trees in 2016 | Present in 2019 | % of Trees in 2019 | % Change in 2019 |
| ***Chino Creek Sites*** | | | | | | | | | | | | | | | | | | | | | | | | | |
| Chino 3 | 59% | NM | NM | NM | - | NM | NM | NM | NM | -- | NM | NM | NM | NM | -- | NM | NM | NM | NM | -- | NM | NM | NM | NM | -- |
| Chino 3B | NM | 97% | 96% | 96% | -- | NM | 100% | 0% | 33% | -67% | NM | 0% | 100% | 44% | 44% | NM | 0% | 0% | 22% | 22% | no | 0% | no | 0% | 0% |
| Chino 4 | 80% | 94% | 98% | 84% | 4% | NM | 100% | 7% | 55% | -45% | NM | 0% | 80% | 40% | 40% | NM | 0% | 13% | 5% | 5% | no | 0% | no | 0% | 0% |
| Chino 9 | 92% | 96% | 95% | 96% | 4% | NM | 100% | 0% | 23% | -77% | NM | 0% | 100% | 59% | 59% | NM | 0% | 0% | 18% | 18% | no | 0% | no | 0% | 0% |
| Chino 11 | 94% | 96% | 96% | 98% | 4% | NM | 100% | 50% | 69% | -31% | NM | 0% | 42% | 0% | 0% | NM | 0% | 8% | 31% | 31% | no | 0% | no | 0% | 0% |
| Chino 16 | 46% | 61% | 81% | 52% | 7% | NM | NM | 27% | 50% | 23% | NM | NM | 64% | 50% | -14% | NM | NM | 9% | 0% | -- | no | 0% | no | 0% | 0% |
| Chino 18 | 38% | 87% | 90% | 77% | 39% | NM | 100% | 7% | 15% | -85% | NM | 0% | 67% | 69% | 69% | NM | 0% | 27% | 15% | 15% | yes | 40% | no | 0% | -40% |
| Chino 21 | 98% | 94% | 88% | 17% | -81% | NM | 100% | 0% | 73% | -27% | NM | 0% | 100% | 0% | 0% | NM | 0% | 0% | 27% | 27% | yes | 17% | no | 0% | -17% |
| Chino 24 | 93% | 93% | 98% | 94% | 1% | NM | 100% | 6% | 32% | -68% | NM | 0% | 94% | 56% | 56% | NM | 0% | 0% | 12% | 12% | yes | 6% | no | 0% | -6% |
| Chino 30 | 79% | 88% | NM | NM | -- | NM | NM | NM | NM | -- | NM | NM | NM | NM | -- | NM | NM | NM | NM | -- | NM | NM | NM | NM | -- |
| Chino 30B | NM | NM | 89% | 74% | -15% | NM | | 0% | 20% | 20% | NM | NM | 89% | 50% | -39% | NM | NM | 11% | 30% | 19% | yes | 100% | no | 0% | -100% |
| Chino 31 | 82% | 93% | 97% | 91% | 9% | NM | 100% | 7% | 4% | -96% | NM | 0% | 93% | 72% | 72% | NM | 0% | 0% | 24% | 24% | yes | 7% | no | 0% | -7% |
| Chino 34 | 96% | 97% | 89% | 75% | -21% | NM | 100% | 0% | 33% | -67% | NM | 0% | 67% | 33% | 33% | NM | 0% | 33% | 33% | 33% | no | 0% | no | 0% | 0% |
| Chino 78 | 95% | 98% | 87% | 98% | 3% | NM | 100% | 0% | 45% | -55% | NM | 0% | 80% | 55% | 55% | NM | 0% | 20% | 0% | 0% | yes | 80% | no | 0% | -80% |
| Chino 81 | 92% | 0% | NM | NM | - | NM | NM | NM | NM | -- | NM | NM | NM | NM | -- | NM | NM | NM | NM | -- | NM | NM | NM | NM | -- |
| Chino 85 | 89% | 0% | NM | NM | -- | NM | NM | NM | NM | -- | NM | NM | NM | NM | -- | NM | NM | NM | NM | -- | NM | NM | NM | NM | -- |
| Chino X3 | NM | NM | 93% | 94% | 1% | NM | NM | 25% | 83% | 58% | NM | NM | 75% | 17% | -58% | NM | NM | 0% | 0% | 0% | no | 0% | no | 0% | 0% |
| Chino X4 | NM | NM | 92% | 94% | 2% | NM | NM | 0% | 43% | 43% | NM | NM | 100% | 14% | -86% | NM | NM | 0% | 43% | 43% | yes | 100% | yes | 71% | -29% |
| Chino X5 | NM | NM | 96% | 95% | -1% | NM | NM | 75% | 89% | 14% | NM | NM | 25% | 11% | -14% | NM | NM | 0% | 0% | 0% | yes | 25% | no | 0% | -25% |
| Chino X6 | NM | NM | 98% | 99% | 1% | NM | NM | 87% | 47% | -40% | NM | NM | 13% | 47% | 34% | NM | NM | 0% | 7% | 7% | yes | 13% | no | 0% | -13% |
| Chino X7 | NM | NM | 88% | 66% | -22% | NM | NM | 0% | 43% | 43% | NM | NM | 70% | 43% | -27% | NM | NM | 30% | 14% | -16% | yes | 70% | no | 0% | -70% |
| Chino X8 | NM | NM | 85% | 99% | 14% | NM | NM | 0% | 71% | 71% | NM | NM | 62% | 24% | -38% | NM | NM | 38% | 6% | -32% | yes | 46% | yes | 6% | -40% |
| ***Average*** | **81%** | **78%** | **92%** | **83%** | **-3%** | **-** | **100%** | **16%** | **46%** | **-21%** | **-** | **0%** | **73%** | **38%** | **10%** | **-** | **0%** | **11%** | **16%** | **12%** | **yes** | **28%** | **no** | **4%** | **-24%** |
| | | | | | | | | | | | | | | | | | | | | | | | | | |
| ***Mill Creek Sites*** | | | | | | | | | | | | | | | | | | | | | | | | | |
| Mill 1 | 40% | 0% | NM | NM | -- | NM | NM | NM | NM | -- | NM | NM | NM | NM | -- | NM | NM | NM | NM | -- | NM | NM | NM | NM | -- |
| Mill 3 | 8% | 13% | NM | NM | -- | NM | NM | NM | NM | -- | NM | NM | NM | NM | -- | NM | NM | NM | NM | -- | NM | NM | NM | NM | -- |
| Mill 4 | 38% | 6% | 0% | 0% | -38% | NM | 0% | 0% | 100% | 100% | NM | 63% | 50% | 0% | -63% | NM | 37% | 50% | 0% | -37% | yes | 50% | no | 0% | -50% |
| Mill 8 | 66% | 88% | 82% | 79% | 13% | NM | 33% | 33% | 0% | -33% | NM | 67% | 0% | 50% | -17% | NM | 0% | 67% | 50% | 50% | yes | 33% | no | 0% | -33% |
| Mill 11 | 75% | 80% | NM | NM | -- | NM | 90% | NM | NM | -- | NM | 0% | NM | NM | -- | NM | 10% | NM | NM | -- | NM | NM | NM | 0% | -- |
| Mill 18 | 62% | 68% | 78% | 90% | 28% | NM | 100% | 38% | 10% | -90% | NM | 0% | 38% | 80% | 80% | NM | 0% | 25% | 10% | 10% | yes | 38% | no | 0% | -38% |
| Mill 22 | 89% | 93% | 96% | 93% | 4% | NM | 86% | 0% | 43% | -43% | NM | 0% | 79% | 43% | 43% | NM | 14% | 21% | 14% | 0% | yes | 64% | no | 0% | -64% |
| Mill 30 | 63% | 63% | NM | NM | -- | NM | NM | NM | NM | -- | NM | NM | NM | NM | -- | NM | NM | NM | NM | -- | NM | NM | NM | 0% | -- |
| Mill 35 | 81% | 95% | NM | NM | -- | NM | 100% | NM | NM | -- | NM | 0% | NM | NM | -- | NM | 0% | NM | NM | -- | NM | NM | NM | 0% | -- |
| Mill 39 | 94% | 87% | 96% | 96% | 2% | NM | 92% | 0% | 13% | -79% | NM | 0% | 67% | 63% | 63% | NM | 8% | 33% | 25% | 17% | yes | 44% | yes | 38% | -6% |
| Mill 60 | 76% | 90% | 83% | 51% | 6% | NM | 86% | 0% | 0% | -86% | NM | 0% | 93% | 69% | 69% | NM | 14% | 7% | 31% | 17% | yes | 29% | no | 0% | -29% |
| Mill 62 | 66% | 96% | 96% | 63% | 30% | NM | 100% | 0% | 6% | -94% | NM | 0% | 94% | 25% | 25% | NM | 0% | 6% | 69% | 69% | yes | 94% | yes | 25% | -69% |
| Mill 63 | 70% | 97% | 78% | 43% | 8% | NM | 100% | 0% | 15% | -85% | NM | 0% | 68% | 23% | 23% | NM | 0% | 32% | 62% | 62% | yes | 41% | yes | 23% | -18% |
| Mill 67 | 75% | 95% | NM | NM | -- | NM | 100% | NM | NM | -- | NM | 0% | NM | NM | -- | NM | 0% | NM | NM | -- | NM | NM | NM | 0% | -- |
| Mill 69 | 92% | 84% | 75% | 98% | 6% | NM | 90% | 0% | 67% | -23% | NM | 0% | 64% | 0% | 0% | NM | 10% | 36% | 33% | 23% | yes | 64% | yes | 22% | -42% |
| Mill 82 | 92% | 96% | 56% | 91% | -1% | NM | 100% | 0% | 69% | -31% | NM | 0% | 75% | 15% | 15% | NM | 0% | 25% | 15% | 15% | yes | 25% | yes | 8% | -17% |
| Mill 101 | 90% | 94% | 83% | 88% | -2% | NM | 96% | 0% | 26% | -70% | NM | 0% | 87% | 48% | 48% | NM | 4% | 13% | 26% | 22% | yes | 83% | no | 0% | -83% |
| Mill X9 | NM | NM | 94% | 94% | 0% | NM | NM | 70% | 42% | -28% | NM | NM | 30% | 58% | 28% | NM | NM | 0% | 0% | 0% | yes | 10% | no | 0% | -10% |
| Mill X10 | NM | NM | 89% | 95% | 6% | NM | NM | 0% | 70% | 70% | NM | NM | 50% | 30% | -20% | NM | NM | 50% | 0% | -50% | yes | 50% | no | 0% | -50% |
| ***Average*** | **69%** | **73%** | **77%** | **75%** | **5%** | **-** | **84%** | **11%** | **35%** | **-38%** | **-** | **9%** | **61%** | **39%** | **23%** | **-** | **7%** | **28%** | **26%** | **15%** | **yes** | **48%** | **no** | **7%** | **-39%** |
| | | | | | | | | | | | | | | | | | | | | | | | | | |
| ***Santa Ana River Sites*** | | | | | | | | | | | | | | | | | | | | | | | | | |
| SAR X1 | NM | NM | 58% | 86% | 28% | NM | NM | 76% | 75% | -1% | NM | NM | 5% | 13% | 8% | NM | NM | 19% | 13% | -6% | yes | 3% | no | 0% | -3% |
| SAR X2 | NM | NM | 93% | 79% | -14% | NM | NM | 11% | 60% | 49% | NM | NM | 89% | 30% | -59% | NM | NM | 0% | 10% | 10% | yes | 17% | no | 0% | -17% |
| SAR X11 | NM | NM | 88% | 94% | 6% | NM | NM | 27% | 44% | 17% | NM | NM | 64% | 11% | -53% | NM | NM | 9% | 44% | 35% | yes | 82% | no | 0% | -82% |
| SAR X12 | NM | NM | 96% | 100% | 4% | NM | NM | 9% | 44% | 35% | NM | NM | 91% | 44% | -47% | NM | NM | 0% | 13% | 13% | yes | 91% | no | 0% | -91% |
| SAR X13 | NM | NM | 87% | 100% | 13% | NM | NM | 0% | 17% | 17% | NM | NM | 67% | 67% | 0% | NM | NM | 33% | 17% | -16% | yes | 67% | no | 0% | -67% |
| SAR X14 | NM | NM | 88% | 97% | 10% | NM | NM | 0% | 75% | 75% | NM | NM | 100% | 25% | -75% | NM | NM | 0% | 0% | 0% | yes | 100% | no | 0% | -100% |
| ***Average*** | **-** | **-** | **85%** | **93%** | **8%** | **-** | **-** | **21%** | **53%** | **32%** | **-** | **-** | **69%** | **32%** | **-38%** | **-** | **-** | **10%** | **16%** | **6%** | **yes** | **60%** | **no** | **0%** | -60% |
| **Average all Sites** | **75%** | **76%** | **86%** | **82%** | **8%** | **-** | **91%** | **15%** | **43%** | **-19%** | **-** | **5%** | **68%** | **37%** | **7%** | **-** | **4%** | **17%** | **19%** | **12%** | **yes** | **40%** | **no** | **5%** | **-35%** |

**Notes:**

NM - Not Measured

(a) Canopy cover is a measurement of the percentage of a ground area directly covered by vertical projections of tree crowns. In the field, canopy cover is measured using a spherical densiometer standing five meters from the center of the plot in the four cardinal directions (north, south, east, west). Canopy Cover percent herein is the average of the four measurements.

(b) Tree condition is a qualitative measurement of the health of the tree. Trees were assessed and classified as "live," "stressed," or "dead". The percentage of each classification per plot is shown here.

(c) In 2016 and 2019 trees were assessed for the presence of polyphagous shot-hole borers (PSHB). If a tree showed signs of the beetle it was noted. The percent of trees in each plot that showed signs of beetle infestation was then calculated.

The USBR vegetation surveys in 2016 and 2019 noticed the presence of the invasive pest—the PSHB. Overall, the presence of the PSHB decreased in 2019 at all of the sites where it was noted in 2016, and some of the sites no longer indicated the presence of the PSHB in 2019 where it was noted in 2016. The vegetation surveys provide a measurement of the change in riparian habitat health from 2016 to 2019 for those survey locations impacted by the PSHB. This is discussed in further detail in Section 3.6.2.

### *3.1.4 Summary*

The extent of the riparian habitat in the Prado Basin has been delineated from air photos and maps of NDVI. The extent increased from about 1.85 $mi^2$ in 1960 to about 6.7 $mi^2$ by 1999 and has remained relatively constant through 2021.

The quality of riparian habitat has been characterized through the analysis of air photos, maps of NDVI, and time-series charts of NDVI for large and small areas located throughout the Prado Basin:

- The NDVI change map shows mostly no change or varying levels of NDVI decreases throughout the riparian vegetation in the Prado Basin. Notable decreases in the NDVI spatially are observed in large patches along the SAR and lower portion of Chino Creek and below the OCWD wetlands.
- The analyses of NDVI time series indicate that from 2020 to 2021 there was a slight decrease in the greenness of the riparian vegetation across the Prado Basin when analyzed as a whole and the along the Chino Creek and Mill Creek reaches analyzed as a whole. Throughout the riparian vegetation extent, there were varying levels of stable and decreasing trends in the greenness of the vegetation from 2020 to 2021 as indicated by the NDVI time series. However, at all areas but one, these one-year changes in the Average Growing-Season NDVI are relatively minor and within the historical ranges of one-year NDVI variability, and most were less than the average annual change in NDVI. For the LP area, the recent one-year decline in the Average Growing Season NDVI exceeds the magnitude of any historical one-year change in this area. Inspection of the air photos corroborates the observation of this decreased greenness in LP area.
- The Mann-Kendall test result on the Average Growing-Season NDVI for the post Peace II Agreement period from 2007 to 2021 indicates an “increasing trend” or “no trend” for the Prado Basin riparian vegetation as whole and all the other areas analyzed through the Prado Basin.
- Visual inspection of the 2020 and 2021 air photos for the MC-2 area, where NDVI decreased from 2020 to 2021, shows a notable decrease in green vegetated areas.

The remainder of Section 3.0 describes the factors that can affect the riparian habitat, how these factors have changed over time, and how the changes in these factors may explain the changes that are being observed in the riparian habitat described above.

## 3.2 Groundwater and Its Relationship to Riparian Habitat

Peace II Agreement implementation was projected to change groundwater pumping patterns and reduce artificial recharge through 2030, both of which would change groundwater levels in the Chino Basin. These groundwater level changes caused by Peace II Agreement implementation and other unrelated water management activities[13] have the potential to impact the extent and quality of Prado Basin riparian habitat.

This section characterizes the history of groundwater pumping and changes in groundwater-levels in the GMP study area and compares this history to the trends in the extent and quality of the riparian habitat described in Section 3.1.

### *3.2.1 Groundwater Pumping*

Table 3-4 lists the groundwater pumping estimates for the GMP study area for WY 1961 to 2021.[14] Figure 3-9 is a map that illustrates the spatial distribution of groundwater pumping from wells within the GMP study area for WY 2021. This figure includes a bar chart of the annual groundwater pumping in the GMP study area (from Table 3-4 below). Figure 3-9 illustrates the following history of groundwater pumping within the GMP study area:

- From 1961 to 1990, groundwater pumping averaged about 45,900 afy. Pumping mainly occurred at private domestic and agricultural wells distributed throughout the area.
- From 1991 to 1999, groundwater pumping steadily declined, primarily due to conversions of agricultural land uses to urban. By WY 1999, groundwater pumping was estimated to be about 23,600 afy—about 49 percent less than average annual pumping from 1961-1990.
- From 2000 to 2021, CDA pumping commenced and increased to replace the declining agricultural groundwater pumping—as envisioned in the OBMP/Peace Agreement and Peace II Agreement. By WY 2021, total groundwater pumping was about 46,650 afy—an increase of about 98 percent from 1999.
- Over the last two years from 2019 to 2021, the CDA pumping increased by about 8,500 afy. In mid-2020 the CDA pumping reached its intended pumping rate of 40,000 afy to maintain hydraulic control of the Chino Basin.

**Table 3-4. Annual Groundwater Pumping in the Groundwater Monitoring Program Study Area**

| Water Year | Non-CDA Pumping, afy[a] | CDA Pumping, afy | Total Pumping, afy[a] |
|---|---|---|---|
| 1961 | 48,577 | 0 | 48,577 |
| 1962 | 43,811 | 0 | 43,811 |
| 1963 | 43,293 | 0 | 43,293 |
| 1964 | 45,170 | 0 | 45,170 |
| 1965 | 43,294 | 0 | 43,294 |
| 1966 | 46,891 | 0 | 46,891 |

---

[13] Other water management activities unrelated to Peace II Agreement implementation include changes in wastewater discharge to the SAR due to conservation, recycling, and drought response; increases in storm water diverted and recharged; increases in recycled water recharge; management of groundwater in storage; and the implementation of the Dry-Year Yield Program with MWD.

[14] Production for years prior to WY 2001 were estimated in the calibration of the 2013 Chino Basin groundwater model (WEI, 2015). Production estimates for WY 2001 and thereafter are based on metered production data and water-duty estimates compiled by Watermaster.

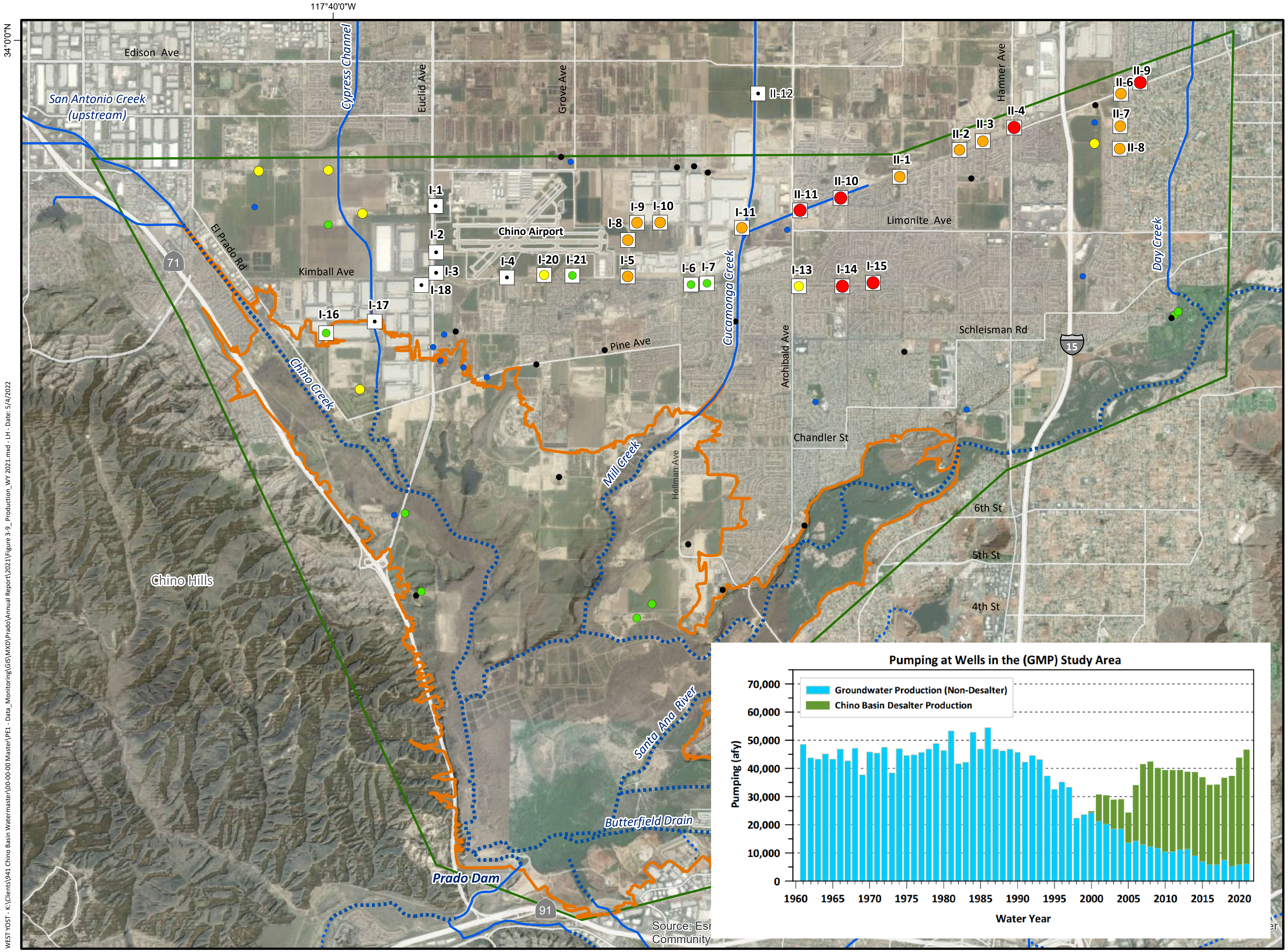
## Table 3-4. Annual Groundwater Pumping in the Groundwater Monitoring Program Study Area

| Water Year | Non-CDA Pumping, afy[a] | CDA Pumping, afy | Total Pumping, afy[a] |
|---|---|---|---|
| 1967 | 42,709 | 0 | 42,709 |
| 1968 | 47,180 | 0 | 47,180 |
| 1969 | 37,754 | 0 | 37,754 |
| 1970 | 45,849 | 0 | 45,849 |
| 1971 | 45,492 | 0 | 45,492 |
| 1972 | 47,541 | 0 | 47,541 |
| 1973 | 38,427 | 0 | 38,427 |
| 1974 | 47,014 | 0 | 47,014 |
| 1975 | 44,606 | 0 | 44,606 |
| 1976 | 44,847 | 0 | 44,847 |
| 1977 | 45,710 | 0 | 45,710 |
| 1978 | 46,881 | 0 | 46,881 |
| 1979 | 48,829 | 0 | 48,829 |
| 1980 | 46,402 | 0 | 46,402 |
| 1981 | 53,326 | 0 | 53,326 |
| 1982 | 41,719 | 0 | 41,719 |
| 1983 | 42,200 | 0 | 42,200 |
| 1984 | 52,877 | 0 | 52,877 |
| 1985 | 46,876 | 0 | 46,876 |
| 1986 | 54,501 | 0 | 54,501 |
| 1987 | 46,875 | 0 | 46,875 |
| 1988 | 46,277 | 0 | 46,277 |
| 1989 | 46,835 | 0 | 46,835 |
| 1990 | 45,732 | 0 | 45,732 |
| 1991 | 42,266 | 0 | 42,266 |
| 1992 | 44,617 | 0 | 44,617 |
| 1993 | 43,186 | 0 | 43,186 |
| 1994 | 37,390 | 0 | 37,390 |
| 1995 | 32,604 | 0 | 32,604 |
| 1996 | 35,200 | 0 | 35,200 |
| 1997 | 33,340 | 0 | 33,340 |
| 1998 | 22,366 | 0 | 22,366 |
| 1999 | 23,632 | 0 | 23,632 |
| 2000 | 24,299 | 523 | 24,822 |
| 2001 | 21,249 | 9,470 | 30,719 |
| 2002 | 20,271 | 10,173 | 30,445 |
| 2003 | 18,600 | 10,322 | 28,922 |
| 2004 | 18,606 | 10,480 | 29,086 |

### Table 3-4. Annual Groundwater Pumping in the Groundwater Monitoring Program Study Area

| Water Year | Non-CDA Pumping, afy[(a)] | CDA Pumping, afy | Total Pumping, afy[(a)] |
|---|---|---|---|
| 2005 | 13,695 | 10,595 | 24,290 |
| 2006 | 14,261 | 19,819 | 34,079 |
| 2007 | 12,988 | 28,529 | 41,517 |
| 2008 | 12,293 | 30,116 | 42,409 |
| 2009 | 11,694 | 28,456 | 40,150 |
| 2010 | 10,452 | 28,964 | 39,416 |
| 2011 | 10,460 | 28,941 | 39,401 |
| 2012 | 11,193 | 28,230 | 39,423 |
| 2013 | 11,433 | 27,380 | 38,813 |
| 2014 | 9,059 | 29,626 | 38,685 |
| 2015 | 6,985 | 29,877 | 36,862 |
| 2016 | 5,900 | 28,249 | 34,148 |
| 2017 | 5,899 | 28,351 | 34,250 |
| 2018 | 7,504 | 29,191 | 36,695 |
| 2019 | 5,348 | 32,004 | 37,352 |
| 2020 | 5,875 | 37,973 | 43,848 |
| 2021 | 6,155 | 40,501 | 46,656 |
| Average: 1961-1990 | 45,917 | 0 | 45,917 |
| Average: 1991-1999 | 34,956 | 0 | 34,956 |
| Average: 2000-2021 | 12,289 | 23,203 | 39,492 |

(a) Prior to water year 2001 production is estimated with the calibrated 2013 Chino Basin groundwater model (WEI, 2015).



Groundwater Pumping Water Year 2021 (af)

- ● < 10
- ● 10 - 100
- ● 100 - 500
- ● 500 - 1,000
- ● 1,000 - 2,500
- ● 2,500 - 5,000

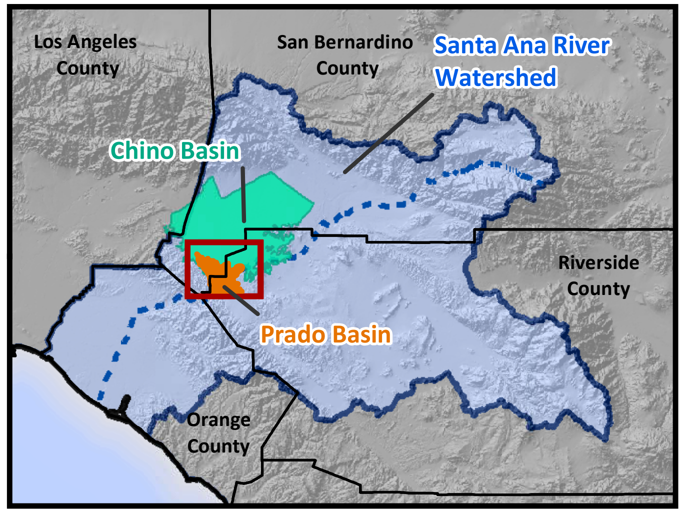
☐ Chino Basin Desalter Well

▭ Groundwater Monitoring Program (GMP) Study Area

Prado Basin Management Zone (Prado Basin)

Concrete-Lined Channels

Unlined Rivers and Streams



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**Groundwater Pumping**
*Water Year 2021*

**Figure 3-9**

### 3.2.2 Groundwater Levels

Figures 3-10a and 3-10b are groundwater-elevation contour maps of the GMP study area for the shallow aquifer system in September 2016 (first Annual Report condition) and September 2021 (current condition).[15] The contours were created from rasterized surfaces of groundwater elevations that were created based on measured groundwater elevations at wells. The raster of groundwater elevation for September 2016 was subtracted from the raster of groundwater elevation for September 2021 to create a raster of change in groundwater elevation from 2016 to 2021 (Figure 3-11). Figure 3-11 shows that groundwater levels changed by about +/- 10 feet across the GMP study area from 2016 to 2021. The greatest areas of change in groundwater elevation occurred in the northern portion of the GMP study area near the Chino Basin Desalter well field. Groundwater levels declined by slightly more than 10 feet near the central portion of Chino Basin Desalter well field north of Mill Creek (Wells I-5, I-6, I-8, I-9, I-10, I-11, I-13, I-21) and increased by about 10 feet to the north of the western portion the Chino Basin Desalter well field (Wells I-16, I-17, I-18).

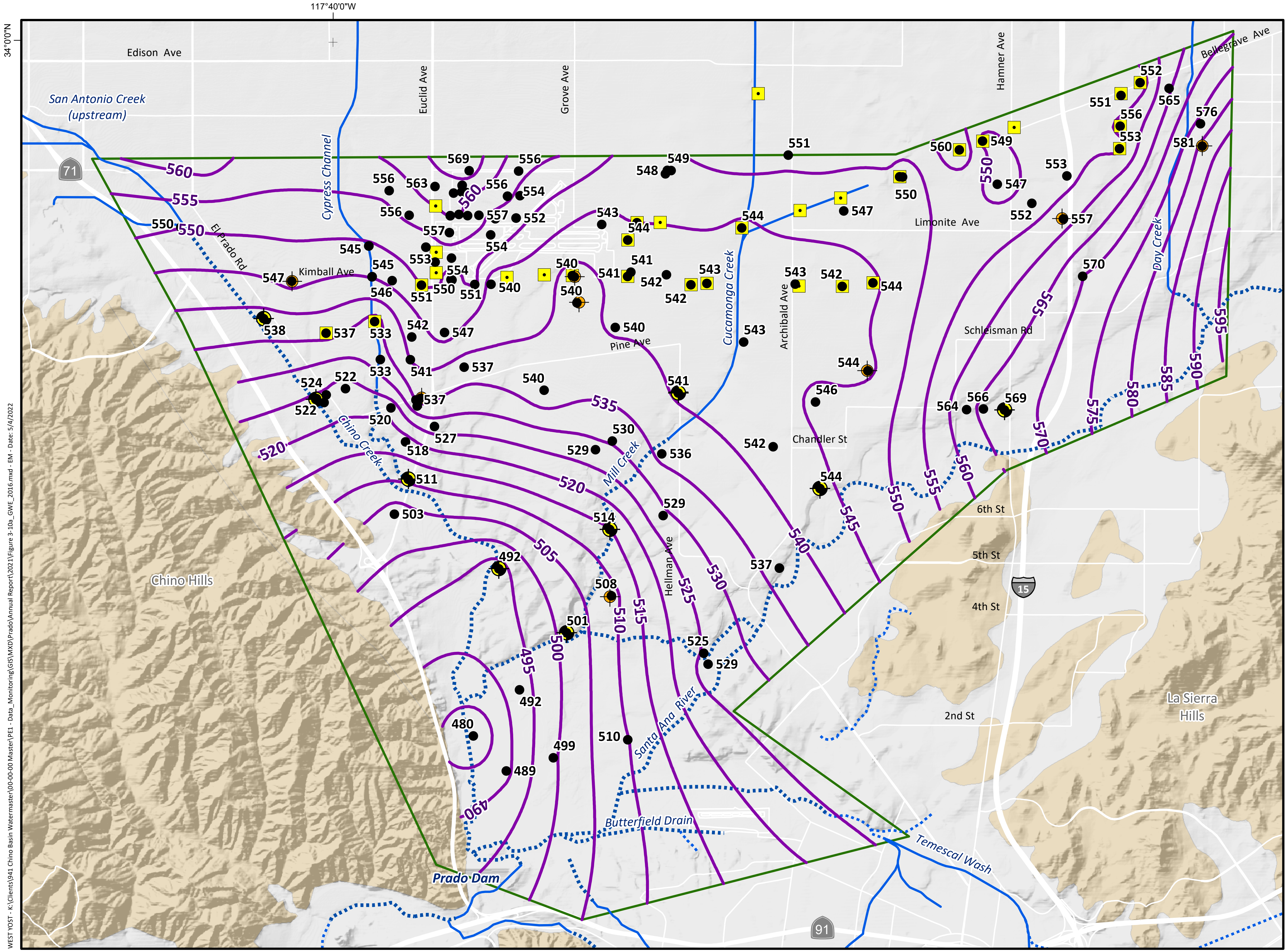
Within the extent of the riparian vegetation, groundwater elevations have remained relatively stable throughout most of the extent from 2016-2021, but there are some notable areas where groundwater levels have declined: the northernmost reach of Mill Creek just south of PB-2 to PB-1 (decline of 1 to 5 feet); and northern reach of the SAR within Prado Basin near PB-3 (decline of about 2 feet). The north portions of Mill Creek and the SAR where we observe these declines in groundwater levels from 2016 to 2021 are a part of the regional pumping depression that is expanding around the increased pumping at the Chino Basin Desalters to the north.

Figure 3-12 is a map of depth-to-groundwater in September 2021. It was created by subtracting a one-meter horizontal resolution digital-elevation model of the ground surface (Associated Engineers, 2007) from the raster of groundwater elevation for September 2021. An outline of the Prado Basin riparian habitat extent is superimposed on the 2021 depth-to-groundwater raster. With few exceptions,[16] the riparian habitat overlies areas where the depth-to-groundwater is less than 15 feet below the ground surface (ft-bgs). The shallow groundwater could exit the Prado Basin via rising groundwater discharge to the SAR and its tributaries and/or evapotranspiration by the riparian vegetation.

---

[15] Historical groundwater-elevation data for the Prado Basin are scarce due to a lack of wells and/or monitoring. As such, the discussion and interpretation of measured groundwater elevations focuses on the GMP's period of record.

[16] Exceptions include: the upstream reach of Temescal Wash in the Prado Basin, some limited areas west of the southern reach of Chino Creek, small patch in the upper portion of Chino Creek, small patch in the northernmost reach of Mill Creek, and small patches along the SAR east of well PB-3.



- 500 Equal Elevation Contour of Groundwater Elevation (feet above mean sea level)
- 505 ● Well with Measured Groundwater Elevation in September 2016 Used to Draw Contours; Labeld by Groundwater Elevation (feet above mean sea level)
- ⊕ PBHSP Monitoring Well Site
- ⊕ HCMP Monitoring Well Site
- ▣ Chino Basin Desalter Well
- ▭ Groundwater Monitoring Program (GMP) Study Area
- ∿ Concrete-Lined Channels
- ⋯ Unlined Rivers and Streams

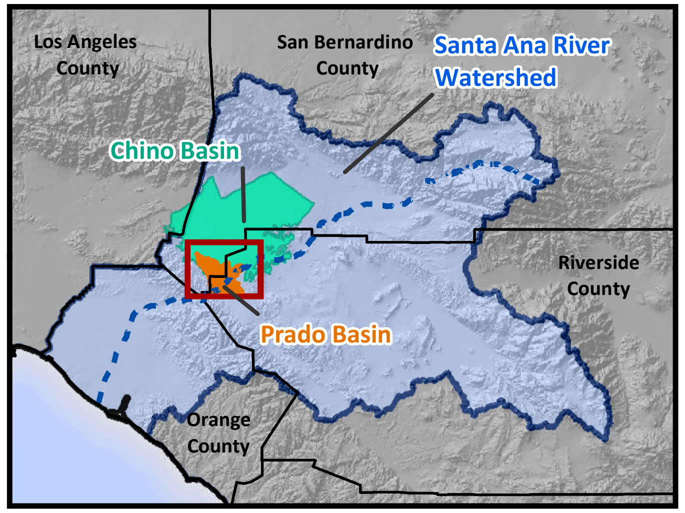
Surface Geology

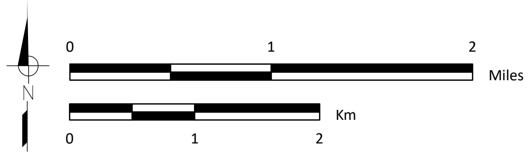
*Consolidated Bedrock*

- ▢ Quaternary Alluvium

*Water-Bearing Sediments*

- ▨ Undifferentiated Pre-Tertiary to Early Pleistocene Igneous, Metamorphic, and Sedimentary Rocks





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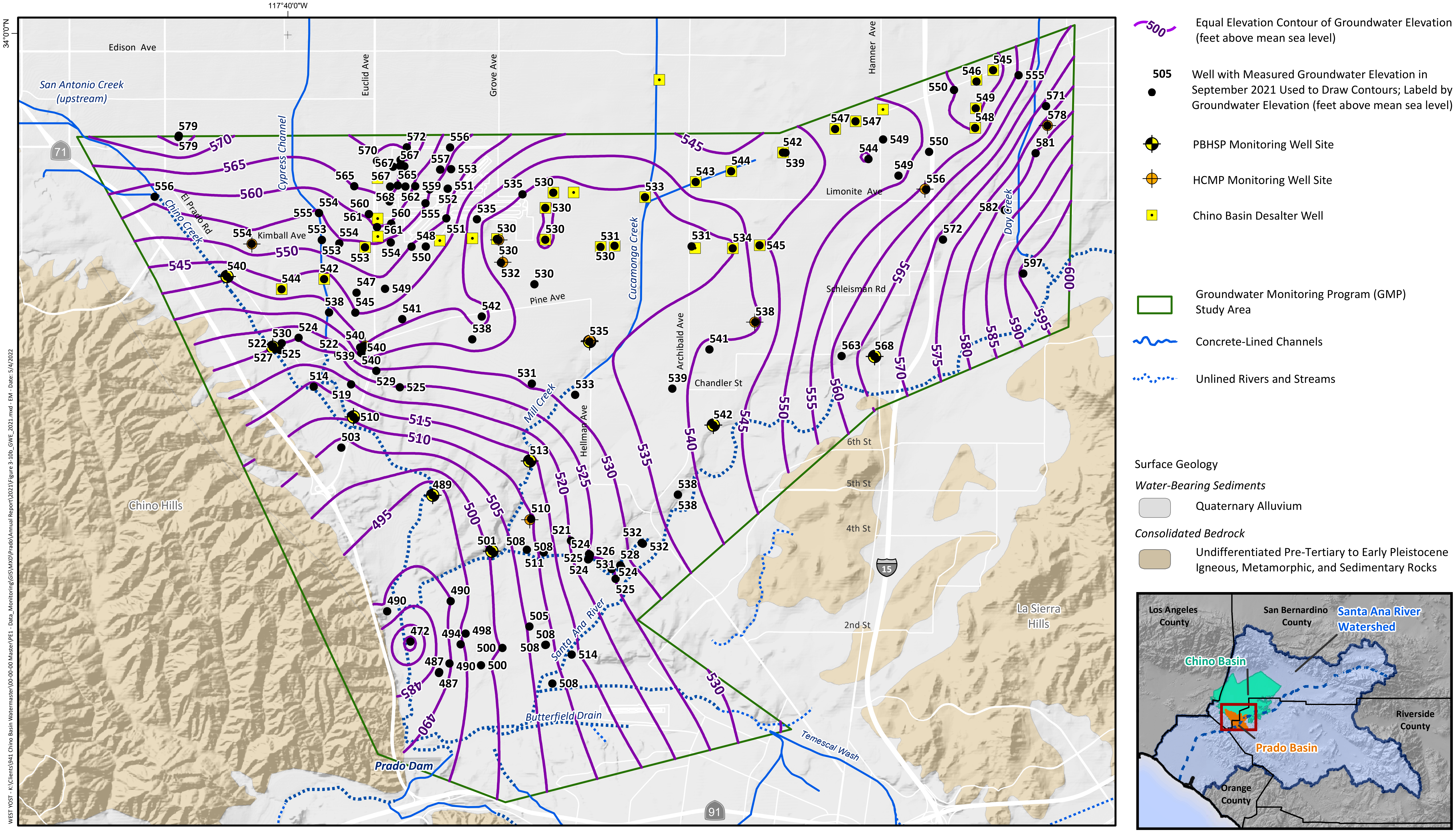
## Map of Groundwater Elevation
*September 2016 - Shallow Aquifer System*

**Figure 3-10a**



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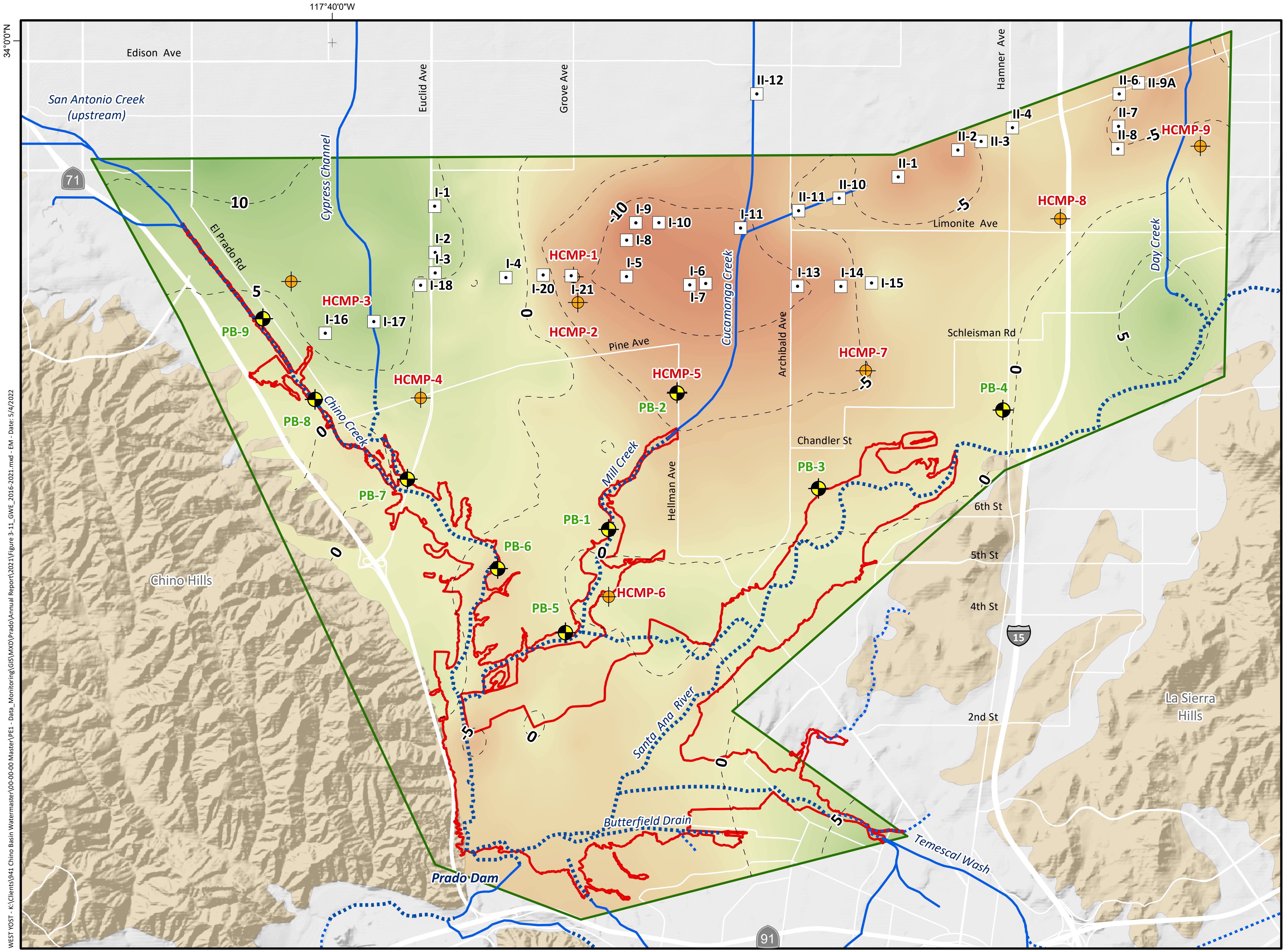
## Map of Groundwater Elevation
*September 2021 - Shallow Aquifer System*

**Figure 3-10b**



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+ 25
0
- 25

Change in Groundwater Elevation from September 2016 to September 2021

Contour of Change in Groundwater Elevation from September 2016 to September 2021 (feet)

Chino Basin Desalter Well

HCMP Monitoring Well Site

PBHSP Monitoring Well Site

Groundwater Monitoring Program (GMP) Study Area

Maximum Extent of the Riparian Vegetation in Prado Basin

Concrete-Lined Channels

Unlined Rivers and Streams

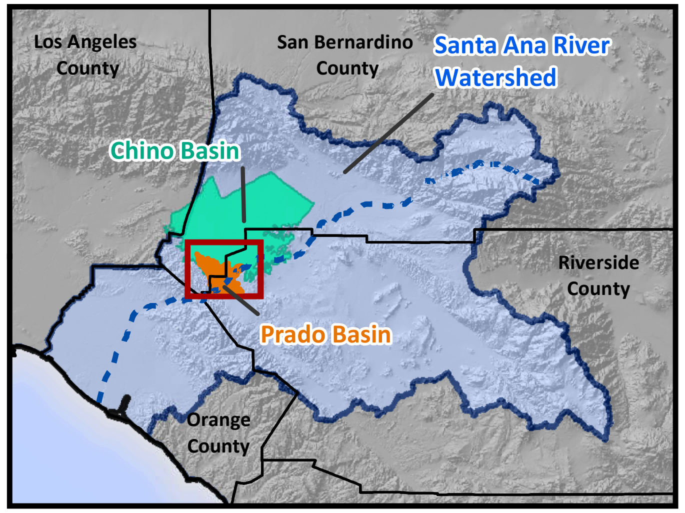
Surface Geology

*Water-Bearing Sediments*

Quaternary Alluvium

*Consolidated Bedrock*

Undifferentiated Pre-Tertiary to Early Pleistocene Igneous, Metamorphic, and Sedimentary Rocks



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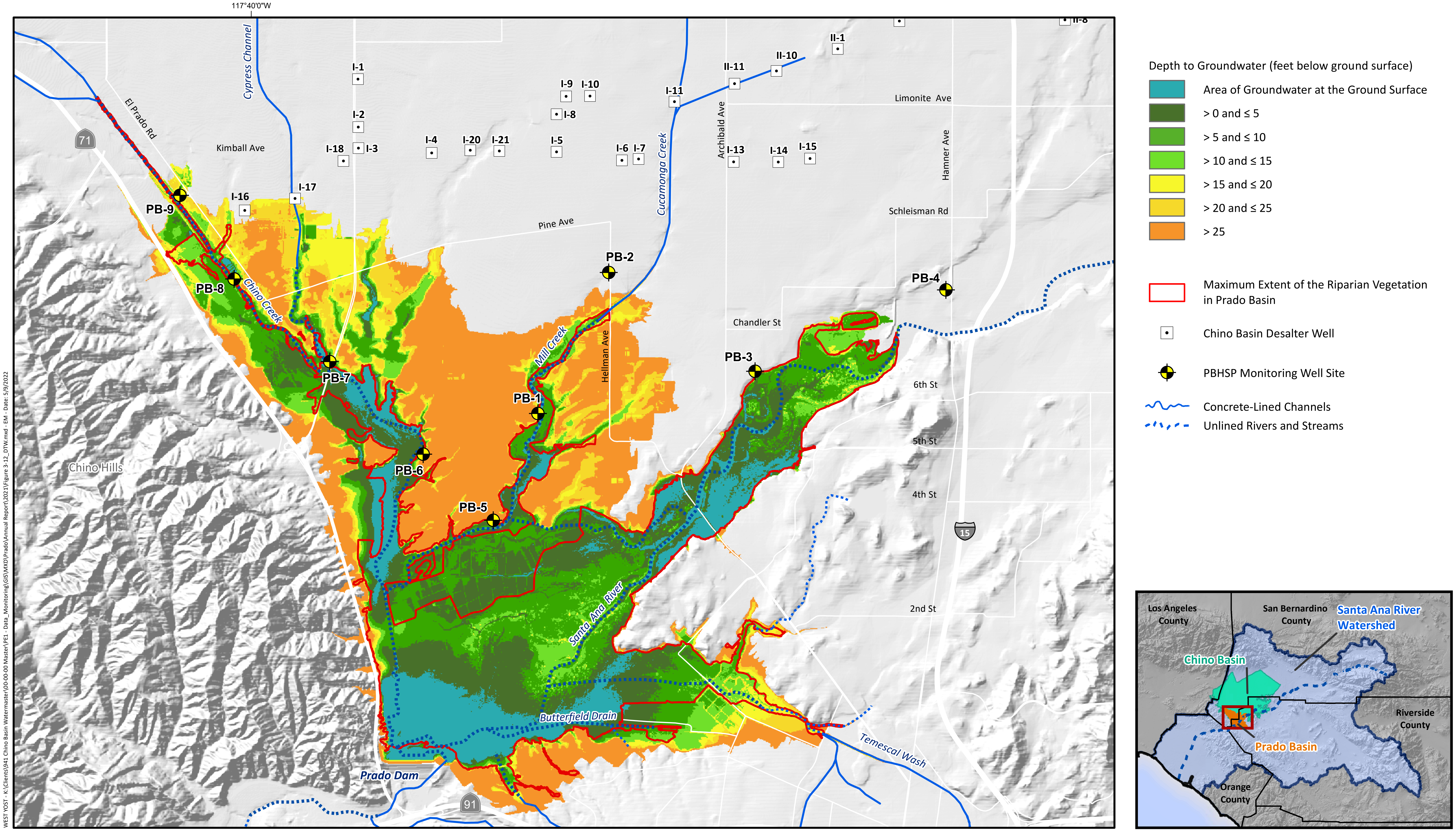
## Change in Groundwater Elevation
*September 2016 to September 2021*

**Figure 3-11**



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**Depth to Groundwater**
*September 2021*

**Figure 3-12**

### 3.2.3 Groundwater Levels Compared to NDVI

Figures 3-13a through 3-13c are time-series charts that compare long-term trends in groundwater pumping and groundwater elevations to the trends in the quality of the riparian vegetation as indicated by the NDVI for three areas in the Prado Basin: Chino Creek, Mill Creek, and the SAR. The period of analysis for these charts is 1984 to 2021—the period of NDVI availability. The upper chart in these figures compares changes in groundwater levels for each respective area to long-term trends in groundwater pumping within the respective regions of the GMP study area (Chino Creek, Mill Creek, and SAR regions). The annual groundwater pumping for wells within the respective regions is a stacked bar chart for the Chino Basin Desalter wells and non-Chino Basin Desalter wells. Groundwater-elevation estimates for the period of 1984 to 2018 were extracted from Watermaster's most recent calibration of its groundwater-flow model at the monitoring well locations (WEI, 2020). The more recent groundwater-elevation data shown on these charts were measured at monitoring wells constructed by Watermaster and the IEUA to support the Hydraulic Control Monitoring Program (HCMP) (beginning in 2005) and the PBHSP (beginning in 2015). Where the measured and model-estimated groundwater elevations overlap in time, the model-estimated elevations mimic the seasonal fluctuations and longer-term trends of the measured elevations and are typically no more than 10 feet different. This supports the use of these model-estimated groundwater elevations in this analysis.

The lower chart in Figures 3-13a through 3-13c displays the time series of the Average Growing-Season NDVI for the defined areas (discussed in Section 3.1) along Chino Creek, Mill Creek, and the SAR. For reference, the Mann-Kendall test results for trends in the Average Growing-Season NDVI for 1984-2021, 1984-2006, and 2007-2021 are shown in the legend.

The NDVI observations and interpretations below focus on recent changes in Average Growing-Season NDVI (Section 3.1) and whether observed groundwater level trends may be contributing to recent NDVI changes.

***Chino Creek (Figure 3-13a)***. During the late 1990s, groundwater levels along Chino Creek increased, particularly along the north reach of Chino Creek, where groundwater levels increased by over 30 feet. The increase in groundwater levels was most likely due to reduced pumping in the area. Since 2000, groundwater levels have remained relatively stable, even as Chino Basin Desalter pumping commenced and increased at wells I-I, I-2, I-3, I-4, I-16, I-17, I-18, I-20, and I-21 to the north of Chino Creek (see inset map on Figure 3-13b). Since 2017, total pumping at these Chino Basin Desalter wells in the Chino Creek area has been at historically low volumes, contributing to a decrease in pumping in this area.

From 2015-2021, the measured groundwater levels at the PBHSP monitoring wells along Chino Creek show a stable trend along the northern portion of Chino Creek (PB-9/1, PB-8, and RP2-MW3) and stable trend along the central reach, (PB-7/1), and a slight decreasing trend along the southern reach (PB-6/1). Groundwater levels fluctuate seasonally, in some cases by more than 15 feet, under the seasonal stresses of pumping and recharge. During the winter months of WY 2017 and 2019, groundwater levels at the PBHSP monitoring wells increased to their highest recorded levels, likely in response to the recharge of stormwater discharge in unlined creeks and the associated surface-water reservoir that ponds behind Prado Dam. Over the last year (September 2020 to September 2021) groundwater levels remained stable along the upper northern reach of Chino Creek (PB-9/1), decreased by up to two feet along lower northern reach (PB-8, and RP3-MW3), and decreased by up to one foot along the southern reach of Chino Creek (PB-7/1 and PB-6/1).

The Average Growing-Season NDVI and the air photo analyses along Chino Creek show that changes in the vegetation were relatively minor (discussed in Section 3.1) during 2020-2021. Hence, the main observations and conclusions for the period of 2020 to 2021 in this area are that groundwater levels remained relatively stable or decreased and the riparian vegetation did not change significantly.

***Mill Creek*****.** ***(Figure 3-13b).*** During the 1990s, groundwater levels along Mill Creek increased, particularly along the north reach of Mill Creek where groundwater levels increased by about 10 feet, most likely due to reduced agricultural pumping in the area. Since 2000, groundwater levels have declined, particularly along the north reach of Mill Creek where groundwater levels have declined by up to 15 feet. The decline in groundwater levels was most likely due to the onset and progressive increase in Chino Basin Desalter pumping at wells I-5, I-6, I-7, I-8, I-9, I-10, I-11, I-20, I-21 to the north of Mill Creek (see inset map on Figure 3-13b). Since 2017, total pumping at these Chino Basin Desalter wells in the Mill Creek area have progressively increased to a historically high volume, contributing to the increase in the total pumping observed in this area.

From 2015-2021, the measured groundwater levels at the PBHSP monitoring wells along Mill Creek show a decreasing trend in the northern portion of Mill Creek (PB-2 and HCMP-5/1), a slight decreasing trend in the central and southern reaches (PB-1/2 and PB-5/1). The decreases in groundwater levels in the northern Mill Creek area are likely due to the increase in pumping observed in this area. Groundwater levels fluctuate seasonally, in some cases by more than 10 feet, under the seasonal stresses of pumping and recharge. During the winter months in WY 2017 and WY 2019, groundwater levels at most of the PBHSP monitoring wells increased to their highest recorded levels, likely in response to the recharge of stormwater discharge in unlined creeks and the associated surface-water reservoir that ponds behind Prado Dam. Over the last year (September 2020 to September 2021) groundwater levels at the monitoring wells along Mill Creek decreased by about three feet just north of the top of Mill Creek (PB-2 and HCMP-5/1), decreased about one foot along the central and southern reaches (HCMP-6/1, PB-1/2, and PB-5/1).

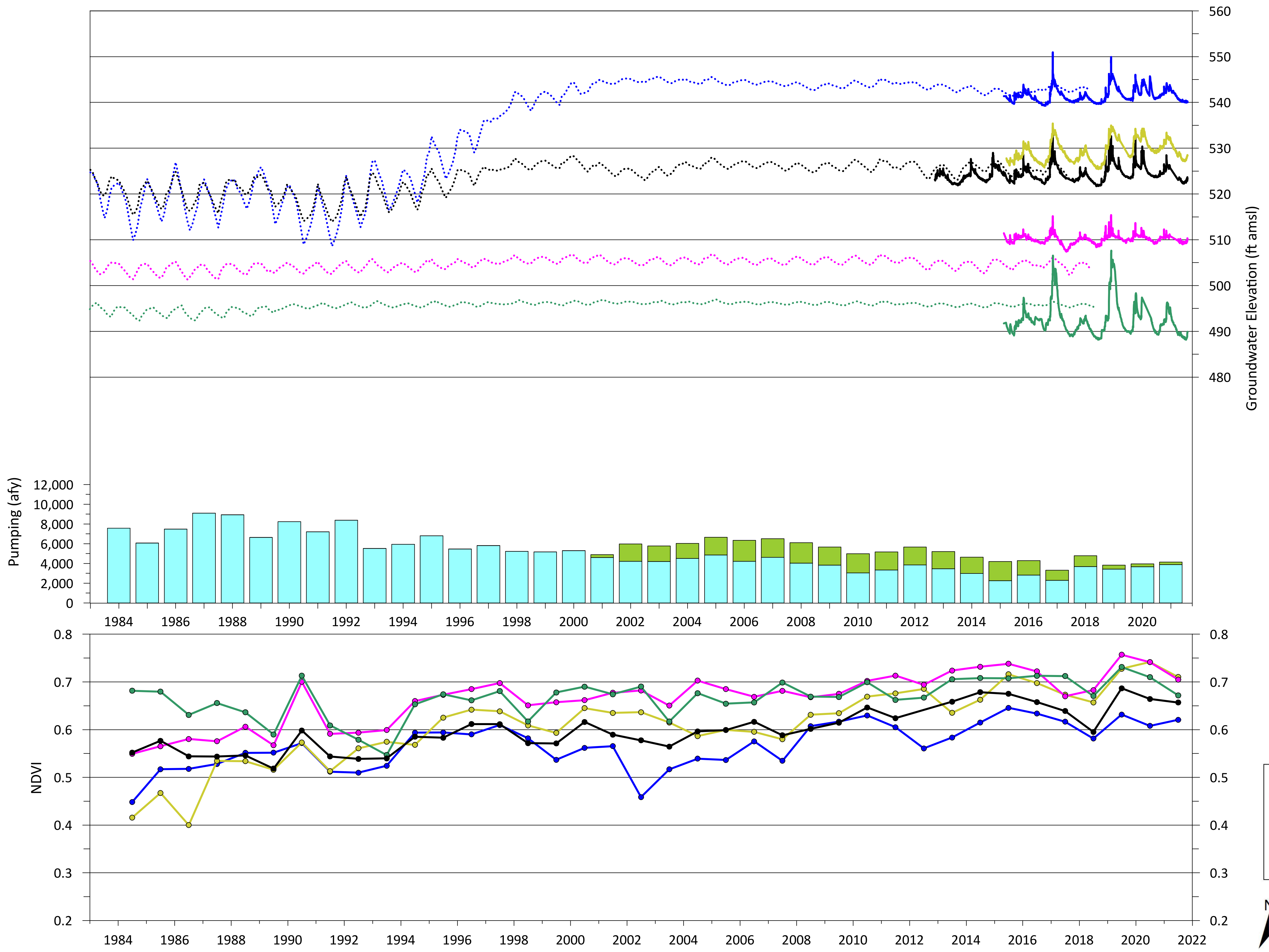
The Average Growing-Season NDVI analyses along Mill Creek show that changes in the vegetation were relatively minor during 2020-2021 (discussed in Section 3.1). The analyses of the air photos at MC-2 indicate that there is a notable decrease in the vegetation from 2020-2021. Hence, the main observations and conclusions for the period of 2020 to 2021 in this area are that groundwater levels decreased along Mill Creek and the riparian vegetation did not change significantly except for a decrease observed in the air photo at MC-2 in the central portion of Mill Creek. The MC-2 area is within the central portion of Mill Creek where groundwater levels slightly declined by about one foot during 2020 to 2021. These changes in groundwater levels near the MC-2 area in the central portion of Mill Creek are within the range of the long-term variability for these areas and not likely the cause of the decrease in the green vegetation observed at MC-2 from 2020 to 2021. Where groundwater levels decreased by 3 feet from 2020 to 2021 at PB-2, the NDVI for the MC-1 area in the northern portion of Mill Creek closest to this well slightly decreased, but this change is less than the average annual change observed historically (see Table 3-2) and there is an increasing trend in the NDVI at the MC-1 area for the post Peace II Agreement period.

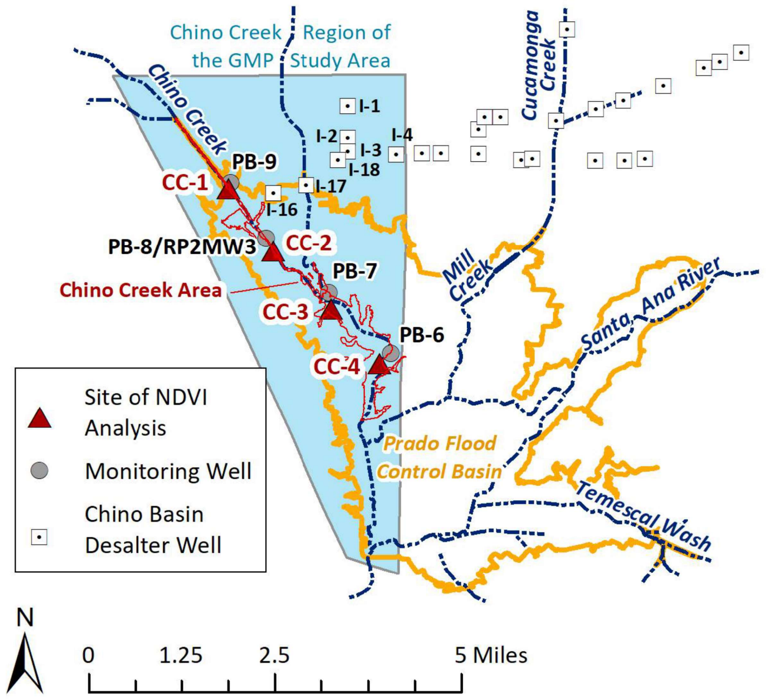
***Santa Ana River*** (***Figure 3-13c***). During the 1990s, the groundwater levels along SAR increased in response to a decline in pumping from 1990 to 2000. These responses were greatest along the eastern portion of SAR where they increased up to five feet. Since 2000, groundwater levels have declined by a similar magnitude along the eastern portion of the SAR due to the onset and progressive increase in Chino Basin Desalter pumping at wells I-13, I-14, I-15, and II-1 through II-11 to the north of the SAR (see inset map on Figure 3-13c), while groundwater levels slightly increased along the western portion of the SAR near the

Archibald well. Since 2018, total pumping at these Chino Basin Desalter wells in the SAR area have progressively increased to a historically high volume, contributing to the increase in the total pumping observed in this area.

From 2015-2021, the measured groundwater levels at the PBHSP monitoring wells show a stable trend along the northeastern portion near PB-4, a slightly decreasing trend along the northern portion near PB-3, and a stable trend along the southwestern portion near the Archibald 1 well. The decreases in groundwater levels in the northern portion of the SAR area are likely due to the increase in pumping observed in this area. Groundwater levels fluctuate seasonally, in some cases by up to three feet under the seasonal stresses of pumping and recharge. During this past year, from September 2020 to September 2021, groundwater levels at the monitoring wells along the SAR slightly decreased by about 0.5 to 1 foot along the eastern and central portions (PB-4/1 and PB-3/1) and remained stable along the western portion (Archibald 1).

The Average Growing-Season NDVI and air photo analyses along the SAR show that changes in the vegetation were relatively minor for two of the four areas along the SAR (discussed in Section 3.1) during 2020-2021. The NDVI and air photos for the SAR-1 and LP areas show a notable decrease in the green vegetation from 2020 to 2021. As described in Section 3.1, the decrease in the vegetation at the SAR-1 area is due to clearing of the vegetation for bridge construction. The LP area is in the very southern portion of Prado Basin below the OCWD Wetlands, were groundwater levels remained stable from 2020-2021, therefore changes in groundwater levels are and not the cause of the decrease in the green vegetation observed at the LP area. Hence, the main observations and conclusions for the period of 2020 to 2021 along the SAR, are that groundwater levels remained relatively stable and the riparian vegetation did not change significantly, except in the LP and SAR-1 areas, and the changes overserved at LP and SAR-1 are not caused by changes in groundwater levels.





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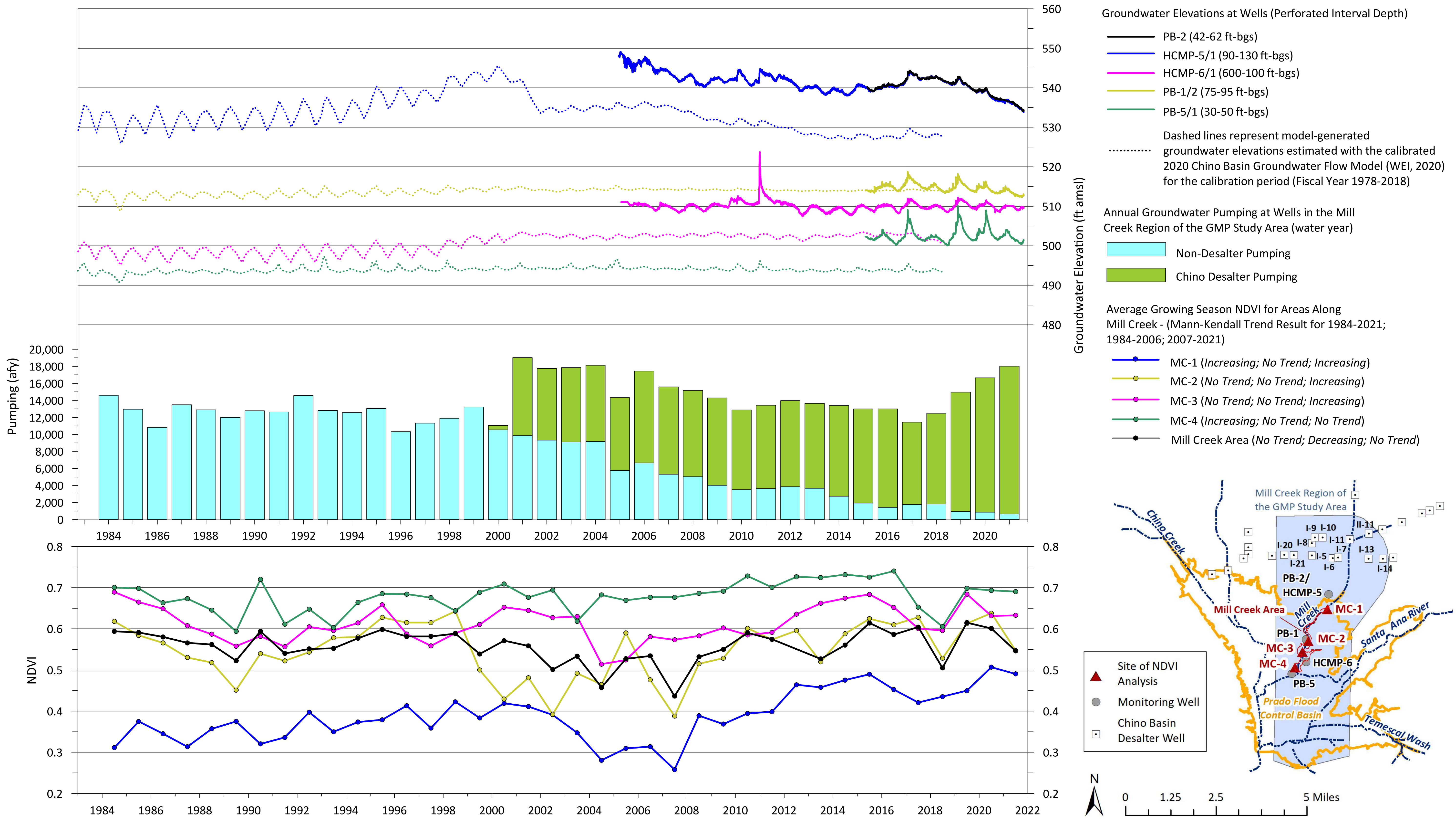
## Groundwater Levels and Production versus NDVI
*Chino Creek Area for 1984-2021*

**Figure 3-13a**

WEST YOST - K:\Clients\941 Chino Basin Watermaster\00-00-00 Master\PE1 - Data_Monitoring\GRAPHER\GRF\Prado\AnnualR\Figure 3-13a_Prod_GWLs_ChinoCk.grf - lhedley - 5/3/2022



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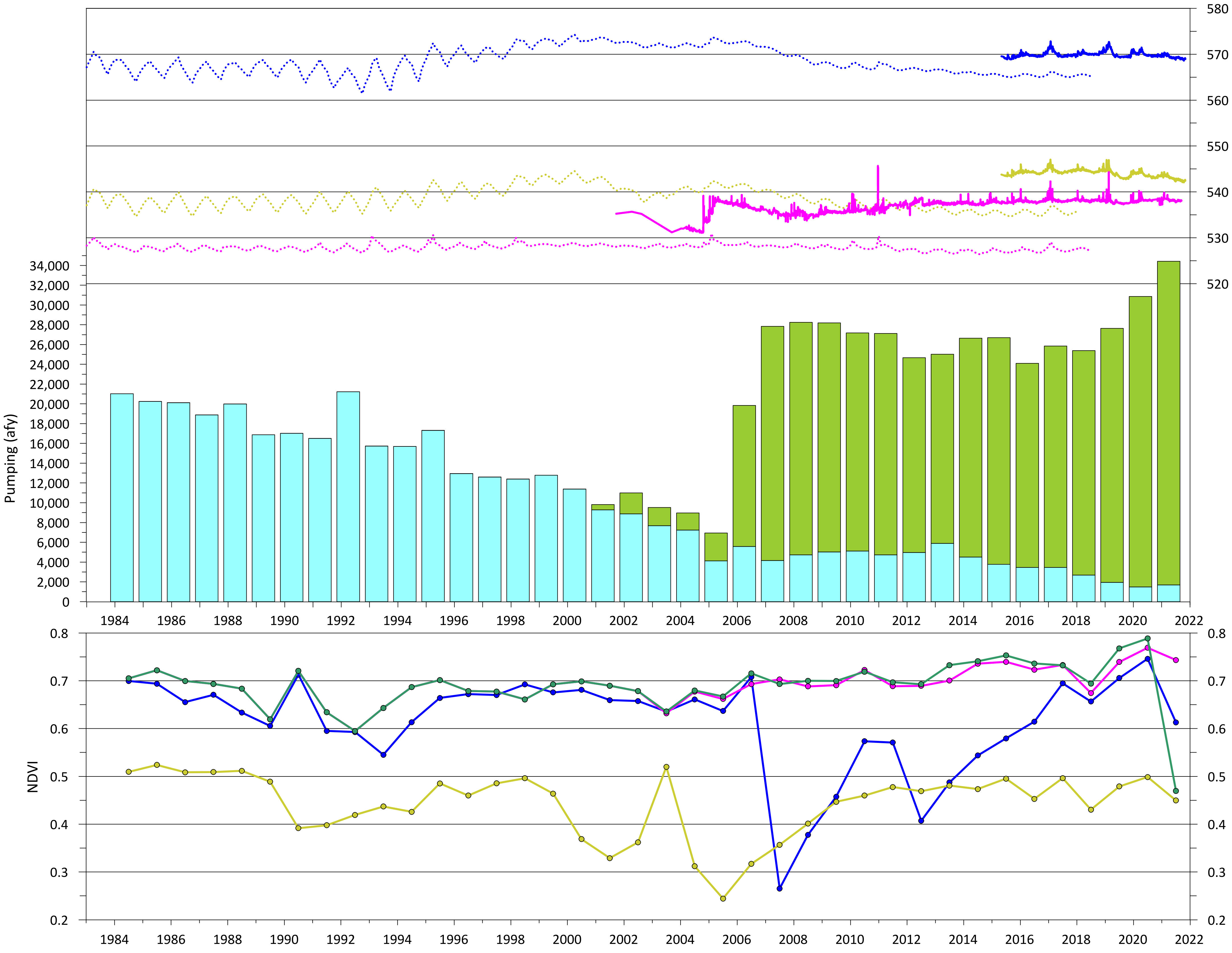
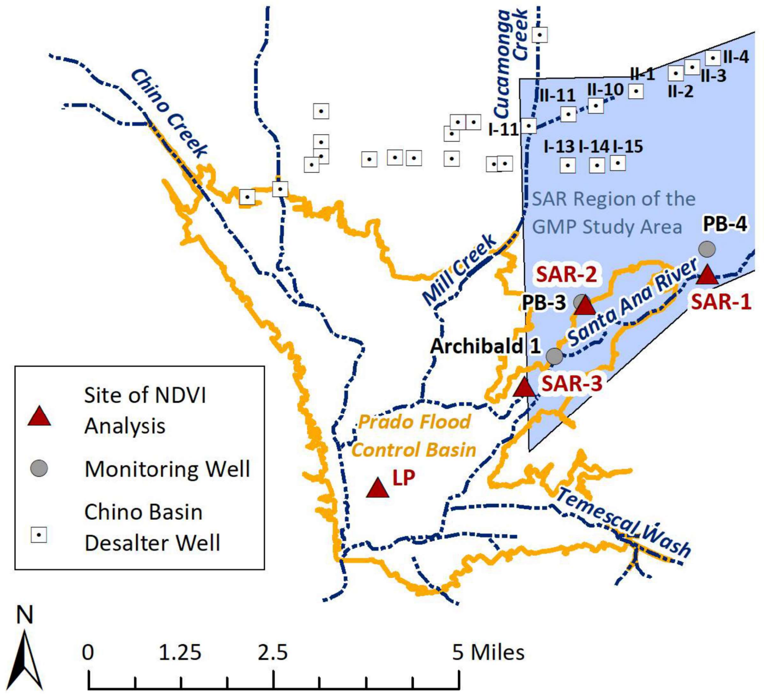
**Groundwater Levels and Production versus NDVI**
*Mill Creek Area for 1984-2021*

**Figure 3-13b**





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**Groundwater Levels and Production versus NDVI**
*Santa Ana River Area for 1984-2021*

**Figure 3-13c**

### *3.2.4 Summary*

The following observations and interpretations were derived from the analysis of groundwater pumping, groundwater levels, and NDVI:

- From 1961 to 1990, groundwater pumping from private domestic and agricultural wells in the study area averaged about 45,900 afy. From 1991 to 1999, groundwater pumping steadily declined to about 23,600 afy primarily due to conversions from agricultural to urban land uses. In 2000, CDA pumping commenced to replace the declining agricultural production, and by 2018, groundwater pumping in the study area was about 37,000 afy. From WY 2019 to WY 2021, total groundwater pumping in the study area increased almost 10,000 afy to 46,700 afy due to increased CDA pumping.
- Since groundwater-level measurements commenced at the PBHSP monitoring wells in 2015, there have been some increasing and decreasing trends in groundwater levels observed along the reaches of Chino Creek, Mill Creek, and SAR. From September 2016 to September 2021, groundwater levels near the edges of the riparian habitat have changed up to +/- 5 feet. Groundwater levels have declined the most at the PB-2 monitoring well near the upper reach of Mill Creek, which was likely due to increased pumping at the Chino Basin Desalter wells to the north. Areas of minor declines in groundwater levels near the riparian habitat since 2015 include the central reach of Mill Creek, the very southern reach of Chino Creek, and the northeastern reach of the SAR.
- Over the past year from 2020 to 2021 groundwater levels generally remained stable or decreased in the Prado Basin near the riparian vegetation areas along the reaches of the SAR, Mill Creek and Chino Creek. From 2020 to 2021 groundwater levels declined the most at the northern portion of Mill Creek by up to 3 feet. Other areas of groundwater level declines from 2020 to 2021 are: the central and southern reaches of Mill Creek (up to 1 foot), the northern reach of Chino Creek (up to 2 feet), the southern reach of Chino Creek (up to 1 foot), and the eastern and central portions of the SAR (up to 1 foot). In Section 3.1, the analysis of air photos and NDVI for the riparian habitat areas in these areas of groundwater declines, indicate that the riparian vegetation did not change significantly over 2020-2021, except for the MC-2 area.
- The air photo of the MC-2 area shows a notable decrease in the green riparian vegetation from 2020-2021. The slight decline in groundwater levels of about 1 foot along the center portion of Mill Creek near MC-2 is within the historical range of variability in groundwater levels in this region and is therefore not the likely cause of the decreased greenness observed there in 2021. More information is needed to understand the cause of the decrease in greenness at the MC-2 site.

## 3.3 Analysis of Groundwater/Surface Water Interactions

One of the objectives of the PBHSP is to identify factors that contribute to the long-term sustainability of Prado Basin riparian habitat. The depth to groundwater analysis shown in Figure 3-12 indicates that the riparian vegetation exists in areas of shallow groundwater, where groundwater levels are typically 15 ft-bgs or less, and that the riparian vegetation is likely dependent, at least in part, upon the shallow groundwater.

The Annual Reports for WY 2017 and WY 2018 (Section 3.3) included a comprehensive analysis to understand the sources of the shallow groundwater in the Prado Basin and the groundwater/surface-water interactions that may be important to the long-term sustainability of the riparian habitat (WEI, 2018; 2019). The analysis included using surface-water discharge and quality, groundwater quality, groundwater levels, and groundwater modeling as multiple lines of evidence to analyze the groundwater/surface water interactions at the nine PBHSP well locations—along the fringes of the riparian habitat and adjacent to Chino Creek, Mill Creek, and the SAR. In general, the analysis concluded that the SAR and northern portion of Mill Creek are losing reaches, characterized by streambed recharge. Most other areas along Chino and Mill Creeks are gaining reaches, characterized by groundwater discharge. That said, at most locations in the Prado Basin, there appear to be multiple and transient sources that feed the shallow groundwater, and the groundwater/surface-water interactions are complex. Additional monitoring is needed to better characterize the sources of shallow groundwater and groundwater/surface-water interactions. This additional monitoring began in 2018 as a pilot program, which included:

- High-frequency water-quality monitoring at two PBHSP monitoring well sites along Chino Creek: PB-7 and PB-8 (two wells at each site). Each monitoring well was equipped with data logger to measure and record EC, temperature, and water levels at a 15-minute frequency. The wells were visited quarterly to download data from the data loggers and measure water levels. Groundwater quality samples were collected quarterly (for two years) then semiannually (for one year) for laboratory analyses of TDS and general mineral chemistry to validate and support the high-frequency data.
- High-frequency water-quality monitoring at two surface-water sites along Chino Creek adjacent to the monitoring well sites. Each site was equipped with a data logger to measure and record EC, temperature, and stage at a 15-minute frequency. The surface-water sites were visited quarterly to download data from the data loggers. Groundwater quality samples were collected quarterly then semiannually for laboratory analyses of TDS and general mineral chemistry to validate and support the high-frequency data.

The data loggers were installed at the groundwater and surface-water sites in July 2018. Since installation there has been periodic disruptions of the data collected in the surface water data loggers: in late-2018, the data loggers were lost during large storm events; and the casing that house the data loggers experienced accumulation of mud which periodically compromised the accuracy of the collected data. These monitoring challenges have been resolved. The high-frequency data collected thus far has provided more support for the characterization of groundwater/surface water interactions at these locations and warrants the continuation of the pilot program to collect more data. More intervals of simultaneous high-frequency data of surface water and groundwater needs to be collected in order to draw defensible conclusions.

## 3.4 Climate and Its Relationship to the Riparian Habitat

Precipitation and temperature are climatic factors that can affect the extent and quality of riparian habitat. Precipitation can provide a source of water for consumptive use by the riparian vegetation via the direct infiltration of precipitation and runoff, which increases soil moisture that can be directly used by the vegetation, or by maintaining groundwater levels underlying the vegetation for its subsequent use. Temperatures affect the rate of plant growth and productivity. Both factors are unrelated to the implementation of the Peace II Agreement. This section characterizes the time series of precipitation and temperature in the Prado Basin area and compares that time series to trends in the quality of the riparian habitat, as indicated by NDVI, to help determine if these factors have influenced the riparian habitat in the Prado Basin.

### 3.4.1 Precipitation

Figure 3-14 is a time-series chart that shows annual precipitation estimates within the Chino Basin for WY 1896 to 2021. These estimates were computed as a spatial average across the Chino Basin using rasterized data from the PRISM Climatic Group (an 800-meter by 800-meter grid). The long-term average annual precipitation in the Chino Basin is 16.28 inches per year (in/yr). The chart includes a cumulative departure from mean (CDFM) precipitation curve, which characterizes the occurrence and magnitude of wet and dry periods: positive sloping segments (trending upward to the right) indicate wet periods, and negative sloping segments (trending downward to the right) indicate dry periods.

Review of the CDFM precipitation curve indicates that the Chino Basin experienced several prolonged wet and dry periods from WY 1896 to 2021. Typically, dry periods are longer in duration than wet periods. The longest dry period occurred between 1946 through 1977 (32 years). The current dry period is a 23-year period, starting in WY 1999, and includes the Peace/Peace II Agreement period (2001 through 2021). Over the 125-year record, about 40 percent of the years had precipitation greater than the average, and 60 percent had below average precipitation. In the 21-year period since the Peace Agreement was implemented, about 35 percent of the years had precipitation greater than the average, and 65 percent had below average precipitation. Precipitation in WY 2021 was 6.57 inches, which is below the long-term average and a notable decrease from 2020.

### 3.4.2 Temperature

Maximum and minimum temperatures during the growing season are the temperature metrics used in this analysis because plant growth and development are dependent upon the temperatures surrounding the plant (Hatfield and Prueger, 2015). Maximum temperatures during the growing season directly influence photosynthesis, evapotranspiration, and breaking of the dormancy of vegetation (Pettorelli, 2015). Minimum temperatures affect nighttime plant respiration rates and can potentially have an effect on plant growth that occurs during the day (Hatfiled et. al, 2011). Hence, both temperature metrics can influence NDVI. All species of plants have a range of maximum and minimum temperatures necessary for growth (Hatfield and Prueger, 2015). Climate change is more likely to increase minimum temperatures while maximum temperatures are affected more by local conditions (Knowles et al., 2006; Alfaro et al., 2006).

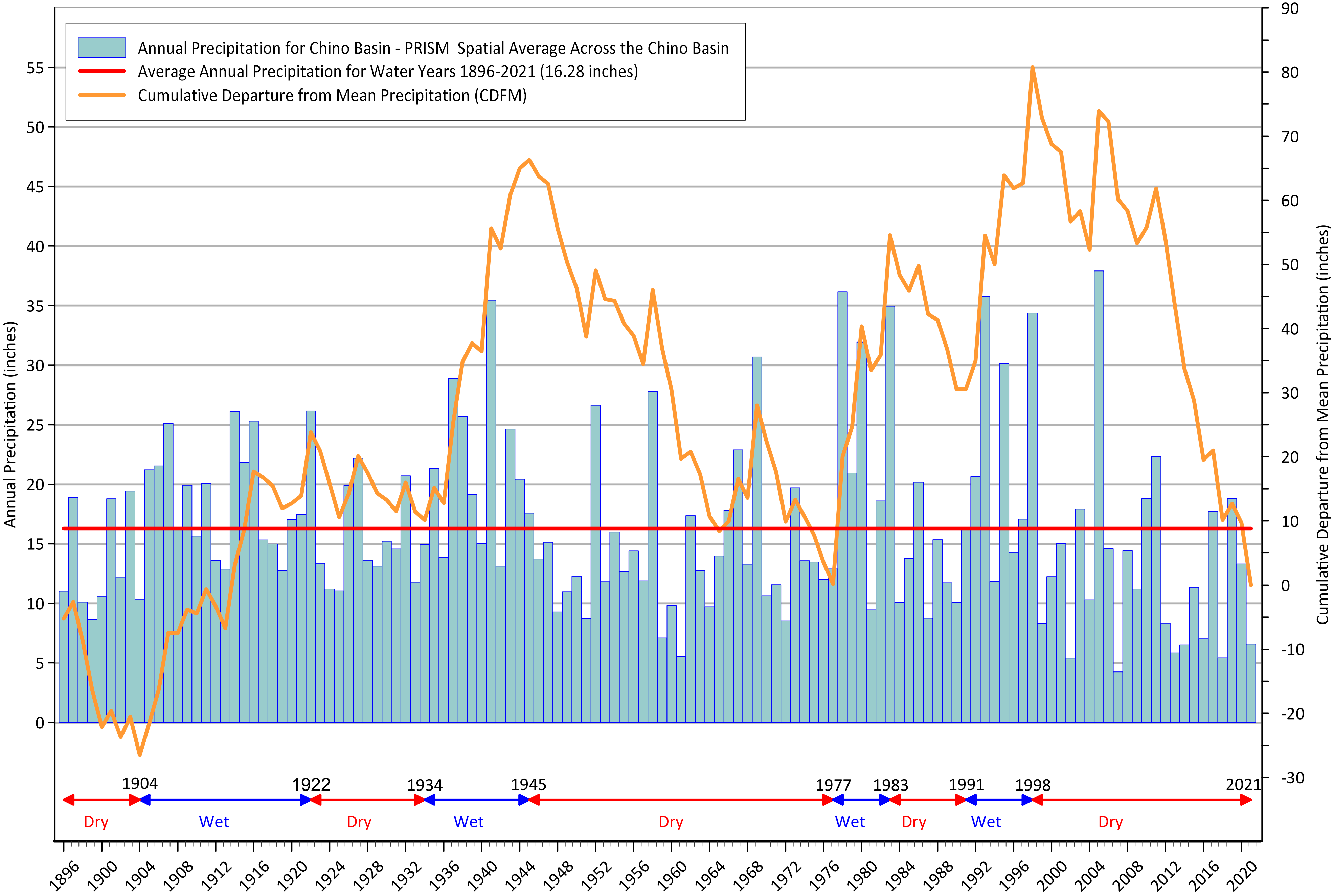
Figure 3-15 is a time-series chart that shows the average maximum and minimum Prado Basin temperatures for the growing-season months of March through October from 1896 to 2021 (growing-season maximum and minimum temperatures). These temperature estimates were computed as a spatial average across the Prado Basin using rasterized data from the PRISM Climatic Group (an 800-meter by 800-meter grid) of monthly maximum and minimum temperature estimates. This chart also shows the five-year moving average of the growing-season maximum and minimum temperatures for the Prado Basin. The five-year moving average is a smoothing technique used to reveal trends over time.

This chart also shows a complete record of atmospheric carbon dioxide (CO2) concentrations assembled from multiple sources:

- Values prior to 1959 were estimated from an analysis of the Law Dome DE08 and DE08-2 ice cores in Antarctica. (Acquired from the Carbon Dioxide Information Analysis Center, http://cdiac.ornl.gov/trends/co2/lawdome.html. Accessed on June 6, 2017).
- Values after 1959 are from measured CO2 concentration data at the Mauna Loa Observatory in Hawaii. (Acquired from the National Oceanic and Atmospheric Association's Earth Systems Research Laboratory, https://www.esrl.noaa.gov/gmd/ ccgg/trends/full.html. Accessed on March 22, 2022).

The time history of atmospheric CO2 concentrations shows a slight increasing trend from about 290 parts per million (ppm) in the late 1890s to about 310 ppm in 1950. After 1950, the CO2 concentration shows an amplified increasing trend and exceeds 400 ppm by 2015.

From 1896 to 2021, the growing-season maximum temperature fluctuates between 80° F to 86° F and does not appear to have a prominent long-term increasing or decreasing trend. From 1896 to 2021, the growing-season minimum temperature fluctuates between 49° F to 59° F and has an increasing trend starting in 1950 of about five degrees Fahrenheit through 2021. This increasing trend in the growing-season minimum temperature beginning 1950 appears to correlate with the increase in atmospheric CO2 concentrations. The five-year moving averages of both the growing-season minimum and maximum temperatures display an increasing trend over the recent six-year period of 2013-2018 and in 2018 had the highest calculated values over the entire period of record. In 2021 , the growing-season minimum and maximum temperatures and the five-year moving averages all decreased from the previous period with the highest values historically.



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**Annual Precipitation in the Chino Basin**
*Water Year 1986 - 2021*

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**Figure 3-14**

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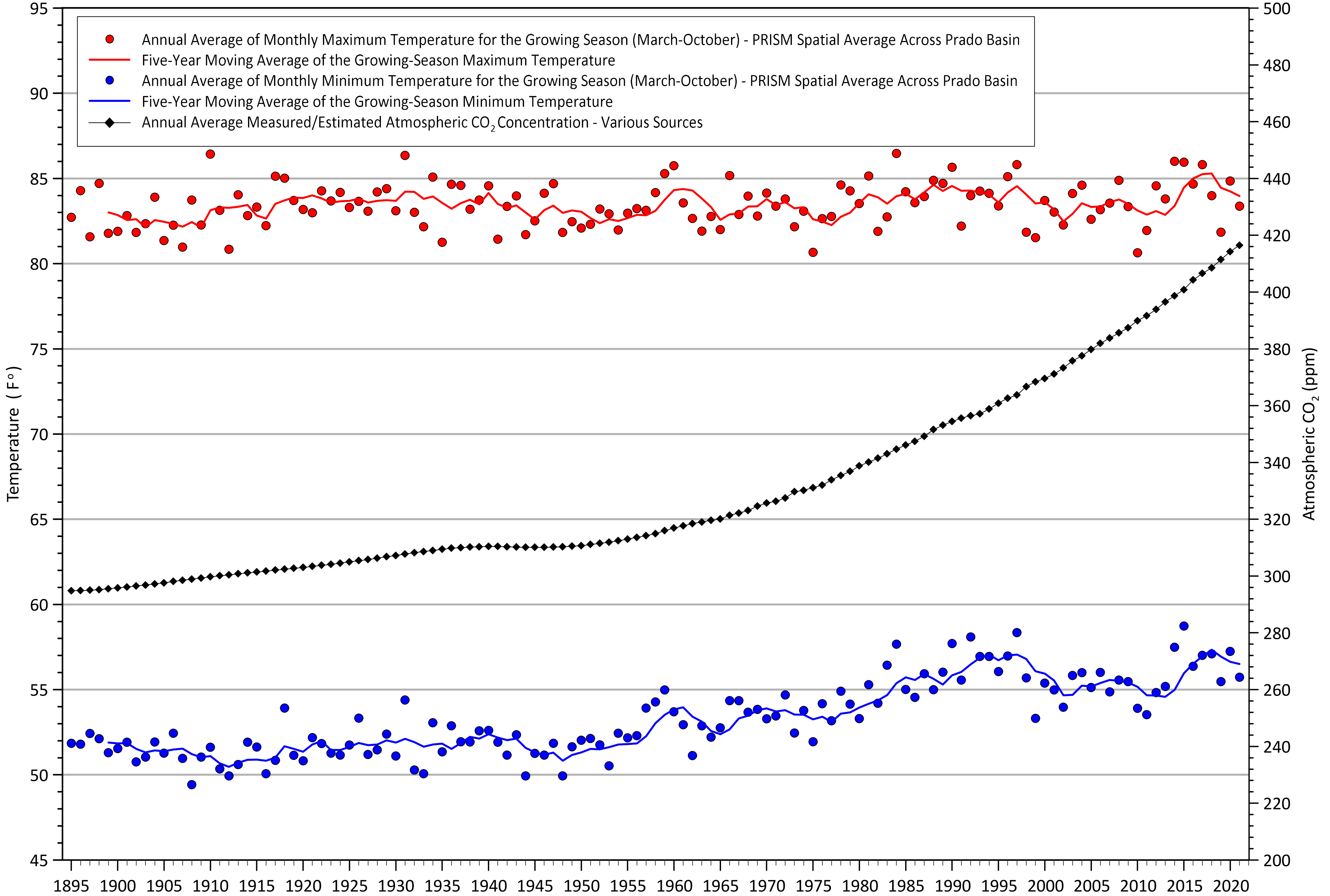

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2021 Annual Report

## Maximum and Minimum Temperature in Prado Basin

*1895-2021*

**Figure 3-15**

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### *3.4.3 Climate Compared to NDVI*

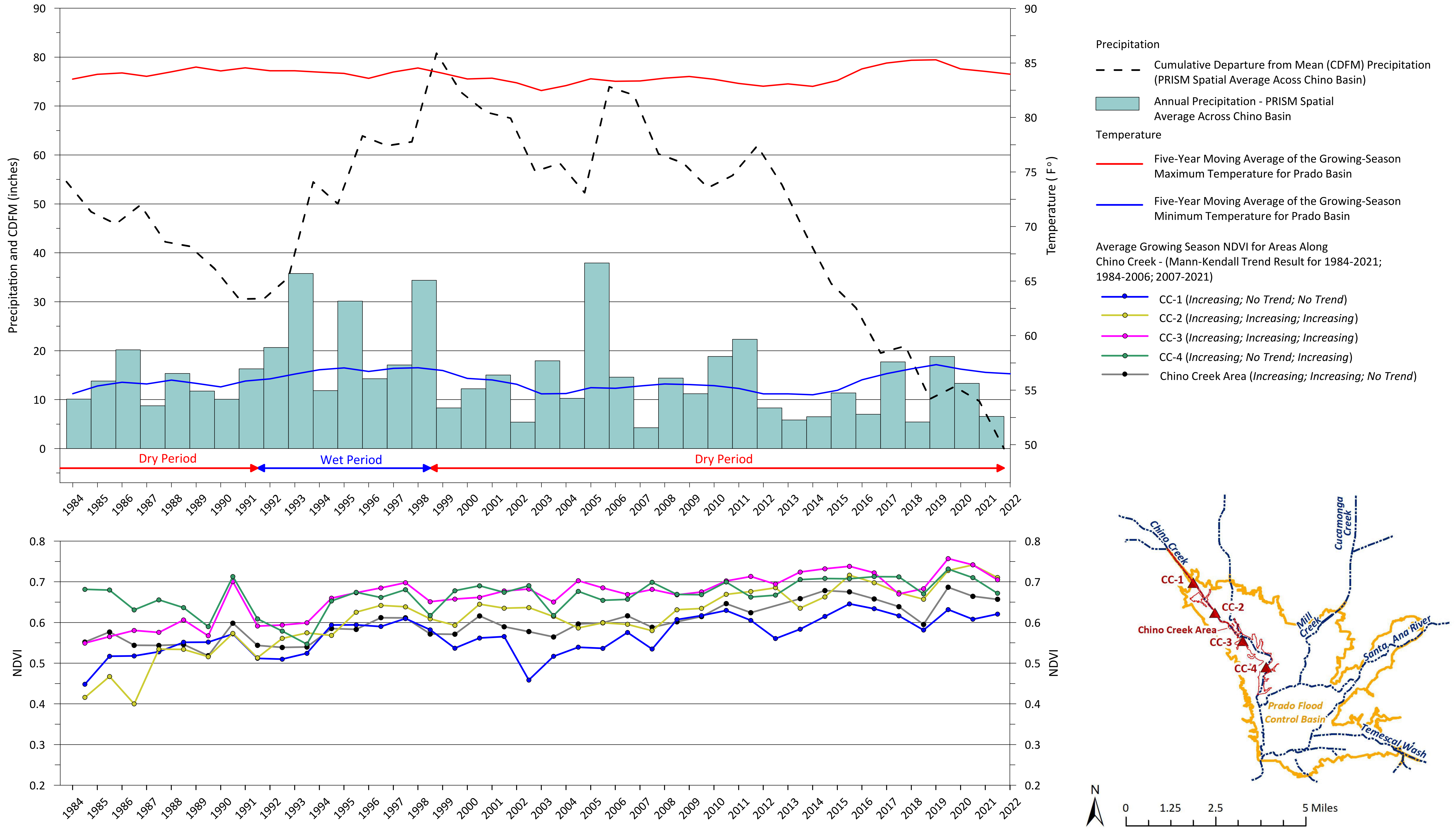
Figures 3-16a through 3-16c are time-series charts that compare long-term trends in precipitation and temperature to trends in the quality of the riparian vegetation, as indicated by NDVI, for three areas in the Prado Basin: Chino Creek, Mill Creek, and the SAR. The period of analysis is 1984-2021—the period of NDVI availability. The upper chart on the figures displays the time series of annual precipitation in Chino Basin, the CDFM precipitation curve, and the five-year moving average for the growing-season maximum and minimum temperatures in the Prado Basin. The lower chart displays the time series of the Average Growing-Season NDVI for the defined areas discussed in Section 3.1 along Chino Creek, Mill Creek, and the SAR. For reference, the Mann-Kendall test results for trends in the Average Growing-Season NDVI for 1984-2021, 1984-2006, and 2007-2021 are shown in the legend.

The observations and interpretations below are focused on recent changes in Average Growing-Season NDVI during 2021 described in Section 3.1 and whether observed trends in temperature and precipitation may be contributing to recent increases in NDVI.

***Chino Creek (Figure 3-16a).*** From 2020 to 2021, Average Growing-Season NDVI for the four areas along Chino Creek decreased at three areas and increased at one area. The Average Growing-Season NDVI for the whole Chino Creek area decreased from 2020 to 2021. For all these areas, the one-year changes in NDVI were relatively minor and within the historical ranges of one-year NDVI variability (see Table 3-2). These recent changes in NDVI occurred during a year of low precipitation of about 10 inches below the long-term average, and slightly lower minimum and maximum temperatures in the Prado Basin than what has occurred the seven prior years. The drier conditions are likely a contributing cause of the slight decreases in the NDVI along Chino Creek. Previous annual reports have observed similar trends with NDVI decreases throughout the Prado Basin in dry years (WEI, 2019). Hence, the main observations and conclusions for the 2020 to 2021 period are that there were very dry and slightly cooler conditions in 2021 and the riparian vegetation did not change significantly along Chino Creek.

***Mill Creek (Figure 3-16b).*** From 2020 to 2021, the Average Growing-Season NDVI of the four areas along Mill Creek: decreased at two areas and did not change at two areas. The Average Growing-Season NDVI for the whole Mill Creek area decreased from 2020 to 2021. At all the areas, the one-year NDVI changes are within their historical ranges of the one-year NDVI variability (see Table 3-2). However, the air photo for the MC-2 area shows a notable decrease in green vegetation. These recent changes in NDVI and vegetation occurred during a year of below-average precipitation and slightly lower minimum and maximum temperatures. The drier conditions are likely a contributing cause of the slight decreases in the NDVI observed along Mill Creek. Previous annual reports have observed similar trends with NDVI decreases throughout the Prado Basin in dry years (WEI, 2019). Hence, the main observations and conclusions for the 2020 to 2021 period are that there were slightly cooler and drier conditions and the riparian vegetation did not change significantly along Mill Creek, except in the area near MC-2. The decrease in the green vegetation observed at MC-2 is likely not caused by the drier and slightly cooler conditions during 2021 and is likely related to some other factor.

***Santa Ana River (Figure 3-16c).*** From 2020 to 2021, the Average Growing-Season NDVI decreased at all four areas along the SAR. For two of these areas, the one-year NDVI changes were relatively minor and within the historical ranges of one-year NDVI variability (see Table 3-2). These changes occurred during a year of below-average precipitation and slightly lower minimum and maximum temperatures. The drier conditions are likely a contributing cause of the slight decreases in the NDVI observed along the SAR. Previous annual reports have observed similar trends with NDVI decreases throughout the Prado Basin in dry years (WEI, 2019). Hence, the main observations and conclusions for the 2020 to 2021 period are that there were slightly cooler and drier conditions and the riparian vegetation did not change significantly along the SAR, except in the LP and SAR-1 areas. The decreases in the green vegetation observed at the LP and SAR-1 areas are likely not caused by the drier and slightly cooler conditions during 2021 and are related to some other factor.



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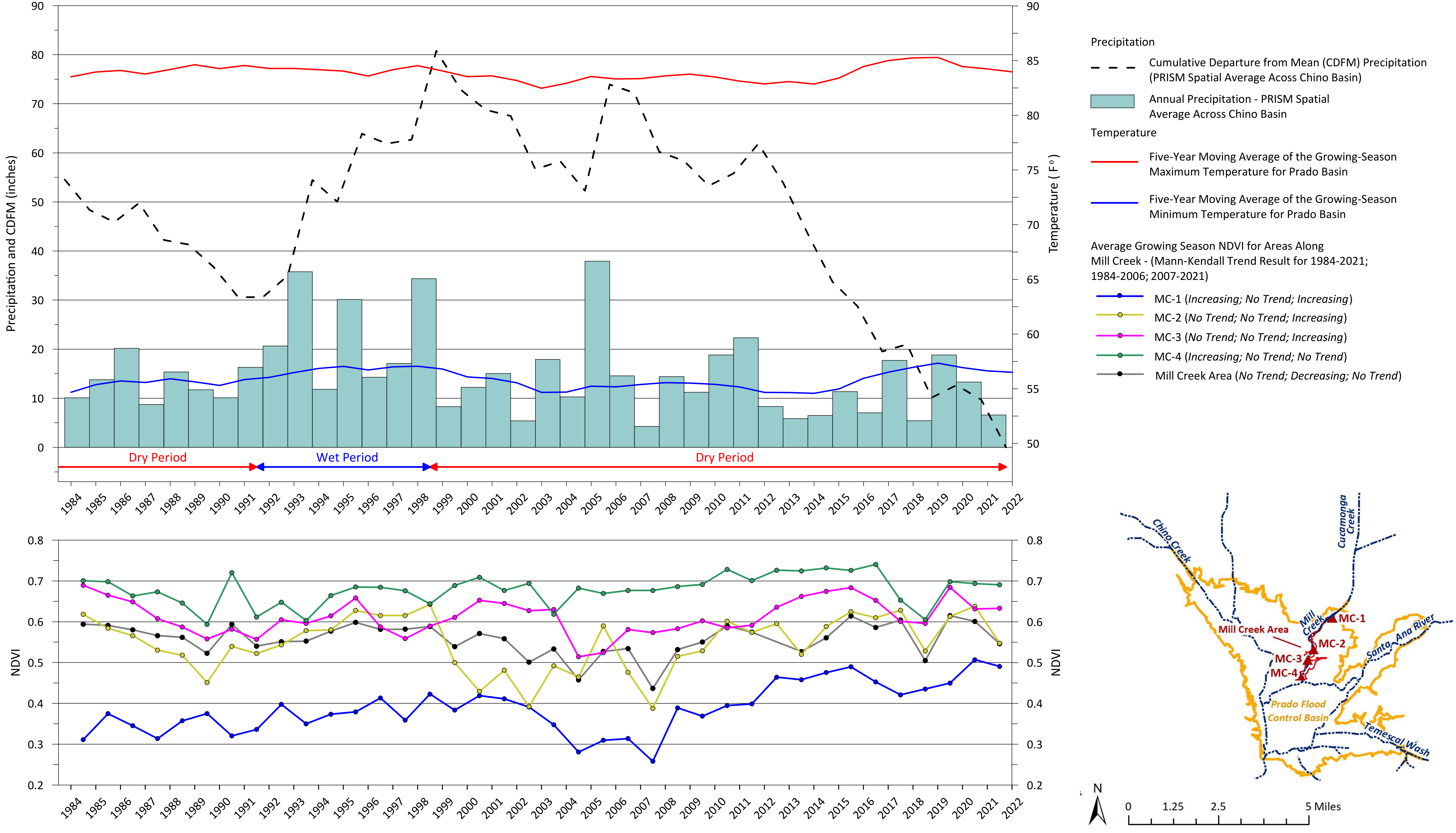
**Climate verus NDVI**
*Chino Creek Area for 1984-2021*

**Figure 3-16a**



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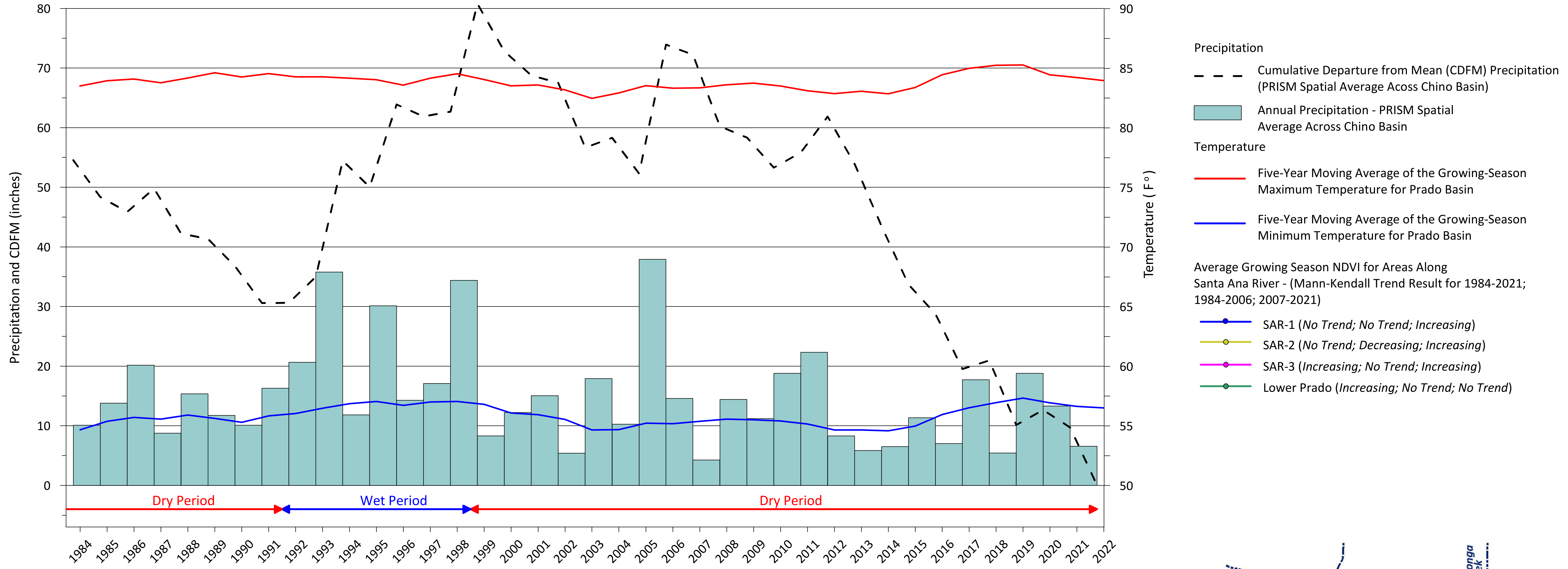
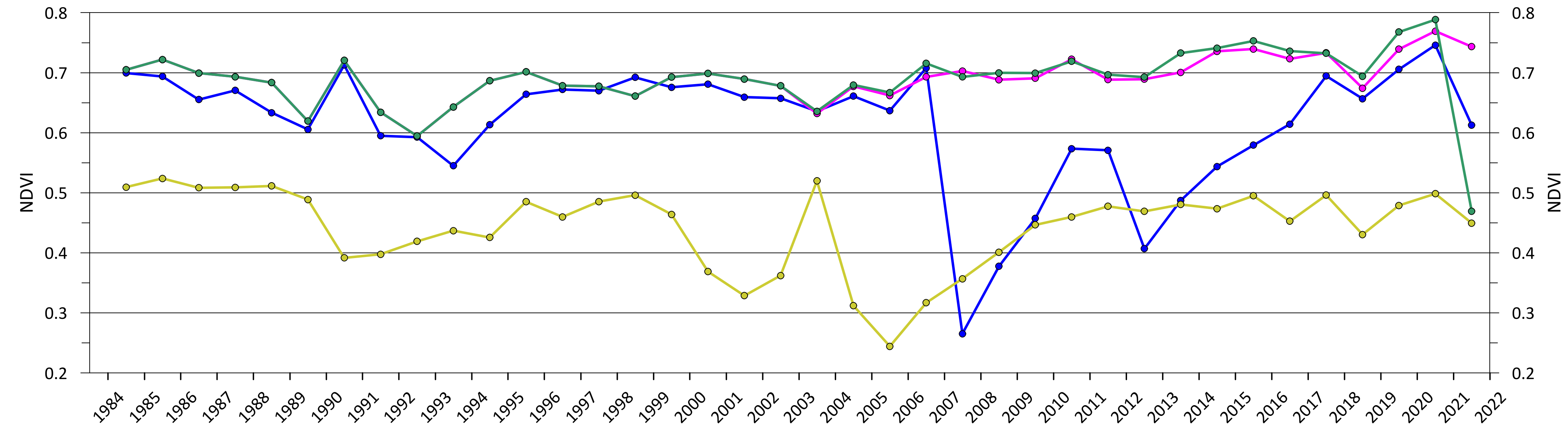
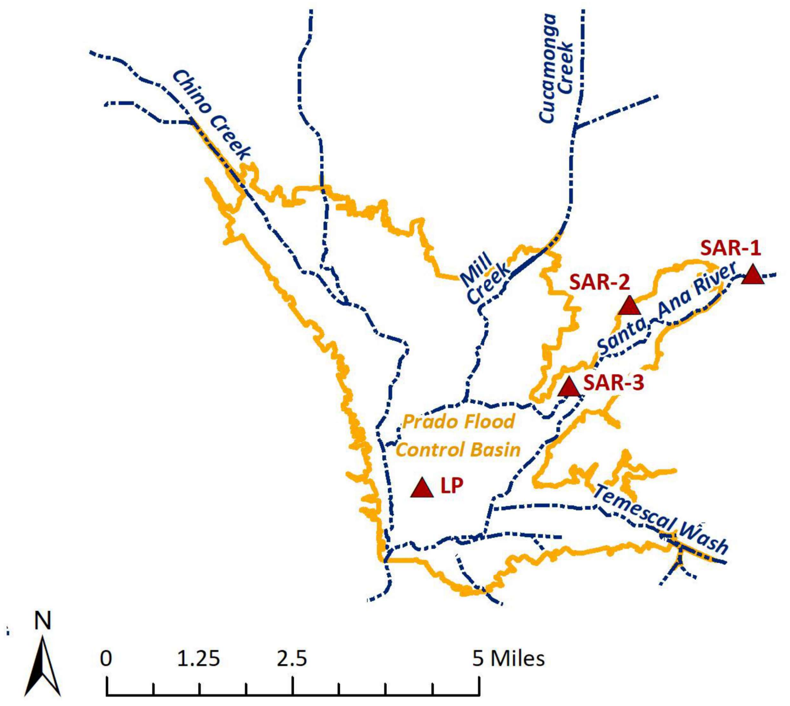
**Climate verus NDVI**
*Mill Creek Area for 1984-2021*

**Figure 3-16b**







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**Climate verus NDVI**
*Santa Ana River and Lower Prado Area for 1984-2021*

**Figure 3-16c**

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## 3.5 Stream Discharge and Its Relationship to the Riparian Habitat

Stream discharge in the SAR and its tributaries that flow through the Prado Basin is a factor that can affect the extent and quality of Prado Basin riparian habitat. Stream discharge can recharge the groundwater system along losing stream reaches and supply water through the groundwater system to riparian vegetation. Stream discharge is also important to fauna living within the stream system. Flooding events and flood-control/water-conservation operations at Prado Dam can scour and inundate areas of the riparian habitat and potentially cause adverse impacts.

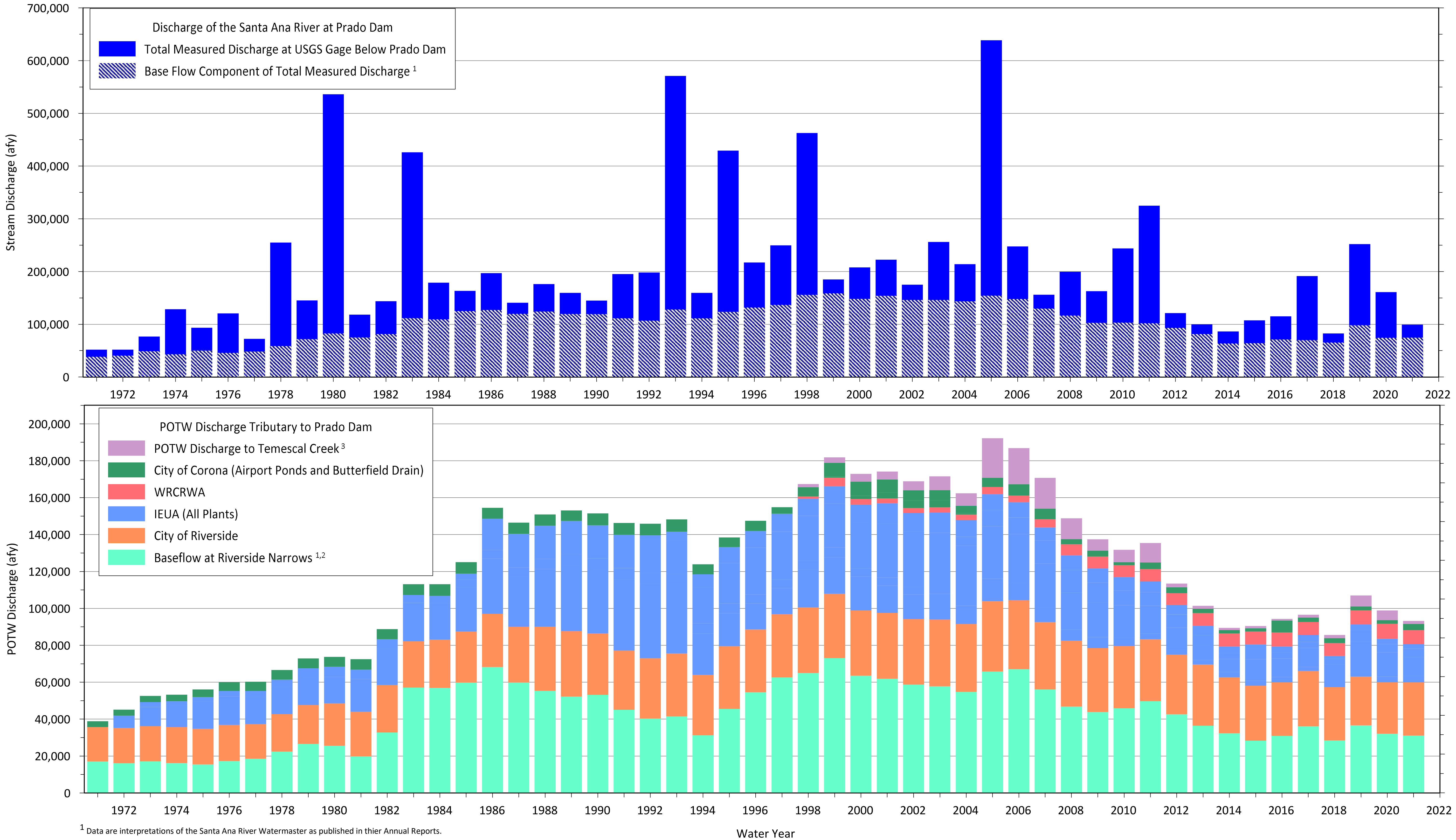
This section characterizes the time series of stream discharge within the Prado Basin and compares that time series to trends in the extent and quality of the riparian habitat, as indicated by NDVI, to help determine whether changes in stream discharge have influenced the riparian habitat in the Prado Basin.

### *3.5.1 Stream Discharge*

There are three primary components of stream discharge in the SAR and its tributaries: storm discharge, non-tributary discharge, and base-flow discharge. Storm discharge is rainfall runoff. Non-tributary discharge typically originates from outside the watershed, such as imported water discharged from the OC-59 turnout on San Antonio Creek. Base-flow discharge, as used herein and by the Santa Ana River Watermaster (SARWM), includes tertiary-treated wastewater discharge from POTWs, rising groundwater, and dry-weather runoff. Figure 3-17 includes time-series charts that summarize important annual discharges within the upper SAR watershed that are tributary to Prado Dam from water years 1971 to 2021 (SARWM, 2022). The upper chart on Figure 3-17 characterizes the annual outflow from the Prado Basin as total measured SAR discharge at USGS gage *SAR at below Prado Dam*. The upper chart also shows the base-flow component of total measured discharge as estimated by the SARWM. This chart shows that base-flow discharge declined from about 154,000 afy in 2005 to an average of about 74,000 afy over the period 2012-2021. The decline in base-flow discharge is primarily related to declines in POTW effluent discharges that are tributary to Prado Basin. In WY 2021, the total discharge at below Prado Dam was below average and base-flow discharge was average, following a wet year in WY 2019 and 2020:

- ***Total Discharge at below Prado Dam in WY 2021.*** Total discharge in WY 2021 was about 99,200 af, which is about 36,100 afy less than the average total discharge over the previous nine years (2012 to 2020), and a 61,800 afy decrease from total discharge in WY 2020.
- ***Base-Flow Discharge at below Prado Dam in WY 2021***. Base-flow discharge was about 74,500 afy, which is about 1,100 afy less than the average base-flow discharge over the previous nine years (2012 to 2020), and about 100 afy less than base-flow discharge in WY 2020.

The lower chart on Figure 3-17 shows the combined POTW discharges that are tributary, at least in part, to Prado Dam. The POTW discharges declined from about 192,000 afy in 2005 to an average of about 97,400 afy for the last nine years (2012-2020). This decrease is mostly attributed to decreases in effluent discharge from the IEUA and the POTWs that discharge to Temescal Creek. The post-2005 decrease in POTW effluent discharge was caused by increased recycled-water reuse, decreased water use due to the economic recession that began in 2008, and the implementation of emergency water-conservation measures during the recent drought since 2012. In WY 2021, POTW discharge was about 93,200 afy, which is about 4,200 afy less than the average POTW discharge over the previous nine years, and about 5,700 afy less than POTW discharge in WY 2020.



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[1] Data are interpretations of the Santa Ana River Watermaster as published in thier Annual Reports.

[2] Baseflow at Riverside Narrows includes POTW discharge from RIX and Rialto plants, rising groundwater, and dry weather runoff

[3] Includes discharge from EVMWD, EMWD, and LLWD plants

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WEST YOST - K:\Clients\941 Chino Basin Watermaster\00-00-00 Master\PE1 - Data_Monitoring\GRAPHER\GRF\Prado\AnnualR\Figure 3-17_SW Discharge_Prado.grf - lhedley - 5/3/2022

**Prado Basin Habitat Sustainability Committee**
2021 Annual Report

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**Discharge Tributary to Prado Dam**
*Water Year 1960-2021*

**Figure 3-17**

### 3.5.2 Stream Discharge Compared to NDVI

Figures 3-18a through 3-18c are time-series charts that compare long-term trends in stream discharge to trends in the quality of the riparian vegetation, as indicated by NDVI, for three areas in Prado Basin: Chino Creek, Mill Creek, and the SAR. The period of analysis for these charts is 1984-2021—the period of NDVI availability. The upper chart on the figures displays the annual volumes of measured discharge to each stream during the growing season (March-October), including: measurements at USGS gaging stations located upstream of the Prado Basin and POTW discharges.[17] The lower chart displays the time series of the Average Growing-Season NDVI for defined areas, as discussed in Section 3.1, along Chino Creek, Mill Creek, and the SAR. For reference, the Mann-Kendall test results for trends in the Average Growing-Season NDVI for 1984-2021, 1984-2006, and 2007-2021 are shown in the legend.

The observations and interpretations below are focused on the recent (2021) changes in Average Growing-Season NDVI, as described in Section 3.1, and whether observed trends in surface-water discharge may be contributing to recent changes in NDVI.

***Chino Creek (Figure 3-18a)***. Chino Creek is a concrete-lined, flood-control channel that transitions into an unlined stream channel at the Prado Basin boundary and flows south to merge with Mill Creek and the SAR behind Prado Dam (see Figure 2-3). The upper chart on Figure 3-18a shows discharge in Chino Creek during the growing season, including: measured discharge at USGS gage *Chino Creek at Schaefer* and the POTW discharges downstream of the USGS gage, including discharges from the IEUA Carbon Canyon, RP-2, RP-5, and RP-1 plants. Measured discharge at *Chino Creek at Schaefer* includes storm-water and dry-weather runoff in the concrete-lined channel upstream of the IEUA discharge locations and imported water discharge from the OC-59 turnout. Discharges not characterized in this figure are storm-water runoff, dry-weather runoff, and rising-groundwater discharge downstream of the *Chino Creek at Schaefer* gage. From 1984 to 2021, discharge in Chino Creek during the growing season progressively increased through 1999 and then decreased. The decreasing trend in growing-season discharge since about 1999 was caused by dry climatic conditions, water conservation in response to drought, and decreases in effluent discharge from the IEUA plants. During the recent eight-year period, from 2013 to 2020, growing-season discharge in Chino Creek averaged about 7,900 afy. In 2021, growing-season discharge was about 7,100 afy, which is about 900 af less than the average growing-season discharge over the last nine years, and about 1,900 af less than growing-season discharge in 2020. This decrease in growing-season discharge in Chino Creek during 2021 is mostly attributed to decreases in the storm-water/dry-weather runoff.

From 2020 to 2021, Average Growing-Season NDVI at the four areas along Chino Creek: decreased at three of the areas and increased at one area. The Average Growing-Season NDVI for the whole Chino Creek area decreased from 2020 to 2021. For all these areas, the one-year NDVI changes were relatively minor and within the historical ranges of one-year NDVI variability (see Table 3-2). These recent changes in NDVI occurred during a year of below-average discharge in Chino Creek. Hence, the main observations and conclusions for the 2021 period are that there were below-average discharge conditions in Chino Creek and the riparian vegetation did not change significantly along Chino Creek.

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[17] These charts do not describe other hydrologic processes that affect surface-water discharge within the Prado Basin, including evaporation, evapotranspiration, the infiltration of water along unlined stream segments, and rising groundwater discharge.

***Mill Creek (Figure 3-18b)***. Cucamonga Creek is a concrete-lined flood-control channel and transitions into an unlined stream channel at the Prado Basin boundary, and at that point, its name changes to Mill Creek (see Figure 2-3). The upper chart on Figure 3-18b shows discharge in Mill Creek during the growing season, including: POTW effluent discharge from the IEUA RP-1 plant to Cucamonga Creek and measured discharge downstream at USGS gage *Cucamonga Creek near Mira Loma* (less the RP-1 discharge). The measured discharge at *Cucamonga Creek near Mira Loma* (less the RP-1 discharge) is representative of storm-water and dry-weather runoff in Cucamonga Creek upstream of this gaging station during the growing season. Discharges not characterized on this figure are storm-water runoff, dry-weather runoff, and rising-groundwater discharge downstream of the *Cucamonga Creek near Mira Loma* gage. Also not characterized on this figure is the volume of water diverted from Cucamonga Creek to the Mill Creek Wetlands just north of where Mill Creek begins (see inset map for location of Mill Creek Wetlands). During this next year, all the surface water diversion measurements to the Mill Creek Wetlands will be collected and used to better characterize the discharge in Mill Creek during the growing season. It is likely that the growing-season discharge in the northernmost region of Mill Creek will be about 50 percent less since the Mill Creek Wetlands began operating at full capacity.

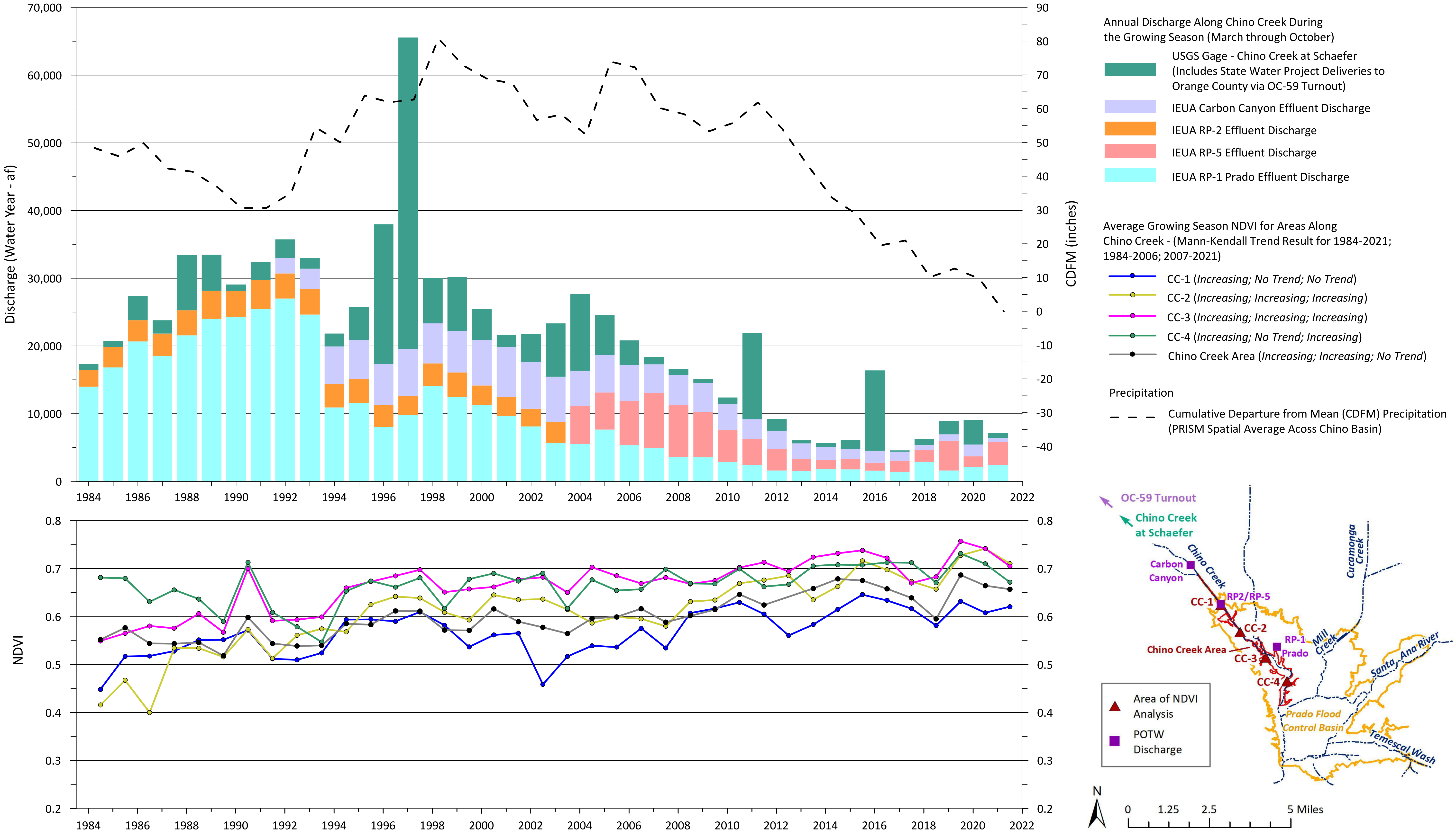
From 1984 to 2021, growing-season discharge in Mill Creek progressively increased through 2004 and then decreased. The decreasing trend in growing-season discharge since about 2004 was caused by dry climatic conditions, water conservation in response to drought conditions after 2012, and the decrease in effluent discharge from the IEUA RP-1 plant. During the recent nine-year period from 2012 to 2021 growing-season discharge averaged about 8,800 afy. In 2021, the growing-season discharge was about 10,200 afy, which is about 1,600 af greater than the average growing-season discharge over the last eight years, and about 5,000 af less than growing-season discharge in 2020.

From 2020 to 2021, Average Growing-Season NDVI at the four areas along Mill Creek: decreased at three areas and remained the same at one area. The Average Growing-Season NDVI for the whole Mill Creek area decreased from 2020 to 2021. At all the areas, these recent changes in NDVI are within their historical ranges of the one-year NDVI variability (see Table 3-2). However, the air photos for the MC-2 area shows a notable decrease in green vegetation from 2020 to 2021. These recent changes in NDVI occurred during a year of above slightly above average discharge in Mill Creek, but much lower discharge conditions from the prior year. Hence, the main observations and conclusions for the 2021 period are that there were above average discharge conditions in Mill Creek and the riparian vegetation did not change significantly along Mill Creek, except in the area observed near MC-2. The decrease in NDVI and green vegetation observed at MC-2 is likely not caused by the average discharge conditions in Mill Creek during 2021 but is likely related to some other factor.

***Santa Ana River (Figure 3-18c)***. The SAR is an unlined stream channel from the Riverside Narrows to Prado Dam—its entire reach across the Chino Basin (see Figure 2-3). The upper chart on Figure 3-18c shows the annual growing-season discharge at the USGS gage *Santa Ana River at MWD Crossing* (Riverside Narrows) and the annual growing-season discharges to the SAR downstream of the Riverside Narrows, including POTW effluent from the City of Riverside's Regional Water Quality Control Plant and the Western Riverside County Regional Wastewater Authority (WRCRWA) plant that is conveyed in an unlined channel (along with a portion of SAR discharge) to the OCWD Wetlands. The measured discharge at the *Santa Ana River at MWD Crossing* gage represents storm-water runoff and base-flow discharge in the SAR upstream of the gaging station at the Riverside Narrows. The base-flow discharge includes POTW discharge from the RIX and Rialto treatment plants, dry-weather runoff, and rising groundwater. Discharges not characterized on this figure are storm-water runoff, dry-weather runoff, and rising-groundwater discharge downstream of the *Santa Ana River at MWD Crossing* gage.

From 1984 to 2011, growing-season discharge in the SAR averaged about 78,100 afy with episodic increases in storm-water discharge during wet years. During the recent nine-year period, from 2012 to 2020, growing-season discharge in the SAR gradually declined and averaged about 48,600 afy. The decreasing trend in growing-season discharge was caused by dry climatic conditions, water conservation in response to drought, and decreasing base flow at the Riverside Narrows. In 2021, the growing-season discharge in the SAR was about 43,400 af, which is about 5,200 af less than the average growing-season discharge during 2012 to 2019, and about 16,500 af less than growing-season discharge in 2020.

From 2020 to 2021, the Average Growing-Season NDVI decreased at all four areas. For two of these areas (SAR-2 and SAR-3), the one-year NDVI changes were relatively minor and within the historical ranges of one-year NDVI variability (see Table 3-2). These changes occurred during a year of below-average discharge in the SAR. The lower discharge conditions are likely a contributing cause of the slight decreases in the NDVI observed along the SAR at SAR-2 and SAR-3. Hence, the main observations and conclusions for the 2020 to 2021 period are that there were lower discharge conditions in the SAR and the riparian vegetation did not change significantly along the SAR, except in the LP and SAR-1 areas. The notable decreases in the green vegetation observed at the LP and SAR-1 areas are likely not caused by the lower discharge conditions during 2021 and are related to some other factor/s.



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WEST YOST - K:\Clients\941 Chino Basin Watermaster\00-00-00 Master\PE1 - Data_Monitoring\GRAPHER\GRF\Prado\AnnualR\Figure 3-18a_SW Discharge_NDVI_CC.grf - lhedley - 5/3/2022

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2021 Annual Report

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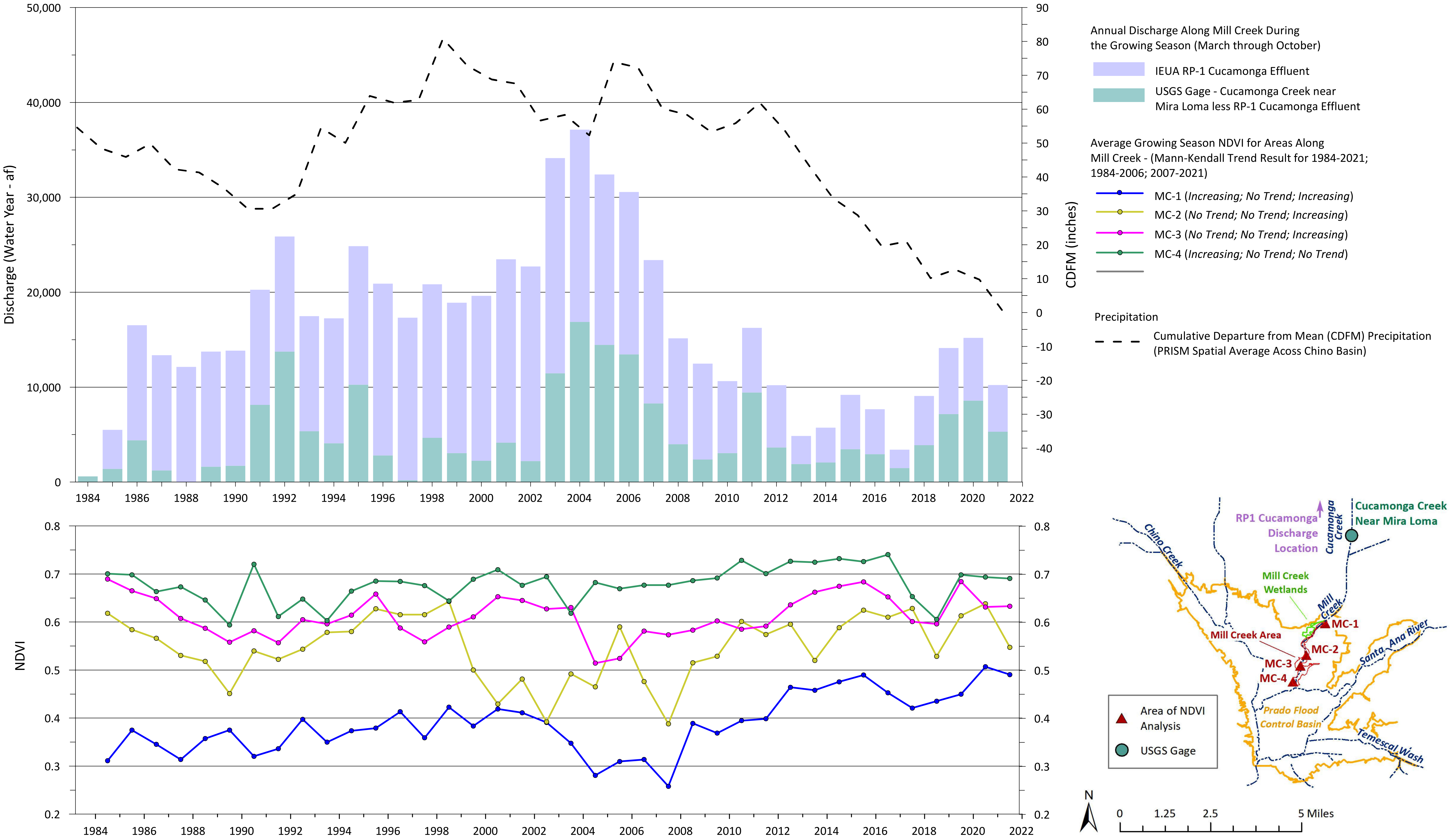
## Surface-Water Discharge versus NDVI
*Chino Creek Area for 1984-2021*

**Figure 3-18a**



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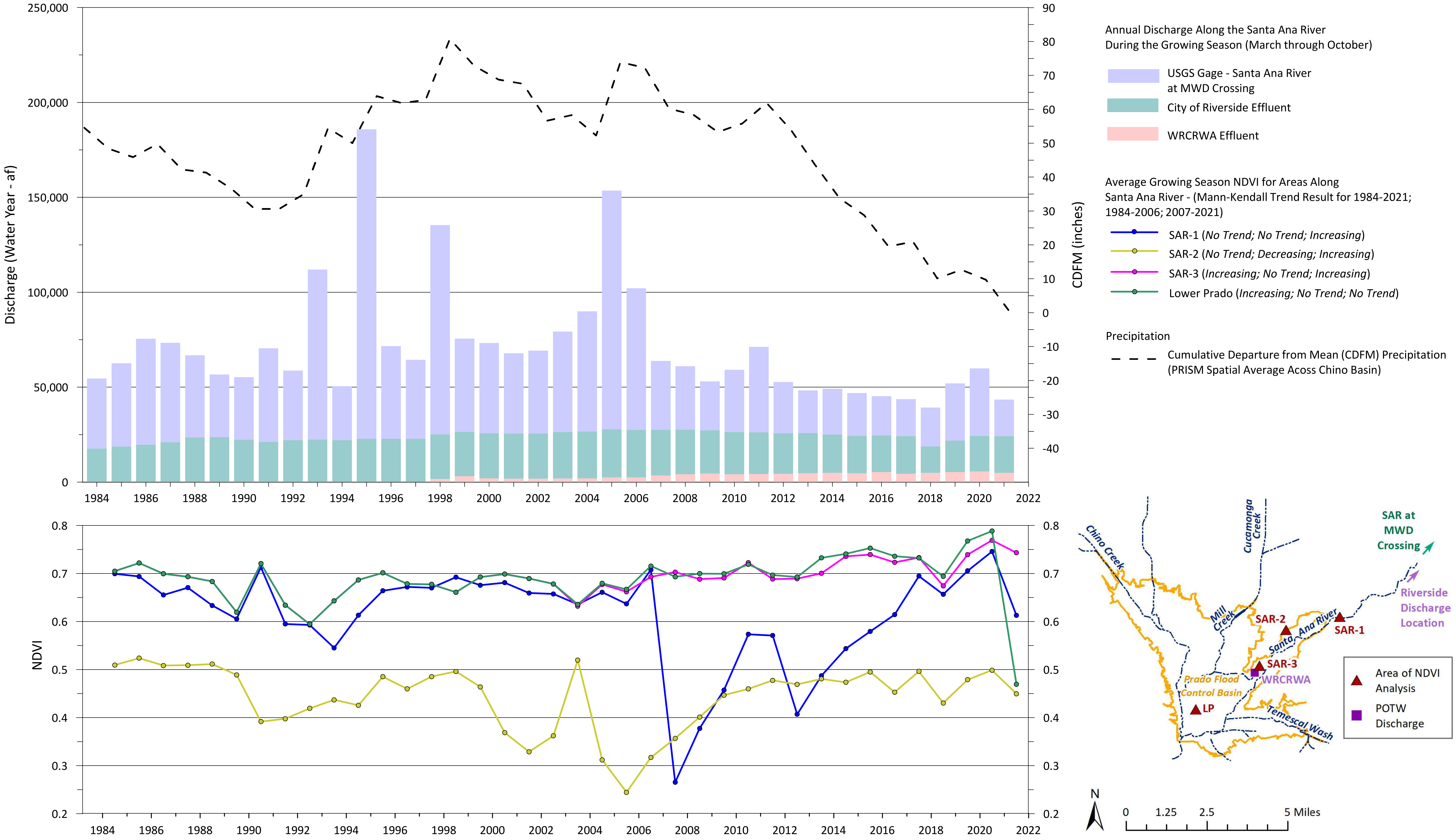
**Surface-Water Discharge versus NDVI**
*Mill Creek Area for 1984-2021*

**Figure 3-18b**



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CHINO BASIN WATERMASTER
Partners in Basin Management

**Surface-Water Discharge versus NDVI**
*Santa Ana River and Lower Prado Area for 1984-2021*

**Figure 3-18c**

## 3.6 Other Factors and Their Relationships to Riparian Habitat

Other factors that can affect the extent and quality of riparian habitat in the Prado Basin analyzed in this Annual Report include wildfire, pests, and Arundo management. These factors are unrelated to Peace II Agreement implementation.

This section characterizes what is known about these factors and compares them to trends in the extent and quality of the riparian habitat to determine their impacts, as characterized by the NDVI.

### *3.6.1 Wildfire*

Available wildfire perimeter data from the FRAP database[18] were compiled within the Prado Basin extent for the period of 1950-2020.[19] The FRAP database shows that wildfires occurred in the Prado Basin in 1985, 1989, 2007, 2015, 2018, and 2020. Figure 3-19a shows the spatial extent of these wildfires, mapped over the 2021 air photo. The most recent wildfire was along the southern portion of the Prado Basin in December 2020. Most of the area impacted by the 2020 wildfire is still identifiable in the air photo by areas of brownish land cover that lack green vegetation. There are still large portions within the 2018 wildfire along the Chino Creek that are areas of brownish land cover with no green vegetation, indicating that this area is still has impacts to the vegetation from the fire. The small LP area, where the recent one-year decline in the Average Growing Season NDVI exceeds the magnitude of any historical one-year change in this area (see Section 3.1), is within the area of the 2020 wildfire. Hence, the most recent wildfire in 2020 is the cause of the decrease in greenness at the LP area in the lower Prado Basin.

Figure 3-19b shows spatial extent of the most recent wildfires in 2015, 2018, and 2020, overlying a side-by-side of the change map of NDVI from 2020 to 2021 and the 2021 air photo for the area along the SAR and lower Prado Basin. The location of these wildfires in 2015, 2018 and 2020 align with the notable areas of NDVI decrease shown on the NDVI change map, the areas of brown land cover in the air photo along the southern Chino Creek and the lower Prado Basin.

Figures 3-20a through 3-20c are time-series charts that explore the relationship between other factors that can impact riparian vegetation and NDVI for three reaches in the Prado Basin: Chino Creek, Mill Creek, and the SAR. The figures show the Average Growing-Season NDVI for 14 defined areas of riparian habitat discussed in Section 3.1 and shown in Figures 3-6, 3-7, and 3-8a through 3-8l. Wildfire occurrences, annotated by date, are shown on the charts if their extent intersects with the extent of the defined area of NDVI analysis. The most recent wildfire in 2020 burned a large portion of the southern region of Prado Basin. The LP area that is within the 2020 wildfire shows a decrease in the Average Growing-Season NDVI of 0.32 following the wildfire. There are other notable declines in the NDVI for some of the defined areas impacted by the 1985, 2007 and 2018 wildfires. And the NDVI time series for the entire vegetation extent in Figure 3-5 shows declines after the recent 2020 fire, and also after the 2018 and 2015 fires which have been described in previous annual reports.

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[18] Link (Website for California Department of Forestry and Fire Protection's Fire and Resource Assessment Program).

[19] Data is updated in late April for the previous year; 2021 data were not available for this annual report.

### *3.6.2 Arundo Removal*

The OCWD and SAWA[20] are the main entities that implement habitat restoration programs, including the removal and management of Arundo in the SAR watershed for the promotion of native habitat for endangered or threatened species. The OCWD and SAWA sometimes work collaboratively with each other on these programs and with other stakeholders in the watershed, such as the USFWS, California Department of Fish and Wildlife (CDFW), ACOE, Regional Board, Counties of Riverside and San Bernardino, and several cities. There are many ongoing programs throughout the Prado Basin for the management and maintenance of riparian habitat that include the management of Arundo. SAWA publishes an annual report on the status of all habitat restoration projects they are involved with in the watershed (SAWA, 2020). Figure 3-21a shows the locations of known areas where habitat restoration activities have occurred recently in the Prado Basin, including the management and removal of Arundo. The current known habitat restoration activities include the area of the 2015 wildfire in the lower Prado Basin area, where the OCWD is controlling the regrowth of Arundo following the 2015 fire, and various patches along the SAR and lower Prado Basin area, where SAWA is leading efforts to remove Arundo between 2019 and 2021. These areas and activities are not inclusive of all activities currently occurring in the Prado Basin but are the known locations identified for the PBHSP where there are current Arundo management activities and notable impacts to vegetation in the PBHSP.

In 2021, there are no identified areas of Arundo removal within the 14 defined areas analyzed in Section 3.1 and shown in Figures 3-6, 3-7, and 3-8a through 3-8l. All of the Arundo removal areas from 2019-2021 are along the SAR and the lower Prado Basin area below the OCWD Wetlands. Figure 3-21b shows spatial extent of the recent Arundo removal and management areas between 2019 to 2021, overlying a side-by-side of the change map of NDVI from 2020 to 2021, and the 2021 air photo for the area along the SAR and lower Prado Basin. The location of these recent Arundo removal and managed areas align with the notable areas of NDVI decrease shown on the NDVI change map and areas of brown land cover in the air photo along the southern Chino Creek and the lower Prado Basin.

### *3.6.3 Polyphagous Shot Hole Borer*

PSHB, from the group known as ambrosia beetles, is a relatively new pest in Southern California. PSHB burrows into trees and introduces fungi that assists in establishing colonies. Infection caused by the fungi can cause a dark stain surrounding the entry holes, discolored bark, leaf discoloration and wilting, and die off of entire branches or trees.

In spring 2016, OCWD biologists observed die off of riparian trees in patches throughout the Prado Basin, especially arroyo and black willows, and confirmed that the cause was from PSHB (ACOE and OCWD, 2017; OCWD 2020). Although PSHB arrived prior to 2016, this was the first notable die off in the Prado Basin. Since 2016, OCWD biologists have noted that the presence of PSHB is widespread throughout the Prado Basin and has reduced tree canopy cover, but tree mortality has remained confined to small local patches (Zembal, R., personal communication, 2018). OCWD biologists observed that the affected trees that had not died were showing signs of severe infestation, exhibiting branch failure, significant staining, and crown sprouting after the upper branches had died back. (ACOE and OCWD, 2017). In infected trees, crown sprouting allows some of the trees to persist, but the PSHB have been observed to attack the recently

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[20] SAWA is a non-profit agency with a five-member board, consisting of one member from the OCWD and the remaining from four resource conservation districts (RCDs) in the watershed, including the Riverside-Corona RCD, Temecula-Elsinore-Anza RCD, San Jacinto RCD, and Inland Empire RCD.

emerged limbs once they grow to two to three inches in diameter, causing the sprouting to be temporary. The die back and crown sprouting has resulted in a reduction of canopy in many areas (OCWD, 2020). Canopy loss in heavily infested areas may allow faster-growing invasive non-native species to colonize and out-compete native trees and shrubs in the understory (OCWD, 2020).

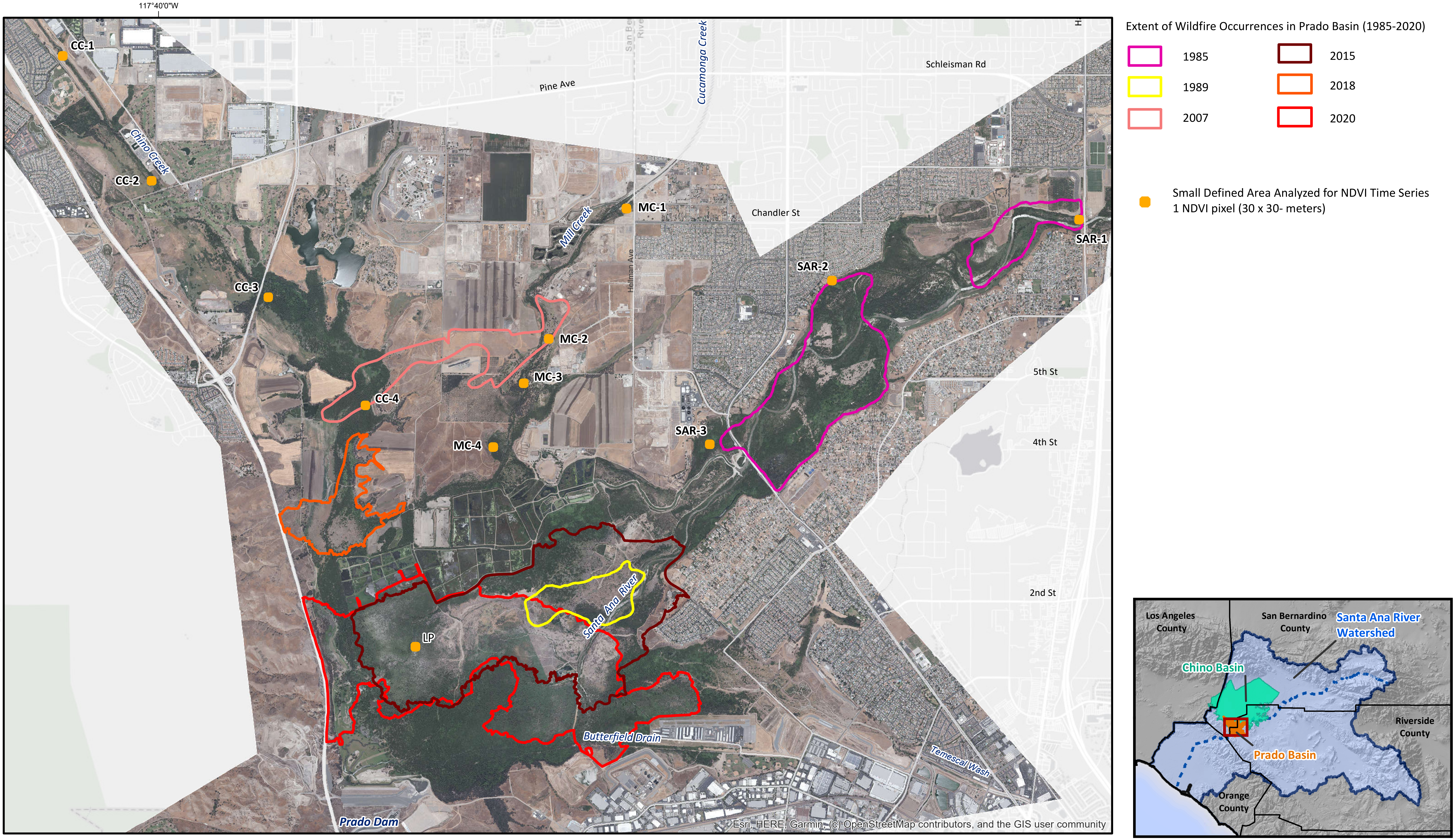
In 2016 and 2017, OCWD biologists in the Prado Basin worked with the University of California, Riverside, the USFWS, and SAWA to actively monitor the occurrence and impact of PSHB within Prado Basin riparian habitat. These agencies conducted studies on how to potentially protect certain areas of the Prado Basin from PSHB using attractants and deterrents; however, there were too many trees to effectively protect the entire forest (Zembal, R., personal communication, 2018). Traps were placed throughout the lower portion of Prado Basin and along the SAR by the OCWD and SAWA. The total number of PBHB beetles trapped at each location between August 2016 and April 2017 ranged from seven to 2,092.

Figure 3-21a shows the locations where the presence of PSHB has been documented within the Prado Basin from 2016 to 2019 by: PSHB traps deployed by the OCWD and SAWA between August 2016 and April 2017; and the USBR vegetation surveys performed in 2016 and 2019.

During the 2016 USBR vegetation surveys, the presence of the PSHB was identified at 30 of the 37 survey sites. At these sites, all the trees identified with the presence of PSHB were noted as “stressed,” except one which was noted as “dead.” The 2016 USBR surveys were the first site-specific surveys that documented the presence and abundance of PSHB for the PBHSP.

During the 2019 USBR vegetation surveys, the presence of the PSHB was identified at only seven of the 30 sites that were originally identified with PSHB presence in 2016—a 61 percent decrease. In 2019, the presence was only noted at sites along Chino and Mill Creeks; no presence was noted at sites along the SAR. The percentage of trees with the noted presence of the PSHB decreased from 28 to three percent at sites along Chino Creek; and decreased from 57 to nine percent at sites along Mill Creek. OCWD biologists have suggested that the wet year of 2019 may have allowed the riparian trees to better resist PSHB burrowing and fungal disease impacts (USBR, 2020). The reduced presence of the PSHB from 2016 to 2019 correlated to less stressed trees at each of the survey sites; however, the PSHB had an adverse impact from 2016 to 2019, as evidenced by the increased percentage of dead trees and some reductions in percent canopy cover at the survey sites (see Table 3-3 and the 2019 Annual Report Section 3.6.2).

Figures 3-20a through 3-20c are time-series charts that explore the relationship between PSHB occurrence and NDVI for three reaches in Prado Basin: Chino Creek, Mill Creek, and the SAR. These figures show the Average Growing-Season NDVI for 14 defined areas of riparian habitat discussed in Section 3.1 and shown in Figures 3-6, 3-7 and 3-8a through 3-8l. For each defined area, the percentage of infected trees relative within each survey site that is within the area are plotted on the charts. At all of these sites, the percentage of trees impacted decreased from 2016 to 2019, and the Average Growing-Season NDVI in the nearby defined areas increased from 2018 to 2020. These observations indicate that the reduced presence of the PSHB in 2019 is a contributing cause of the observed increases in NDVI along Chino Creek, Mill Creek, and the SAR.



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2021 Annual Report of the
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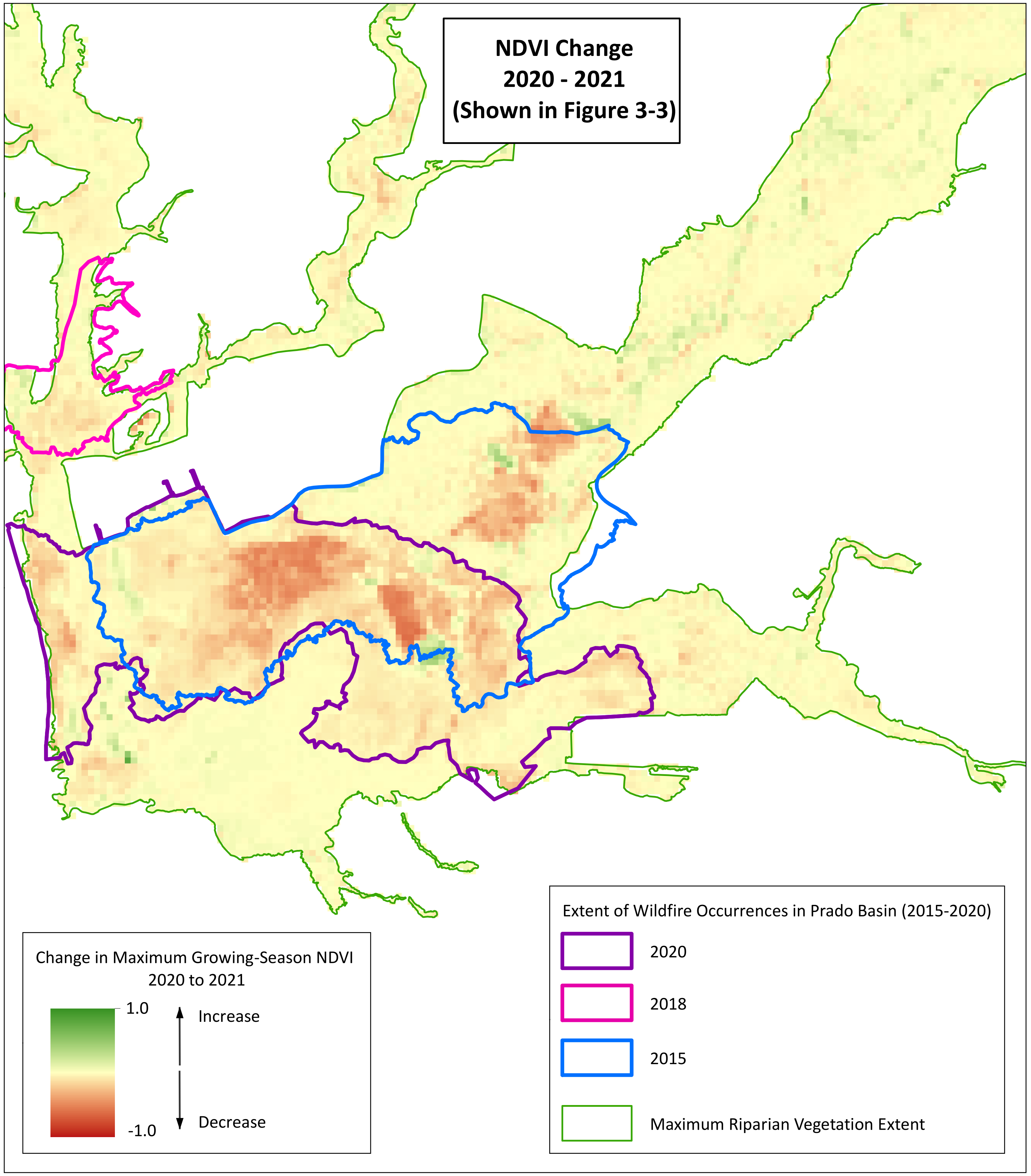
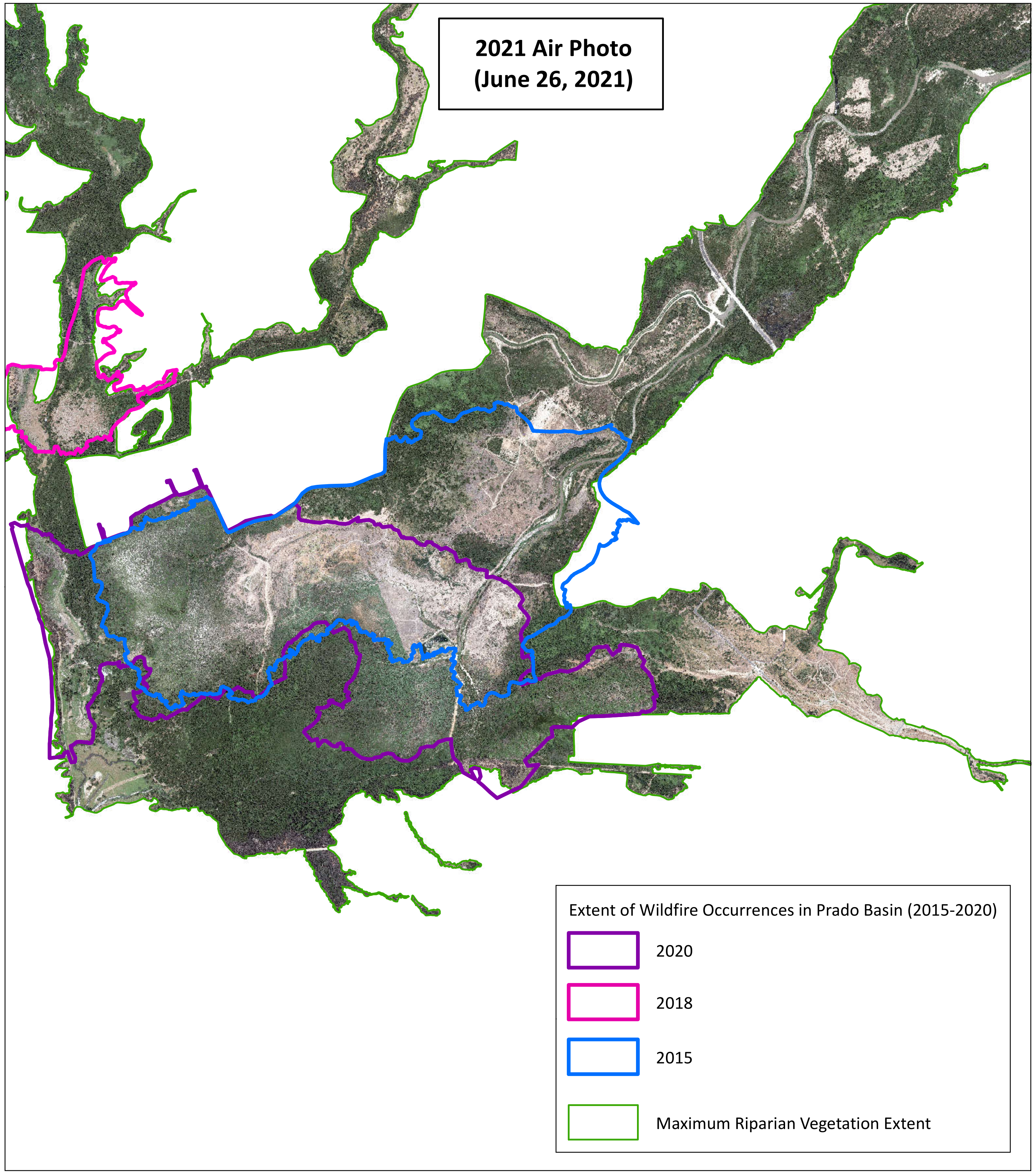
**Location Map of Other Factors That Can Affect Riparian Habitat**

*Wildfire*

**Figure 3-19a**





WEST YOST - K:\Clients\941 Chino Basin Watermaster\00-00-00 Master\PE1 - Data_Monitoring\GIS\MXD\Prado\Annual Report\2021\Figure 3-19b_NDVI_fire.mxd - LH - Date: 5/4/2022

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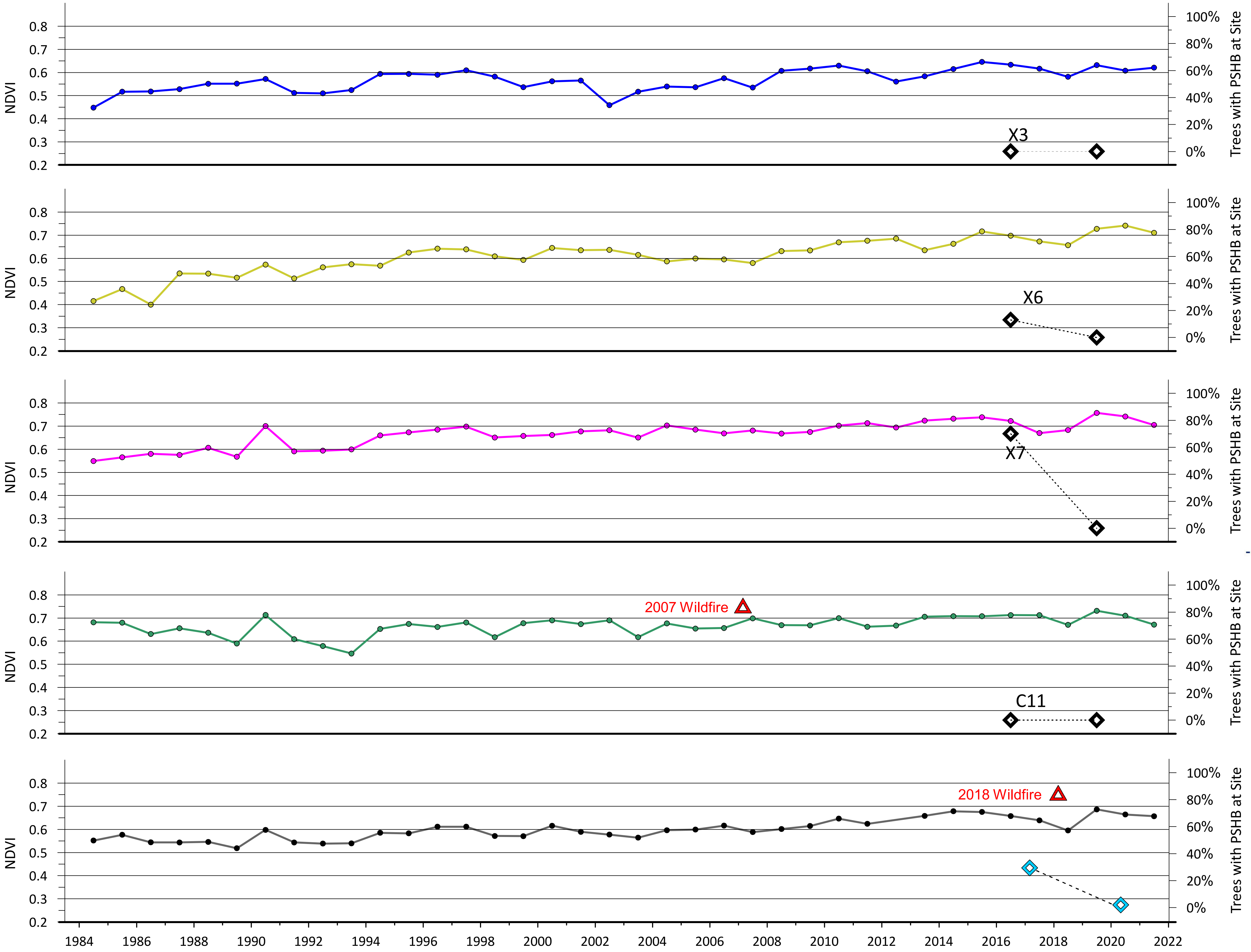
**Spatial NDVI Change 2020-2021 and 2021 Air Photo**
**With Prado Basin Wildfires in 2015, 2018, and 2020**

**Figure 3-19b**



Average Growing Season NDVI for Areas Along
Chino Creek - (Mann-Kendall Trend Result for 1984-2021;
1984-2006; 2007-2021)

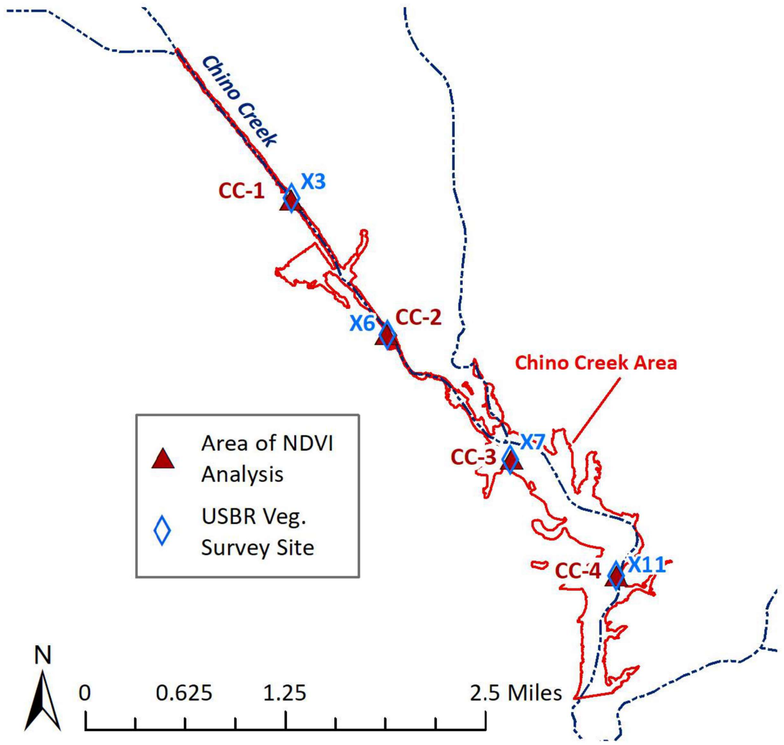
- CC-1 (*Increasing; No Trend; No Trend*)
- CC-2 (*Increasing; Increasing; Increasing*)
- CC-3 (*Increasing; Increasing; Increasing*)
- CC-4 (*Increasing; No Trend; Increasing*)
- Chino Creek Area (*Increasing; Increasing; No Trend*)

Other Factors

◇ USBR vegetation survey sites in the areas, that were surveyed in 2016 and 2019 where the presence of the Polyphagous Shot Hole Borer (PSHB) was noted - plotted by percentage of trees impacted at each site.

◇ Percentage of trees with the PSHB noted for all surveyed sites within the Chino Creek area

△ Occurence of Wildfire in NDVI Area



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WEST YOST - K:\Clients\941 Chino Basin Watermaster\00-00-00 Master\PE1 - Data_Monitoring\GRAPHER\GRF\Prado\AnnualR\Figure 3-20a_Other Factors_NDVI_CC.grf - lhedley - 5/3/2022

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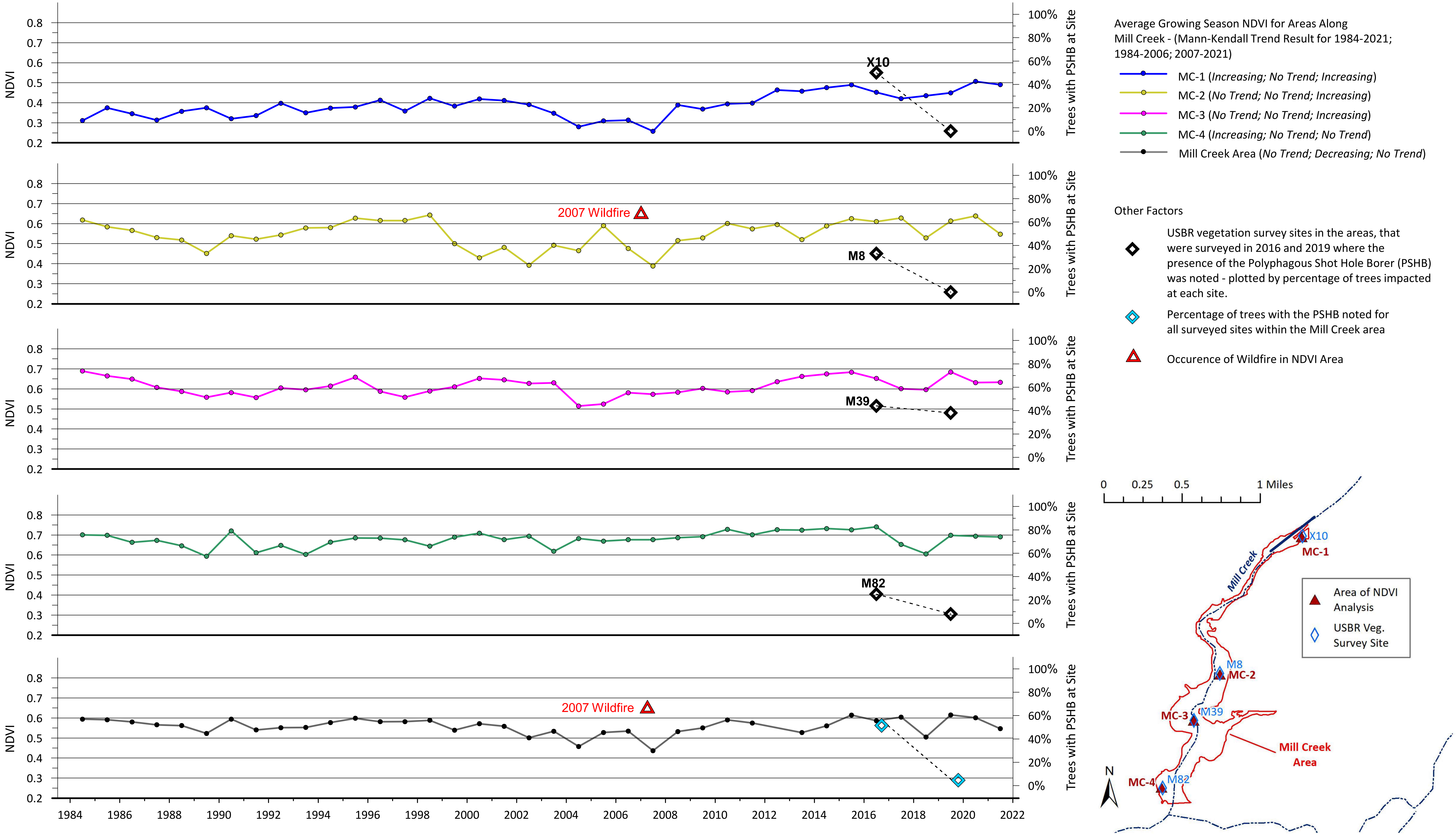
**Other Factors that Affect Riparian Habitat verus NDVI**
*Chino Creek Area for 1984-2021*

**Figure 3-20a**



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WEST YOST - K:\Clients\941 Chino Basin Watermaster\00-00-00 Master\PE1 - Data_Monitoring\GRAPHER\GRF\Prado\AnnualR\Figure 3-20b_Other Factors_NDVI_MC.grf - lhedley - 5/3/2022

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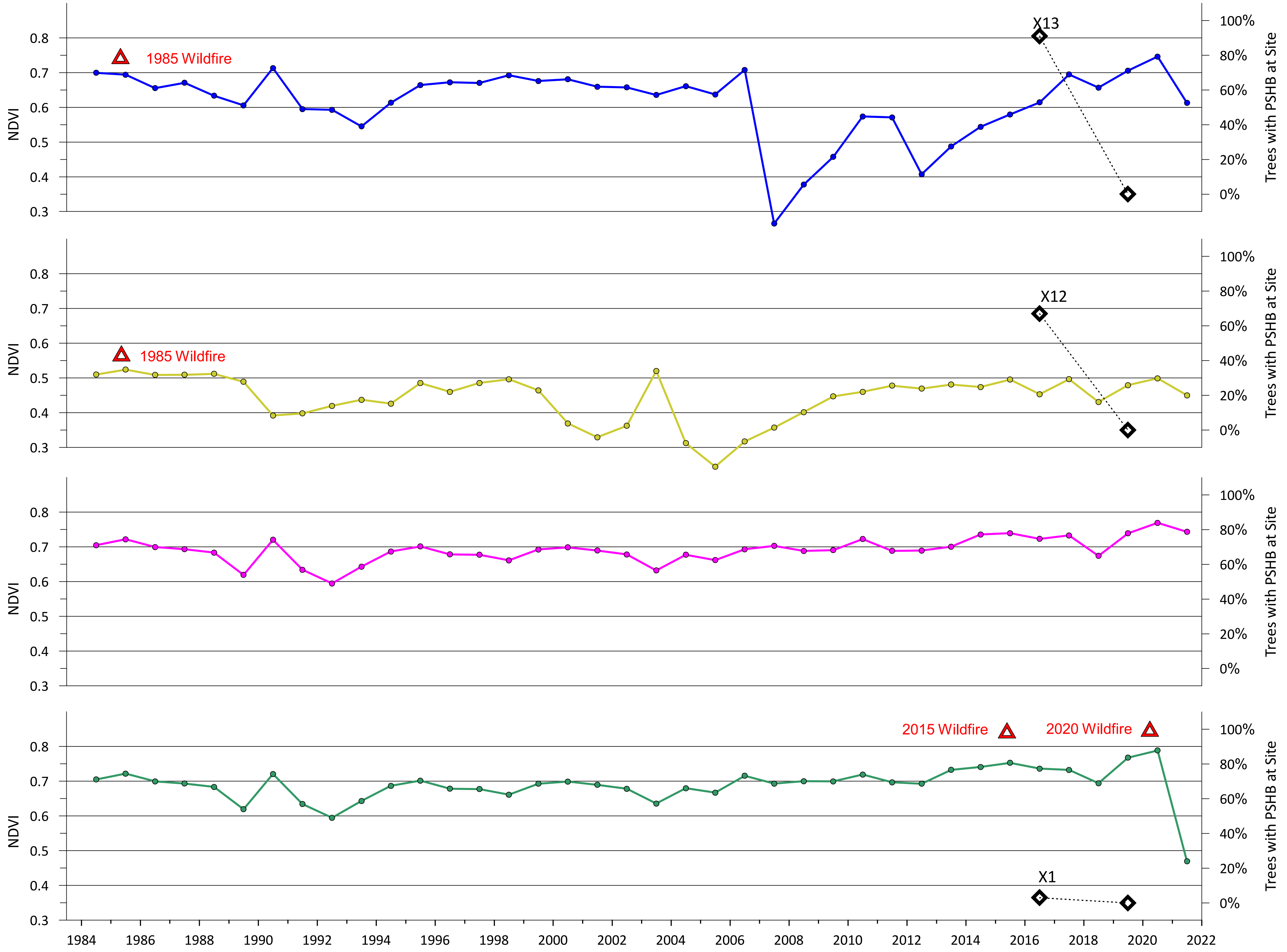
**Other Factors that Affect Riparian Habitat verus NDVI**
*Mill Creek Area for 1984-2021*

**Figure 3-20b**



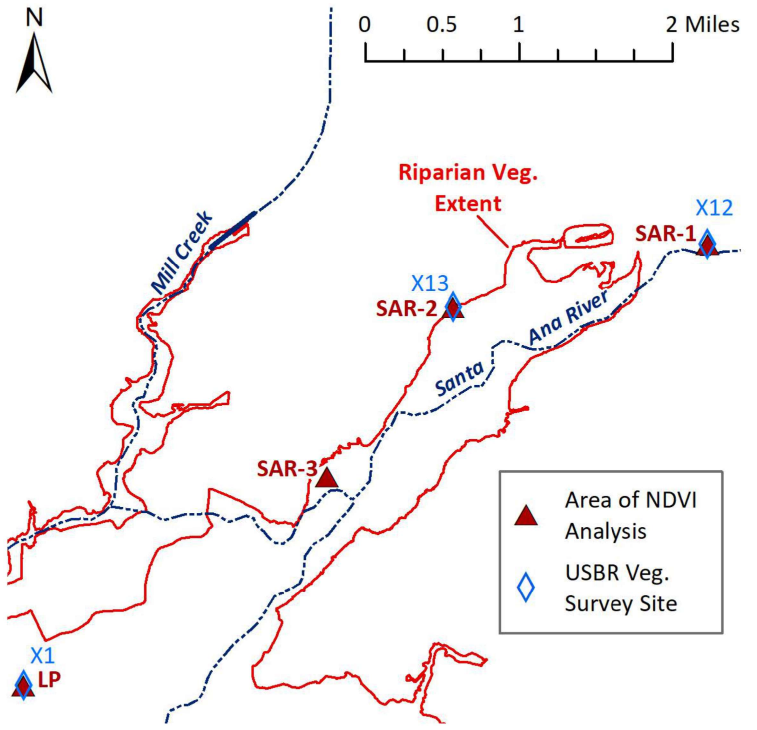
Average Growing Season NDVI for Areas Along Santa Ana River - (Mann-Kendall Trend Result for 1984-2021; 1984-2006; 2007-2021)

- SAR-1 (*No Trend; No Trend; Increasing*)
- SAR-2 (*No Trend; Decreasing; Increasing*)
- SAR-3 (*Increasing; No Trend; Increasing*)
- Lower Prado (*Increasing; No Trend; No Trend*)

Other Factors

◇ USBR vegetation survey sites in the areas, that were surveyed in 2016 and 2019 where the presence of the Polyphagous Shot Hole Borer (PSHB) was noted - plotted by percentage of trees impacted at each site.

△ Occurence of Wildfire in NDVI Area



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WEST YOST - K:\Clients\941 Chino Basin Watermaster\00-00-00 Master\PE1 - Data_Monitoring\GRAPHER\GRF\Prado\AnnualR\Figure 3-20c_Other Factors_NDVI_SAR_LPrado.grf - lhedley - 5/3/2022

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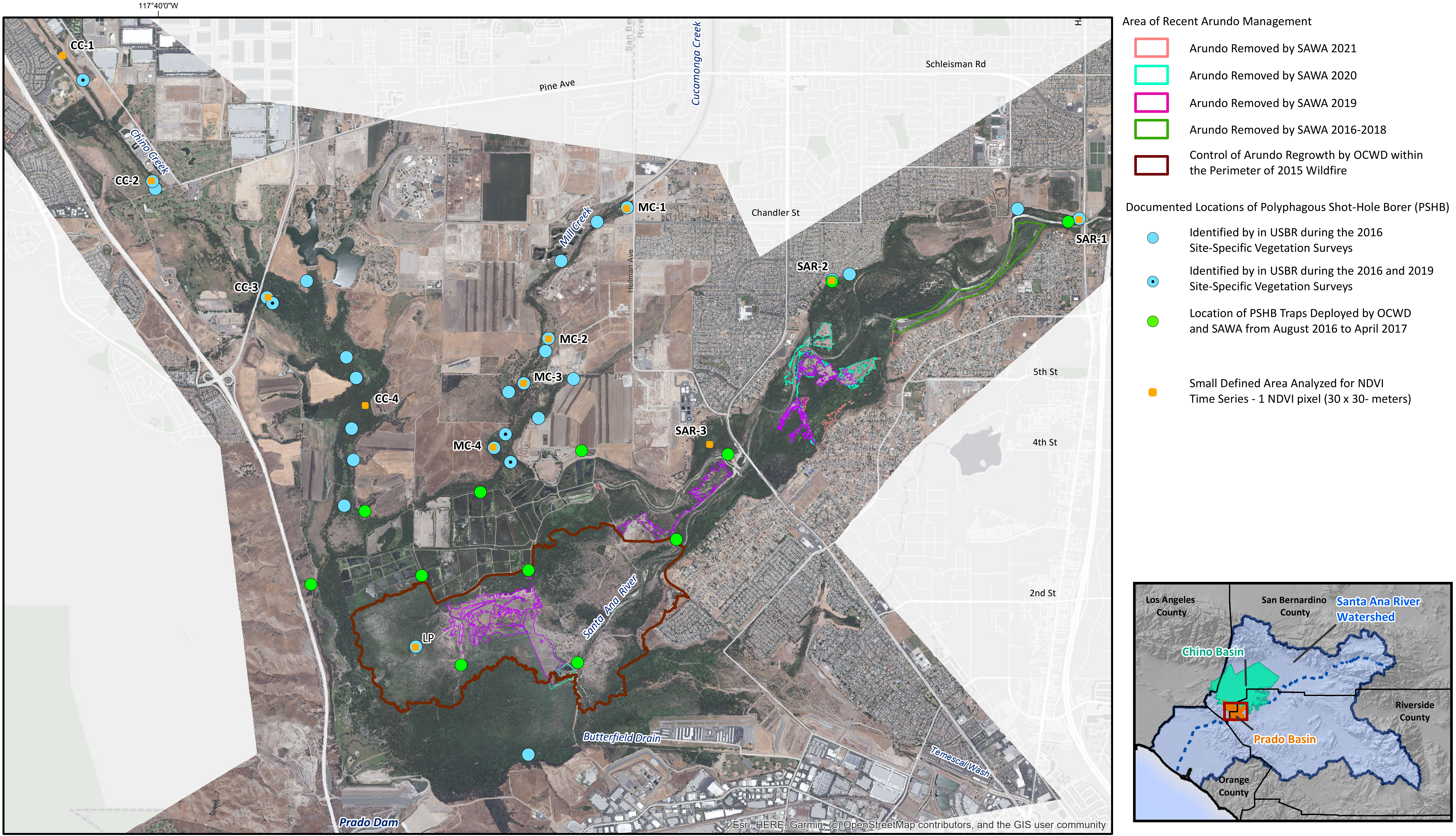
**Prado Basin Habitat Sustainability Committee**
2021 Annual Report

**Other Factors that Affect Riparian Habitat verus NDVI**
*Santa Ana River and Lower Prado Area for 1984-2021*

**Figure 3-20c**



Area of Recent Arundo Management

- 🟥 Arundo Removed by SAWA 2021
- 🟦 Arundo Removed by SAWA 2020
- 🟪 Arundo Removed by SAWA 2019
- 🟩 Arundo Removed by SAWA 2016-2018
- 🟫 Control of Arundo Regrowth by OCWD within the Perimeter of 2015 Wildfire

Documented Locations of Polyphagous Shot-Hole Borer (PSHB)

- ● Identified by in USBR during the 2016 Site-Specific Vegetation Surveys
- ⊙ Identified by in USBR during the 2016 and 2019 Site-Specific Vegetation Surveys
- ● Location of PSHB Traps Deployed by OCWD and SAWA from August 2016 to April 2017
- ■ Small Defined Area Analyzed for NDVI Time Series - 1 NDVI pixel (30 x 30- meters)

WEST YOST - K:\Clients\941 Chino Basin Watermaster\00-00-00 Master\PE1 - Data_Monitoring\GIS\MXD\Prado\Annual Report\2021\Figure 3-21a_other factors-arundo-PSHB.mxd - LH - Date: 5/4/2022

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N

0 1 2 Miles

0 1 2 Km

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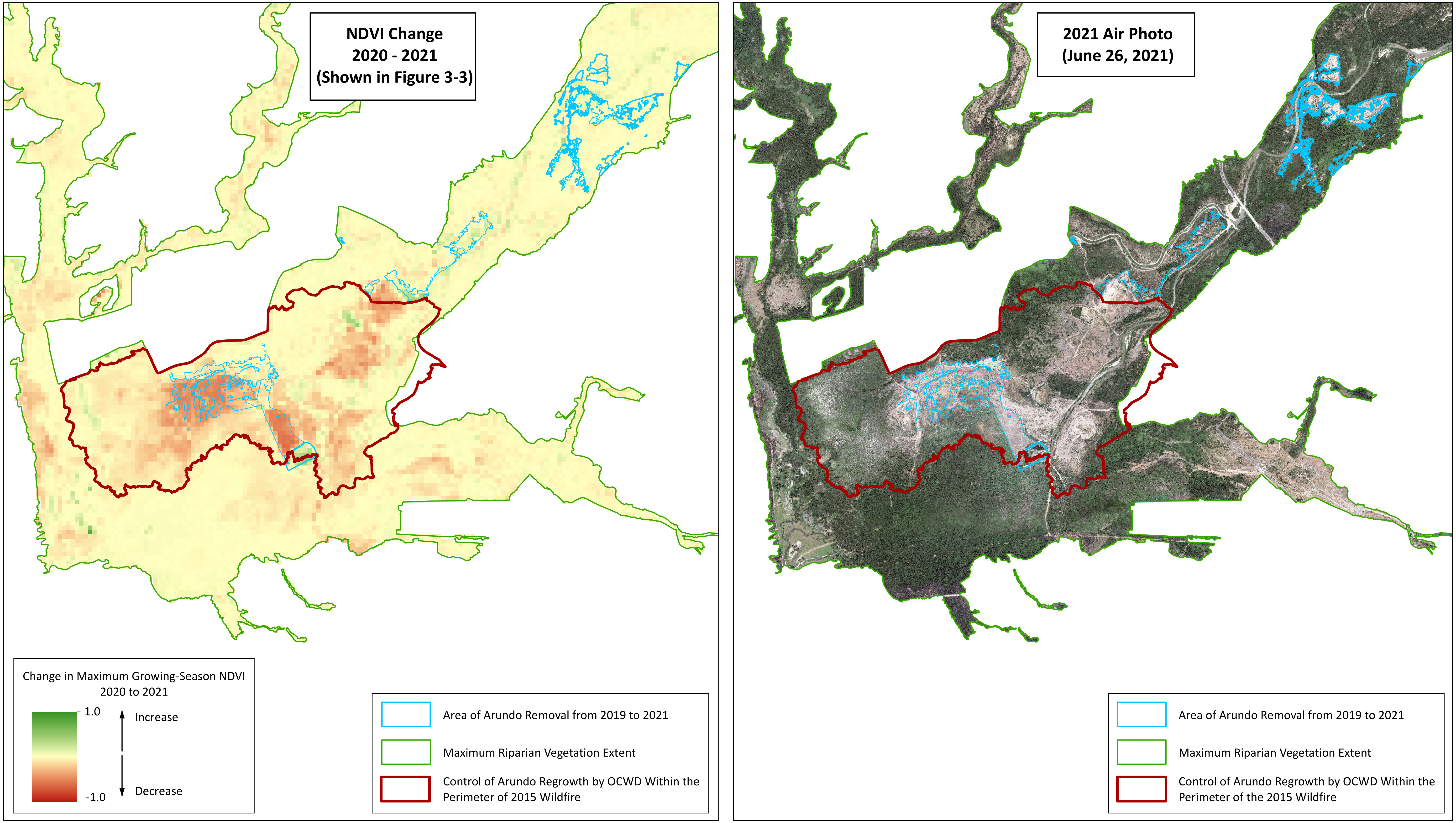
**Location Map of Other Factors That Can Affect Riparian Habitat**
*Arundo and PSHB*
**Figure 3-21a**

WEST YOST - K:\Clients\941 Chino Basin Watermaster\00-00-00 Master\PE1 - Data_Monitoring\GIS\MXD\Prado\Annual Report\2021\Figure 3-21b_NDVI_Arundo.mxd - LH - Date: 5/4/2022



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**Spatial NDVI Change 2020-2021 and 2021 Air Photo With Prado Basin Arundo Removal in 2019-2021**

**Figure 3-21b**

## 3.7 Analysis of Prospective Loss of Riparian Habitat

The meaning of “prospective loss” of riparian habitat in this context is the “future potential loss” of riparian habitat. Watermaster’s recent predictive modeling results[21] were used to identify areas of prospective loss of riparian habitat that may be attributable to the Peace II Agreement by projecting future groundwater-level conditions in the Prado Basin area through 2030. To perform this evaluation, the predictive model results were mapped and charted to identify areas, if any, where groundwater levels are projected to decline to depths that may adversely impact the riparian habitat in the Prado Basin.

Figure 3-22 is a map that shows the model-predicted change in groundwater levels in the Prado Basin area over the period of 2018-2030 from the planning scenario used to recalculate the Safe Yield of the Chino Basin in 2020 using Watermaster’s updated groundwater-flow model (WEI, 2020). The map shows that groundwater levels are predicted to remain steady across most of the Prado Basin area through 2030. The stability in groundwater levels is explained in part by projected declines in groundwater production from private wells in the area, the IEUA’s delivery of treated recycled water to this area for direct uses (such as outdoor irrigation), and the fact that most of the Chino Basin Desalter production will occur to the north and northeast. Figure 3-22 shows that the most likely area where groundwater levels are projected to decline by 2030 is the northern portions of Mill Creek and the SAR.

Figure 3-23 is a time-series chart of model-predicted groundwater levels at the PBHSP monitoring wells for the period of 2018 to 2030. These wells are strategically located adjacent to the riparian habitat south of the Chino Basin Desalter well field to understand the potential impacts of Peace II implementation on groundwater levels and the riparian habitat. The chart shows:

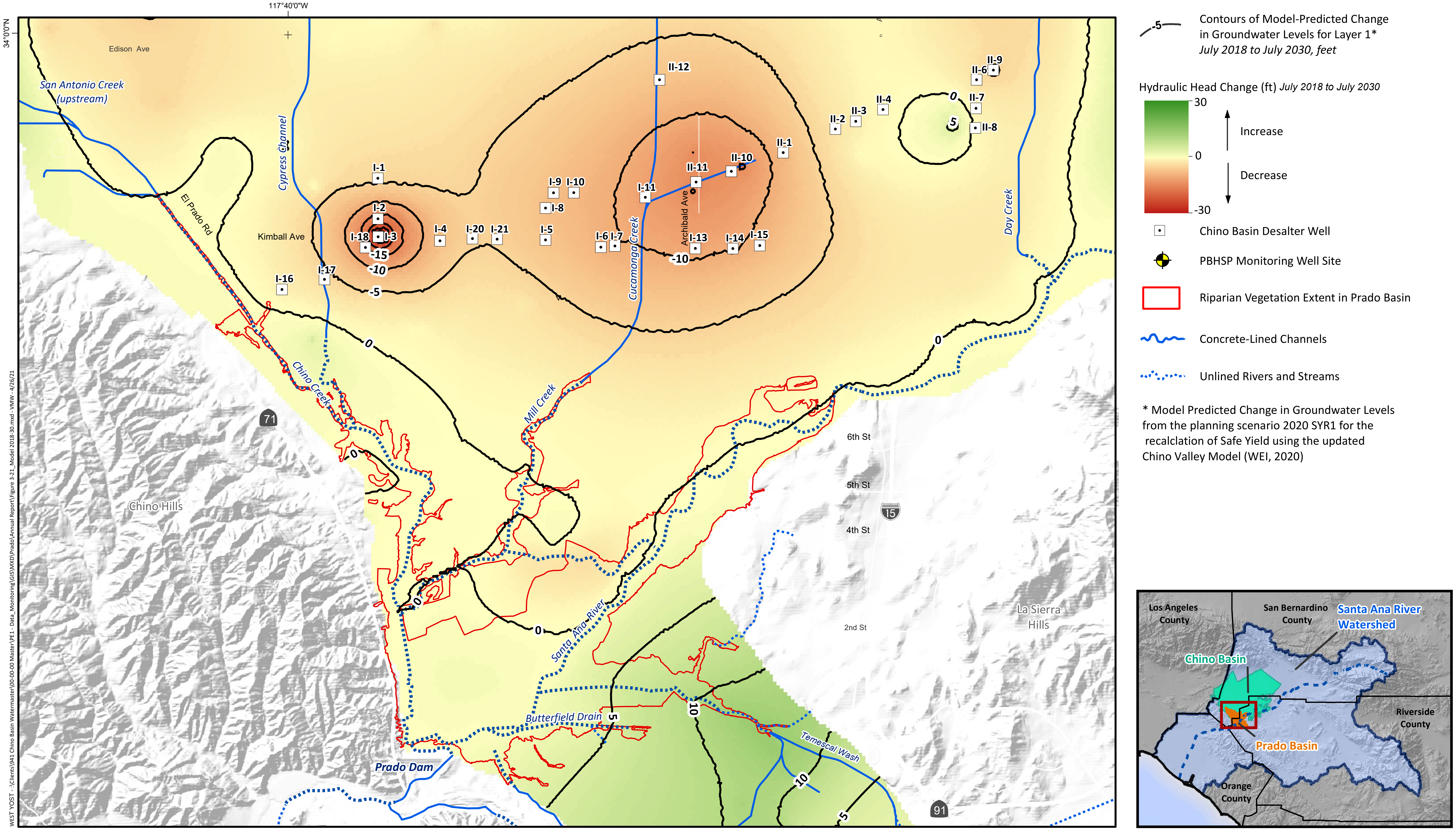
- Groundwater levels are projected to fluctuate seasonally at all PBHSP monitoring wells by about one to two feet.
- Groundwater-level trends are projected to remain stable at most of the PBHSP monitoring wells through the duration of the Peace II Agreement (through 2030).
- At two of the PBHSP monitoring wells, groundwater levels are projected to experience declines of about one to three feet from 2018 to 2030, which may represent a threat for prospective loss of riparian habitat:
    - **PB-2 above the northern reach of Mill Creek.** The model predicts a decline in groundwater levels at PB-2 of about three feet from 2018-2030. Figure 3-13b shows that groundwater levels declined at PB-2 by about five feet from 2018-2021, which is even greater than the decline predicted by the model through 2030. Figure 3-12 shows the current (Fall 2021) depth-to-groundwater where the riparian vegetation is growing along the northernmost reaches of Mill Creek ranges from about 5-16 ft-bgs. Hence, if the groundwater levels

---

[21] The predicted groundwater level changes through 2030 were made with the 2020 Chino Valley Model (CVM) for Scenario 2020 SYR1 for Layer 1 of the aquifer. The results of this model scenario were used to recalculate the 2020 Safe Yield of the Chino Basin (WEI, 2020). Scenario SYR1 is based on the water demands and water supply plans provided by the Watermaster parties, Chino Basin parties’ planning assumptions on pumping groundwater and conducting recharge operations, planning hydrology that incorporates climate change impacts on precipitation and ET0, and assumptions regarding cultural conditions and future replenishment.

continue to decline along Mill Creek, then it could result in adverse impacts to the riparian habitat in this area.

- **PB-3 along the northern portion of the SAR.** The model predicts a decline in groundwater levels at PB-3 of about one foot from 2018-2030. Figure 3-13c shows that groundwater levels declined at PB-3 by about two feet, from 2018-2021, which is greater than the decline predicted by the model through 2030. Figure 3-12 shows the current (Fall 2021) depth-to-groundwater where the riparian vegetation is growing along the northernmost reaches of the SAR ranges from 4-8 ft-bgs. If groundwater levels continue to decline at similar or higher rate through 2030, then it could result in a depth to groundwater greater than 15 ft-bgs and adverse impacts to the riparian habitat in this area.



* Model Predicted Change in Groundwater Levels from the planning scenario 2020 SYR1 for the recalclation of Safe Yield using the updated Chino Valley Model (WEI, 2020)

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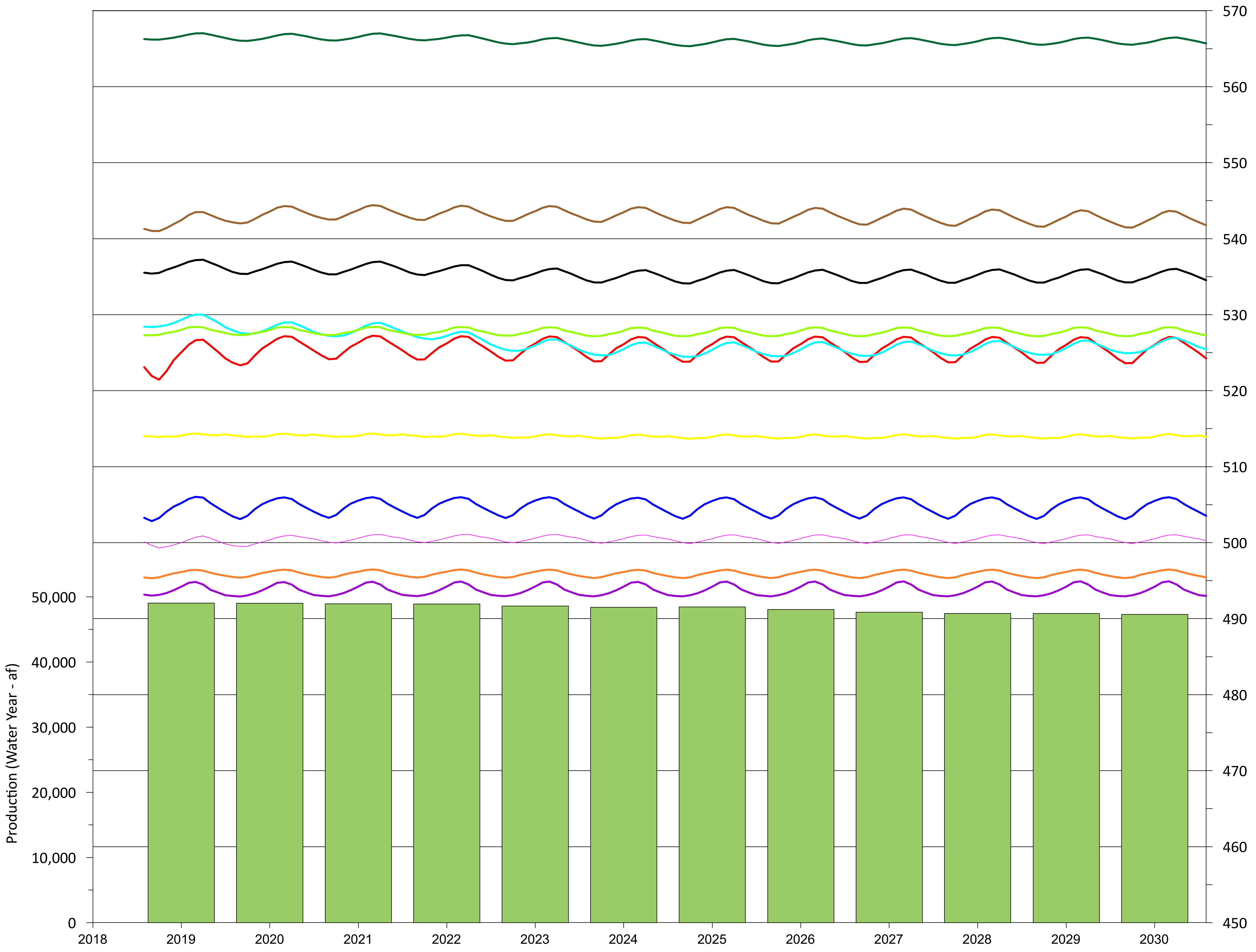
**Predicted Change in Groundwater Levels**
*2018 to 2030 - Scenario 2020 SYR1*

**Figure 3-22**



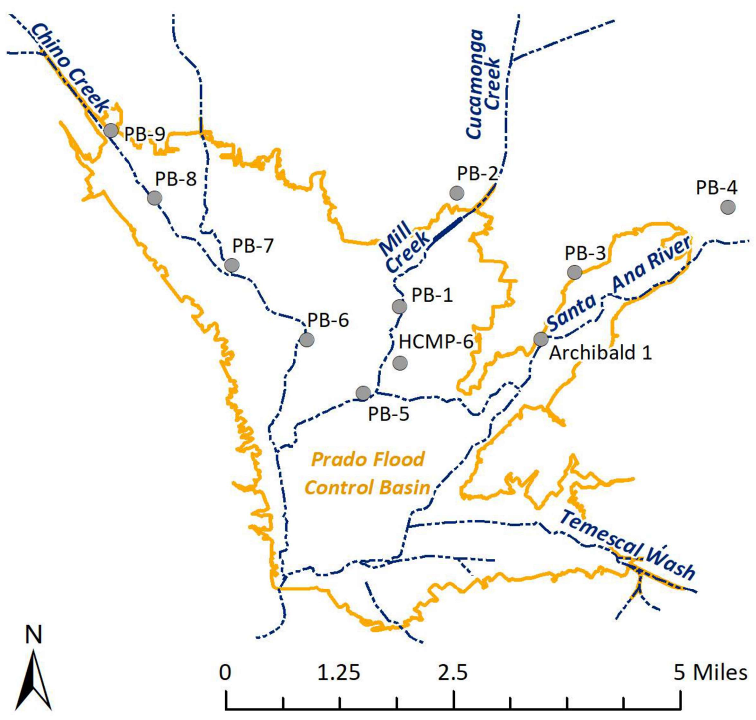
Model-Predicted Groundwater Levels*

- PB-4
- PB-9
- PB-3
- PB-8
- PB-2
- Archibald 1
- PB-1
- PB-7
- HCMP-6
- PB-6
- PB-5

🟩 Model-Predicted Pumping at Wells in the Groundwater Monitoring Program Study Area*

*Model Simulated Groundwater Elevations and Pumping from the planning scenario 2020 SYR1 for the 2020 recalculation of Safe Yield using the updated Chino Basin groundwater-flow model (WEI, 2020)

Well Locations



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2021 Annual Report

**Predicted Change in Groundwater Levels**
*2018 to 2030 - Scenario 2020 SYR1*

**Figure 3-23**

WEST YOST - K:\Clients\941 Chino Basin Watermaster\00-00-00 Master\PE1 - Data_Monitoring\GRAPHER\GRF\Prado\AnnualR\Figure 3-23_Projected_PROD_GWE_2018-2030.grf - lhedley - 5/3/2022

# 4.0 CONCLUSIONS AND RECOMMENDATIONS

The monitoring and mitigation requirements in the Peace II SEIR call for annual reporting for the PBHSP. Annual reports will be prepared and will include recommendations for ongoing monitoring and any adaptive management actions required to mitigate any measured loss or prospective loss of riparian habitat that may be attributable to the Peace II Agreement.

The following describes the main conclusions of this annual report and provides recommendations for future monitoring, reporting, and mitigation, if any.

## 4.1 Main Conclusions and Recommendations

### *4.1.1 Conclusions*

The main conclusions of the PBHSC Annual Report for WY 2021 are:

- The quality (greenness) of the riparian habitat vegetation remained stable or decreased across most of the Prado Basin from 2020 to 2021. Most of the observed decreases were relatively minor and within the range of one-year changes observed historically. These slight decreases occurred during a time of below average precipitation, slightly lower temperatures, and lower stream discharge conditions for WY 2021. The dry conditions and declines in stream discharge may be a contributing cause of the declines observed in 2021. At the small MC-2 area along the center of Mill Creek there was a more notable decrease in green vegetation evident from the comparison of the 2020 and 2021 air photos. Areas of significant decreases observed in the riparian vegetation include: large patches along the SAR, lower Prado Basin below the OCWD Wetlands, and the lower portions of Chino Creek; and the small LP area in the lower Prado Basin. The decreases in the green vegetation at all of these locations are due to wildfires that occurred in 2018 and 2020 and/or areas of Arundo removal and Arundo regrowth management. There is no trend in the degradation of the riparian habitat that is contemporaneous with decreasing groundwater levels during Peace II Agreement.
- Groundwater levels at two of the PBHSP monitoring wells near the fringes of the riparian habitat (PB-2 and PB-3) have declined, to levels below that predicted by the Chino Basin groundwater-flow model. At well PB-2 just to the north of Mill Creek, the model predicts a decline in groundwater levels of about three feet from 2018-2030, and groundwater levels declined at PB-2 by about five feet from 2018-2021. And at PB-3 along the northern reach of the SAR, the model predicts a decline in groundwater levels of about one foot from 2018-2030, and groundwater levels declined at PB-3 by about two feet from 2018-2021.
- These declines in groundwater levels are likely due to increased pumping at the Chino Basin Desalter wells to the north. Groundwater production has increased in the GMP study area by almost 10,000 afy over the last two years from 2019 to 2021, mainly due to increases Chino Basin Desalter pumping. In the northernmost reach of Mill Creek where groundwater levels have declined the most (PB-2), there is no significant impact in the riparian habitat vegetation observed in this area. However, there are some areas along the northernmost reach of Mill Creek where the groundwater levels supporting the riparian vegetation is estimated as 15 to 17 ft-bgs, and if groundwater levels continue to decline then it could result in adverse impacts to the riparian habitat. The groundwater-level declines in the northern reach of the SAR (PB-3) are not a concern because the groundwater levels supporting the

riparian vegetation in this area is shallow (4-8 ft-bgs), and is an area characterized as a losing reach in the SAR where groundwater is supported by SAR recharge.

### *4.1.2 Recommendations*

Based on the conclusions above, the PBHSP monitoring and reporting should continue to monitor the extent and quality of the riparian habitat and factors that can influence it. There are three areas where the monitoring and analysis should be augmented over the next year to track the notable changes observed in WY 2021 that are a concern for the extent and quality of the riparian habitat:

- Vegetation and surface-water discharge in the northernmost reach of Mill Creek. In 2021, groundwater levels at the northernmost reach of Mill Creek declined at rates and magnitudes greater than predicted by the model. Thus far, the monitoring and analysis of the riparian vegetation in this area does not indicate a significant change in the greenness or extent of the vegetation, but some areas underlying Mill Creek are beginning to experience depth to groundwater greater than 15 ft-bgs which could threaten the quality of the riparian habitat. In 2022, additional monitoring should be performed in the northernmost reach of Mill Creek. This additional monitoring should include: i) three additional vegetation-survey sites in the northernmost reach of Mill Creek for the 2022 vegetation surveys; ii) preparation and analysis of NDVI time-series for these new vegetation surveys sites; and iii) collection of information and measurements of the surface-water diversions from Cucamonga Creek to the Mill Creek Wetlands in the northern portion of Mill Creek. These data will improve the characterization of the quality of the riparian habitat and the surface water discharge into this habitat in the upper portion of Mill Creek.
- Updated digital elevation model for the Prado Basin. As described in the bullet above, in 2021 some areas of the riparian habitat along the northernmost reach of Mill Creek are overlying areas where the estimated depth to groundwater is greater than 15 ft-bgs, which could threaten the quality of the riparian habitat. Depth-to-groundwater is determined using the most current (September 2021) groundwater-elevation contours and rasters prepared for the GMP study area and subtracting from a one-meter digital-elevation model of the ground surface prepared in 2007. In 2020, during the acquisition of the 2020 air photo of the Prado Basin that was cost shared with the OCWD and the San Bernardino Valley Municipal Water District, LiDAR data of the entire Prado Basin was collected at a high-resolution (3-inch pixel). This LiDAR data should be post processed and spatial referenced to the vertical datum used in the southern Chino Basin and the PBHSP, to create an updated and higher-resolution digital elevation of the ground surface of the Prado Basin. This data will improve the estimates of current depth-to-groundwater in the PBHSP study area, and in critical areas where there are observed declines in groundwater levels that could potentially threaten the quality of the riparian habitat.
- Riparian vegetation at the MC-2 area. Observation of the 2020 and 2021 air photos for the MC-2 defined area along the central reach of Mill Creek showed a decrease in green vegetated areas during 2020-2021. A site visit should be performed to the MC-2 area to inspect and document the state of the vegetation. This site visit can be done during the field vegetation surveys that will be performed in the summer of 2022. The vegetation site M8 is in the center portion of the MC-2 area (see Figure 3-8f). Based on the results of the site visit, the PBHSC may consider revised monitoring if needed to better characterize the changes in the riparian vegetation and identify the causes of those changes.

## 4.2 Recommended Mitigation Measures and/or Adjustments to the AMP

This annual report documented no trend in the degradation of the extent or quality of riparian habitat along Chino Creek, Mill Creek, or the SAR that is contemporaneous with decreasing groundwater levels during the implementation of the Peace II Agreement. As such, no mitigation measures are proposed at this time.

No adjustments to the AMP are recommended at this time.

## 4.3 Recommended PBHSP for Fiscal Year 2022/23

Based on preliminary analysis of the PBHSP data for WY 2021, a draft *Technical Memorandum Recommended Scope and Budget of the Prado Basin Habitat Sustainability for FY 2022/23* was submitted to the PBSHC on March 2, 2022. On March 9, 2022, Watermaster's Engineer presented the recommended scope and budget for FY 2022/23 to the PBHSC for consideration. There were no changes recommended by the PBHSC on the proposed FY 2022/23 scope of work, and a final scope of work and budget was submitted to the PBHSC and will go through the Watermaster and the IEUA FY 2022/23 budgeting process in May and June of 2022. The scope of work for the PBHSP for FY 2022/23 is shown in Table 4-1 as a line-item cost estimate.

## Table 4-1. Work Breakdown Structure and Cost Estimate Prado Basin Habitat Sustainability Program - Fiscal Year 2022/23

| Task Description | | Notes | | Labor Total | | Other Costs, dollars | | | | | | Notes | Totals, dollars | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | No. of sites | Person Days | Total, dollars | Travel | Equipment Rental | Lab | Outside Pro | Equipment | Total | | Recommended Budget , dollars 2022/23 | Budget 2021/22 | Variance from Prior FY | IEUA Share 2022/23 | CBWM Share 2022/23 |
| **Task 1. Groundwater Level Monitoring Program** | | | | **14.0** | **16,984** | | | | | | **660** | | **17,644** | **13,785** | **3,859** | **-** | **17,644** |
| 1.1 | Collect Transducer Data from PBHSP Wells (Quarterly) | | 17 | 7.8 | 8,115 | 500 | 160 | | | | 660 | | 8,775 | 5,538 | | | |
| 1.2 | Collect, Check, and Upload Transducer Data from PBHSP Wells (Quarterly) | | 17 | 6.2 | 8,869 | | | | | | 0 | | 8,869 | 8,246 | | | |
| **Task 2. Groundwater Quality Monitoring Program** | | | | **0.0** | **5,342** | | | | | | **0** | | **5,342** | **5,373** | **-31** | **-** | **5,342** |
| 2.1 | Check and Upload High-Frequency Probe Data from Pilot Monitoring Program (Quarterly) | | 4 | 3.4 | 5,342 | | | | | | 0 | | 5,342 | 5,373 | | | |
| **Task 3. Surface Water Monitoring Program** | | | | **11** | **14,232** | | | | | | **245** | | **14,477** | **9,807** | **4,670** | **-** | **14,477** |
| 3.1 | Collect, Check, and Upload Surface Water Discharge and Quality Data from POTWs, USGS; and Dam Level data from the ACOE (Annual) | | | 2.5 | 3,532 | | | | | | 0 | | 3,532 | 3,562 | | | |
| 3.2 | Collect, Check, and Upload High-Frequency Probe Data for Chino Creek from Pilot Monitoring Program (Quarterly) | | 2 | 8.8 | 10,700 | 125 | 120 | | | | 245 | | 10,945 | 6,245 | | | |
| **Task 4. Climate Monitoring Program** | | | | **1.3** | **1,902** | | | | | | **275** | | **2,177** | **2,081** | **96** | **1,089** | **1,089** |
| 4.1 | Collect, Check, and Upload Climatic Data (Annual) | | | 1.3 | 1,902 | | | | 275 | | 275 | | 2,177 | 2,081 | | | |
| **Task 5. Riparian Habitat Monitoring Program** | | | | **17.3** | **30,332** | | | | | | **53,500** | | **83,832** | **32,696** | **51,136** | **41,916** | **41,916** |
| 5.1 | Perform a Custom Flight to Acquire a High-Resolution 2022 Air Photo of the Prado Basin | | | 1.3 | 2,500 | | | | 13,500 | | 13,500 | (a) | 16,000 | 11,386 | | | |
| 5.2 | Catalog, and Review the Extent of the Riparian Vegetation in the 2022 Air Photo of the Prado Basin | | | 3.5 | 6,350 | | | | | | 0 | | 6,350 | 6,104 | | | |
| 5.3 | Collect, Check, and Upload 2022 Landsat NDVI Data to the PBHSP Database | | | 9.8 | 16,664 | | | | | | 0 | | 16,664 | 15,206 | | | |
| 5.4 | Conduct the Field Vegetation Monitoring for Summer 2022 | | | 2.8 | 4,818 | | | | 40,000 | | 40,000 | | 44,818 | 0 | | | |
| **Task 6. Prepare Annual Report of the PBHSC** | | | | **52.5** | **86,960** | | | | | | **180** | | **87,140** | **88,628** | **-1,488** | **43,570** | **43,570** |
| 6.1 | Analyze Data and Prepare Admin Draft Report for CBWM/IEUA | | | 38.0 | 60,496 | | | | | | 0 | | 60,496 | 63,060 | | | |
| 6.2 | Meet with CBWM/IEUA to Review Admin Draft Report | | | 2.0 | 4,168 | 90 | | | | | 90 | | 4,258 | 4,090 | | | |
| 6.3 | Incorporate CBWM/IEUA Comments and Prepare Draft Report: Submit Draft Report to PBHSC | | | 5.0 | 8,244 | | | | | | 0 | | 8,244 | 7,904 | | | |
| 6.4 | Meet with PBHSC to Review Draft Report | | | 3.0 | 6,112 | 90 | | | | | 90 | | 6,202 | 5,938 | | | |
| 6.5 | Incorporate PBHSC Comments and Finalize Report | | | 4.5 | 7,940 | | | | | | 0 | | 7,940 | 7,636 | | | |
| **Task 7. Project Management and Administration** | | | | **10.3** | **20,134** | | | | | | **90** | | **20,224** | **20,102** | **122** | **10,112** | **10,112** |
| 7.1 | Prepare Scope and Budget for FY 2022/23 | | | 4.0 | 7,774 | | | | | | 0 | | 7,774 | 7,696 | | | |
| 7.2 | Meet with PBHSC to Review Scope and Budget for FY 2022/23 | | | 3.3 | 6,528 | 90 | | | | | 90 | | 6,618 | 6,862 | | | |
| 7.3 | Project Administration and Financial Reporting | | | 3.0 | 5,832 | | | | | | 0 | | 5,832 | 5,544 | | | |
| **Totals** | | | | **195** | **$ 175,886** | **$ 395** | **120** | **0** | **$ 53,775** | **0** | **$ 54,950** | | **$ 230,836** | **$ 172,471** | **$ 58,365** | **$ 96,687** | **$ 134,150** |

(a) This is half of the cost for the outside professional. OCWD will pay the other half.

The following describes the scope-of-work by major task for the PBHSP for FY 2022/23:

**Task 1. Groundwater-Level Monitoring Program**

The monitoring of groundwater levels in the Prado Basin is a key component of the PBHSP because declining groundwater levels could be a factor related to Peace II implementation that adversely impacts riparian vegetation. Sixteen monitoring wells were installed specifically for the PBHSP in 2015. These wells, plus monitoring wells HCMP-5/1 and RP3-MW3, are monitored for groundwater levels. The 18 monitoring wells are equipped with integrated pressure-transducers/data-loggers that measure and record water-level measurements every 15 minutes. This task includes quarterly field visits to all 18 PBHSP monitoring wells to download data. All data will be checked and uploaded to the PBHSP database. This task is consistent with the work performed during the previous FY.

**Task 2. Groundwater-Quality Monitoring Program**

Since the PBHSP monitoring wells were constructed in 2015, groundwater-quality monitoring has been tailored to discern the groundwater/surface-water interactions that are important to the sustainability of the riparian habitat in Prado Basin. From FY 2015/16 through 2017/18, quarterly groundwater samples were collected from the 18 PBHSP monitoring wells and analyzed at a minimum for general minerals. The general mineral chemistry data collected was analyzed along with groundwater-level data, model-generated groundwater-flow directions, and surface-water quality and flow data to help characterize groundwater/surface-water interactions in the Prado Basin and determine the source of the shallow groundwater that is available for consumptive use by the riparian vegetation.

During FY 2018/19, a pilot monitoring program was initiated at four monitoring wells at two locations along Chino Creek (PB-7 and PB-8) where the data loggers that measure groundwater levels at 15-minute intervals were replaced with data loggers that measure and record EC, temperature, and water levels at 15-minute intervals. The same high-frequency monitoring was initiated at two nearby surface water sites in Chino Creek (Task 3.2). Additionally, groundwater-quality samples were collected at these wells for the first two years either quarterly (FY 2018/19) or semi-annually (FY 2019/20) and were analyzed for EC, temperature, and general minerals to validate and support the high-frequency data, along with the collection of field measurements of EC and temperature. The purpose of the pilot monitoring program is to determine if the high-frequency data better reveals the groundwater/surface-water interactions and enhances the interpretation of the general mineral data derived from sampling. The data collected thus far as a part of the pilot monitoring program has provided more support for the characterization of groundwater/surface water interactions at these locations and warrants the continuation of the pilot program to collect more data. The effort to collect and review the high-frequency data is minimal as the installed data loggers are also part of the groundwater-level monitoring (Task 1) at these four wells.

Tasks 2.1 is to continue the pilot monitoring program in FY 2022/23 to collect the high-frequency data in groundwater to help discern the groundwater/surface water interactions near PB-7 and PB-8. The monitoring wells will be visited quarterly to download the data from the data loggers, and the costs to do so is assumed with Task 1. All data will be checked and uploaded to the PBHSP database.

**Task 3. Surface-Water Monitoring Program**

Surface-water discharge data from the SAR and the tributaries that cross Prado Basin are evaluated to characterize the influence of surface-water discharge on the riparian habitat. The SWMP utilizes publicly-available data sets which include: the USGS daily discharge measurements at six sites along the

SAR and its tributaries; daily discharge and water-quality data from POTWs that are tributary to Prado Basin; ACOE daily measurements of reservoir elevation and releases from the reservoir at Prado Dam; and Watermaster's quarterly surface-water-quality monitoring at two sites along the SAR.

Task 3.1 includes the annual collection of the USGS, POTW, and ACOE data for water year 2022, and the processing, checking, and uploading of these data to the PBHSP database. These tasks do not include the processing, checking, and uploading of the Watermaster-collected SAR data, which is performed for another Watermaster task. The scope of these tasks is consistent with the work performed for the previous FY.

High-frequency surface water-quality data are also collected and analyzed in the pilot monitoring program to help characterize groundwater/surface water interactions. As described in Task 2, a pilot monitoring program was initiated in FY 2018/19 at two locations along Chino Creek adjacent to wells PB-7 and PB-8. At these locations, data loggers were installed in Chino Creek to measure and record EC, temperature, and stage at 15-minute intervals in coordination with the similar high-frequency monitoring in groundwater at PB-7 and PB-8 (Task 2). Grab samples of surface water were also collected quarterly for EC, temperature, and general mineral analyses, along with field measurements of EC and temperature. As described above for *Task 2 – Groundwater-Quality Monitoring Program*, the purpose of the pilot monitoring program is to determine if the high-frequency data better reveals the groundwater/surface-water interactions and enhances the interpretation of the general mineral data derived from grab sampling. Periodically, the data loggers within the creek have been lost during large storm events and the casing that house the probes have experienced the accumulation of mud which has compromised the accuracy of the collected data. These monitoring challenges in the field have resulted in extended periods of no data or erroneous data and have necessitated additional field work to resolve. The data collected thus far for the pilot monitoring program has provided more support for the characterization of groundwater/surface water interactions at these locations and warrants the continuation of the pilot program to collect more data to draw defensible conclusions. The effort to continue to collect and review the high-frequency data from the surface water probes is minimal since the installed data loggers can be visited in the field at the same time as the four nearby monitoring wells (Tasks 1 and 2).

Tasks 3.2 is to continue the pilot monitoring program in FY 2022/23 to collect the high-frequency data in the surface water to help discern the groundwater/surface water interactions near wells PB-7 and PB-8. The probes will be visited quarterly at the same time as the nearby wells to download the data, collect field measurements for temperature and EC, and clean the probes and their housing to prevent the buildup of residue. There will be four additional field visits for routine cleaning of the probes and housing. All data will be checked and uploaded to the PBHSP database. The scope is consistent with the work performed for the previous fiscal year.

### Task 4. Climate Monitoring Program

Climatic data are evaluated in the vicinity of the Prado Basin to characterize trends, and to determine if these trends contribute to impacts on the riparian habitat. The climate monitoring program utilizes publicly-available datasets. Two types of datasets are compiled: time-series data measured at weather stations and spatially-gridded datasets. Task 4 includes the annual collection of the time-series data and spatially-gridded datasets for water year 2021 (October 2021 – September 2022), and the checking and uploading of the data to the PBHSP database. The scope of this task is consistent with the work performed for the previous fiscal year.

**Task 5. Riparian Habitat Monitoring Program**

Monitoring the extent and quality of the riparian habitat in the Prado Basin is a fundamental component of the PBHSP to characterize how the riparian habitat changes over time. To characterize the impacts of Peace II implementation on the riparian habitat (if any) it is necessary to understand the long-term historical trends of its extent and quality and the factors that have affected it. The current riparian habitat monitoring program consists of both regional and site-specific components. The proposed riparian habitat monitoring program for FY 2022/23 is described in the subsections below.

- **Regional Monitoring**: The regional monitoring of riparian habitat is performed via two independent methods that complement each other: mapping and analysis of the riparian habitat using (i) air photos and (ii) the normalized difference vegetation index (NDVI) derived from the Landsat remote-sensing program. Tasks 5.1, 5.2, and 5.3 are for the collection and compilation of the regional monitoring data, including:
- Perform a custom flight (via outside professional services) to acquire a high-resolution air photo (three-inch pixel) of the Prado Basin during summer 2022. The cost for the air photo is shared with OCWD.
- Catalog and review the 2022 high-resolution air photo in ArcGIS and digitize the extent of the riparian habitat.
- Collect, review, and upload the Landsat NDVI data for water year 2022.

**Site-Specific Monitoring:** The site-specific monitoring of the riparian habitat consists of periodic field surveys of the riparian vegetation at selected locations. These surveys provide an independent measurement of vegetation quality that can be used to “ground truth” the regional monitoring of the riparian habitat. To date, the United States Bureau of Reclamation (USBR) along with the OCWD[22] has conducted field surveys once every three years. The most recent triennial field survey was conducted in the summer of 2019. Task 5.4 is to conduct the field surveys during the summer of 2022 at the 36 sites monitored in 2019 and up to three additional sites in the target area along the north portion of Mill Creek. As described above some additional focused monitoring in this area of Mill Creek is recommended to monitor for the potential impact to the riparian habitat from the observed decline in groundwater levels.

The proposed methodology for the 2022 field surveys is modified from the previous surveys to a reduced set of representative measurements and data to collect in the field that are best fit to ground truth the air photos and remote sensing data, and measure and track the quality of the riparian vegetation.[23] This reduced methodology is a cost savings of $10,000. The field surveys will be performed by the USBR staff. Assistance from the OCWD staff in the field as needed, will be provided as in-kind services, and also results in a cost savings.

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[22] OCWD staff provides assistance to the USBR in the field as in-kind services.

[23] The field vegetation surveys were set up and conduced two times prior to the developed of the AMP, and there are measurements that were collected by the USBR in the field during previous surveys that have not been used in the PBHSP analysis and reporting and are no longer needed for the PBHSP. These include: tree/sapling diameter at breast height (DBH); shrub diameter at root collar (DRC); height of a tree, sapling, or shrub; and measurement of the lowest leaf level of a tree to calculate a crown ratio.

### Task 6. Prepare Annual Report of the PBHSC

This task involves the analysis of the data sets collected by the PBHSP through water year 2022. The results and interpretations generated from the data analysis will be documented in the *Annual Report for Prado Basin Habitat Sustainability Committee for Water Year 2022*. This task includes the effort to prepare an administrative draft report for Watermaster and the IEUA staff review, a draft report for the review by the PBHSC, and a final report including comments and responses. A PBHSC meeting will be conducted in May 2023 to review the draft report and facilitate comments on the report. The scope of this task is consistent with the work performed for the previous FY.

### Task 7. Project Management and Administration

This task includes the effort to prepare the PBHSP scope, schedule, and budget for the subsequent fiscal year. A draft *Technical Memorandum Recommended Scope and Budget of the Prado Basin Habitat Sustainability Program for FY 2023/24* will be submitted to the PBHSC in February 2023. A PBHSC meeting will be conducted in March 2023 to review the draft recommended scope and budget and facilitate comments. Also included in this task is project administration, including management of staffing and monthly financial reporting. The scope of this task is consistent with the work performed for the previous FY.

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# Appendix A

## NDVI

# A.1 BACKGROUND

Multi-spectral remote-sensing measurements of the Earth's surface from satellites are a verifiable means of deriving complete spatial coverage of environmental information. Remote-sensing measurements have been collected in a consistent manner over time. They are updated regularly and can be analyzed retrospectively, which has made these measurements useful in various types of ecological and environmental monitoring, including vegetation monitoring (USDA, 1996; Schidt and Karnieli, 2000; Campbell, 2007; Lillesand et al., 2008; Xie et al., 2008; Jones and Vaughnan, 2010).

Remote sensing-based methods of vegetation monitoring commonly use vegetation indices that can be calculated from the wavelengths of light absorbed and reflected by vegetation (Jensen, 2007). NDVI is a widely used numerical indicator of vegetation extent and quality that is calculated from remote-sensing measurements (Ke et al., 2015; Xue,J and Su, B., 2017). Moreover, NDVI is an index of greenness correlated with photosynthesis and can be used to assess temporal and spatial changes in the distribution, productivity, and dynamics of vegetation (Pettorelli, 2013). NDVI is calculated from visible and near-infrared radiation reflected by vegetation using the following formula:

$$NDVI = \frac{(NIR - VIS)}{NIR + VIS}$$

Where: **NIR** = the spectral reflectance of near infrared radiation.
**VIS** = the spectral reflectance of visible (red) radiation.

During photosynthesis, healthy vegetation absorbs incoming visible light and reflects a large portion of near-infrared radiation. Unhealthy or dormant vegetation absorbs less visible light and reflects less near--infrared radiation. The figure[1] illustrates NDVI:

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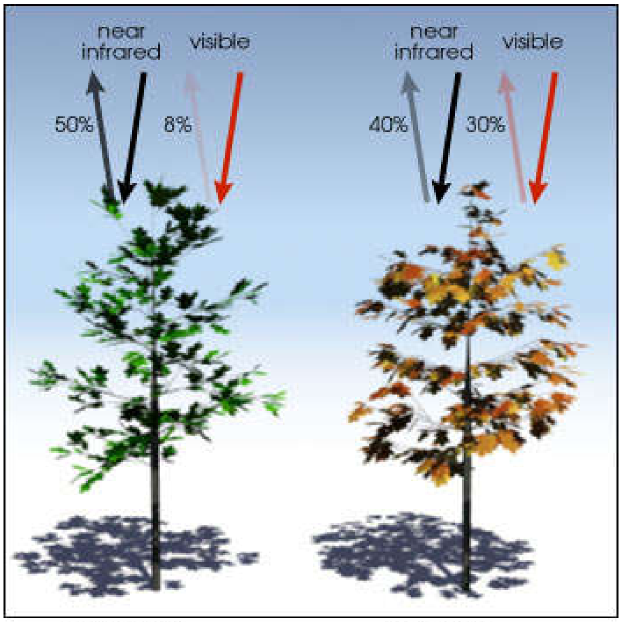
[1] Nasa.gov



$$\frac{(0.50 - 0.08)}{(0.50 + 0.08)} = 0.72 \qquad \frac{(0.4 - 0.30)}{(0.4 + 0.30)} = 0.14$$

Near-infrared radiation and visible light spectral reflectance are both expressed as ratios of the reflected radiation over the incoming radiation (values between 0 and 1); therefore, NDVI estimates range between -1.0 and 1.0. Negative NDVI estimates correspond to standing water, and low positive values (0 to 0.1) correspond to non-vegetated areas, such as barren rock and sand, snow, and water. NDVI estimates ranging from 0.1 to 1.0 correspond to vegetated areas, with very low-end estimates indicating sparse, unhealthy, or dormant vegetation, and increasing estimates towards 0.9 indicating higher amounts of dense, healthy green vegetation.

## Advantages and Limitations.

NDVI was chosen as a method for characterizing and monitoring the riparian habitat for the PBHSP for the following reasons:

- Peace II activities could cause regional changes in groundwater levels, which potentially could result in regional impacts to the riparian habitat that is dependent on shallow groundwater. The regional scale of NDVI makes it an appropriate “first indicator” of regional changes in the extent and quality of riparian vegetation. And, it has been widely used in the past to support similar environmental monitoring and management programs (Peters et al., 2002; Pinzon et al., 2004; Wang et al., 2004; Weiss et al., 2004; Intera, 2014; Verbesselt et al, 2010; Gandhi et al. 2015).
- There is a long time-series of historical NDVI (early 1980s to present) that spatially covers the entire Prado Basin. These datasets can be used to characterize the history of the spatial extent and quality of the riparian vegetation prior to and after the implementation of Peace II activities (2007).

- In the future, it is likely that multi-spectral remote sensing will continue to collect the commonly measured spectral bands that are used to calculate NDVI (red and near-infrared) and that these data will be available for use as part of the PBHSP at a low cost.

Like most monitoring tools, NDVI has its limitations, which can reduce its reliability and usefulness. Important examples include:

- Cloud cover, water vapor, and atmospheric contaminants can lead to false decreases in NDVI estimates compared to clear days (Tanre et al., 1992; Achard and Estreguil, 1995; Chen et. al., 2004; Hird and McDermid, 2009).
- Satellite degradation, sensor errors, and data transmission errors can lead to false increases in NDVI estimates (James and Kalluri, 1994).
- Changes in soil moisture can lead to changes in NDVI estimates that are not necessarily related to changes in vegetation (Pettorelli, 2013).
- NDVI is a composite view of plant species diversity, form, structure, density, and vigor. As such, changes in NDVI may be caused by various changes in riparian habitat (Markon et al., 1995; Markon and Peterson, 2002). In other words, NDVI does not provide a complete picture of how and why vegetative changes are occurring; it simply indicates a change in vegetation.
- In densely vegetated areas, NDVI estimates have been shown to plateau during the growing season, indicating that NDVI can underestimate the green biomass in densely vegetated areas (Tucker et al., 1986).

These limitations demand that NDVI data be screened and filtered to identify or remove errors and noise. To reduce or eliminate noise, processing algorithms can be applied to “smooth” the time-series data and reveal patterns of change over time. For example, a smoothing technique applied in this report was the averaging of all NDVI from the growing season months. The average values are then plotted on time-series charts to display long-term trends in growing season vegetation quality.

The limitations also demand that NDVI not be interpreted in isolation. Interpretations of NDVI (vegetative changes) should be (i) verified with other georeferenced datasets, such as air photos and field vegetation surveys, and (ii) explained by comparison to datasets of causal factors of vegetative changes, such as water availability.

## A.2 LANDSAT PROGRAM AND NDVI

The USGS and the National Aeronautics and Space Administration (NASA) jointly manage the Landsat Program,2 a series of Earth-observing satellite missions that began in 1972 with sensors that observe the Earth’s surface and transmit information to ground stations that receive and process multi-spectral, remote-sensing data. Landsat satellites use technology that collects scenes of remote sensing

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[2] Nasa.gov

measurements at the same time and location on the Earth's surface at a temporal frequency of about every two weeks. Landsat remote sensing measurements (Landsat imagery) is acquired in scenes that are approximately 106 by 115 miles. Landsat imagery is the only data source with more than thirty-years of continuous records of global land surface conditions at a spatial resolution of tens of meters (Tuck et al 2004). Landsat imagery is among the most widely used satellite imagery in ecology and conservation studies (Pettorelli, 2013), and the data have been available for no cost since about 2010.

The United States Geological Survey (USGS), in compliance with the Global Climate Observing System,[3] produces spectral indices products from Landsat imagery to support land surface change studies, which includes NDVI from 1982 to present (USGS, 2016). The USGS uses remote sensing imagery from the Landsat satellites—*Landsat 4, Landsat 5, Landsat 7, and Landsat 8* (*Landsat 4, 5, 7, and 8*)—to generate NDVI estimates of the Earth's surface at a 30 x 30-meter pixel resolution. To apply the necessary atmospheric corrections and generate a surface reflectance product, the USGS uses a specialized software called Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS) to post-process the Landsat imagery (USGS 2015; 2017a). This surface reflectance product is then used to determine NDVI, among the other spectral indices.

# A.3 Collection, Review, and Analysis of NDVI for the PBHSP

## *Collection*

NDVI from the Landsat imagery for the period 1982 to 2021 were collected from the USGS, using the Earth Resources Observation and Science (EROS) Center Science Processing Architecture (ESPA) On Demand Interface[4] (USGS 2017b). The interface requires a bulk request in the form of a text file list of specific Landsat scenes using the Landsat scene identifier ID.[5] To obtain complete spatial coverage of the Prado Basin area, NDVI was requested for all Landsat scenes for Path 040, Rows 036 and 037.[6] Table 1 below summarizes the Landsat satellites and periods for which NDVI was obtained to produce a near-continuous NDVI record.

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[3] Link

[4] USGS LINK

[5] Landsat imagery is captured in scenes that are about 106 by 114 miles. Each Landsat scene has a unique scene ID based on the specific Landsat satellite, Landsat path number, Landsat row number, and date the image was collected.

[6] The Prado Basin is in an area of the Landsat path 040 that straddles Rows 036 and 037. Landsat scenes from Path 040 Row 036 and Path 040 Row 037 overlap each other throughout most of the Prado Basin region, but both are required to obtain complete spatial coverage of the Prado Basin.

**Table 1. Landsat Satellites**

| Satellite | Instrument | Launched | Ended | Period of NDVI Data Obtained from USGS |
|---|---|---|---|---|
| Landsat 4 | Thematic Mapper | July 16, 1982 | December 14, 1993 | 1982 - 1983 |
| Landsat 5 | Thematic Mapper | March 1, 1984 | June 5, 2013 | 1984 - 2011 |
| Landsat 7 | Enhanced Thematic Mapper | April 15, 1999 | Still active | 2012 - 2016 |
| Landsat 8 | Operational Land Imager | February 11, 2013 | Still active | 2013 - 2021 |

NDVI from scenes produced from the *Landsat 4*, *5, 7,* and *8* satellites were obtained from the USGS for the period 1982 through 2020. The source and frequency of availability of NDVI from the USGS varies over the period of record:

- From 1982 to 1989, NDVI is from Landsat 4 and 5 and is patchy, ranging from a frequency of eight days to one year.
- From 1990 to 1999, NDVI is from Landsat 5 at a frequency of 16 days.
- From 1999 to 2012, NDVI is from Landsat 5 and 7 at a frequency of eight days.
- From 2013 to 2021, NDVI is from Landsat 7 and 8 at a frequency of eight days.

NDVI were cataloged, processed, and uploaded into HydroDaVE$^{SM}$, a database management software that manages gridded datasets and features tools for viewing and extracting data.[7] There is some overlap of NVDI data in areas where there is NVDI from Landsat scenes from Rows 036 and 037. HydroDaVE has the ability to compute a stacked average for Landsat scenes from Rows 036 and 037 for each NDVI pixel they overlay[8] when viewing and extracting NDVI data.

## Review

Spatial NDVI were reviewed for disturbances that can be caused by cloud cover, unfavorable atmospheric conditions, or satellite equipment malfunction. In HydroDaVESM, maps were prepared of spatial NDVI for the entire Prado Basin region for each date. The maps were reviewed and documented to identify specific dates for exclusion due to cloud cover or other disturbances. Erroneous NDVI estimates were discernable because NDVI patterns of permanent landscape features were distorted and/or NDVI estimates were clearly not consistent with estimates typically observed for a particular area both seasonally and over time. On average, about 21 percent of the NDVI were identified as erroneous and excluded from the

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[7] Hydrodave Link

[8] Not all dates will have Landsat scenes for both Rows 036 and 037 if cloud cover was greater than 20 percent in one of them; Landsat scenes with a percent cloud cover greater than 20 percent were not obtained from the USGS for this study.

analysis. Most of which were rejected because of cloud coverage, which was further verified by referencing and viewing the specific Landsat scene on the USGS *EarthExplorer* website.[9]

After excluding erroneous NDVI estimates, there was one date for 1982, and there were no dates for 1983; as such, the time-series data discussed throughout Section 3 of the report include NDVI estimates for 1984-2021.

NDVI estimates derived from *Landsat 7* satellite imagery since mid-2003 have to be further reviewed date-by-date for the occurrence of spatial data gaps, resulting from the failure of the Scan Line Corrector (SLC) on the *Landsat 7* satellite, which accounts for the satellite's forward motion. SLC failure results in data gaps along scan line paths of variable widths and occurrences. An estimated 22 percent of any given *Landsat 7* scene is lost because of SLC failure; however, the imagery acquired between these gaps is valid and useable for analysis.[10] All NDVI estimates derived from *Landsat 7* satellite imagery since 2003 were evaluated spatially date-by-date to determine if the valid portion of the data covers the defined areas of interest used for the temporal analysis of NDVI in the time series discussed in Section 3 of this report. Date-by-date analysis is necessary because the spatial position and size of the data gaps from the *Landsat 7* satellite vary for each date. Generally, areas of interest for NDVI analysis that are larger than about 400 square meters cannot use any NDVI determined from *Landsat 7* satellite imagery because it would include data gaps within the area; while areas of interest less than 400 square meters can use NDVI determined from the *Landsat 7* satellite imagery if the data gap area is not within the area of interest.

## *Analyses of Time-series Data*

HydroDaVE$^{SM}$ contains features to calculate and extract a spatial average NDVI for a designated area and time period. The NDVI spatial average for each available date is plotted in time-series charts to analyze seasonal and temporal changes for a defined area. Time-series charts of NDVI for various areas in the Prado Basin are first introduced in Section 3.1 of this report.

When viewing time-series charts of NDVI for the period of record, it should be noted that a methodological factor that can affect observed NDVI trends is the difference between the technology of the *Landsat 4, 5, and 7* satellites, and the *Landsat 8* satellite. The *Landsat 4, 5, and 7* satellites use thematic mapper technology to scan the land surface, whereas *Landsat 8* uses operational land imager sensors. It has been well documented that the NDVI estimates obtained from the operational land imager sensors used on the *Landsat 8* satellite generates slightly higher index values for vegetated land cover (Xu and Guo 2014; She et al., 2015). The *Landsat 8* satellite was launched in orbit in 2013, and since, NDVI has been available from both the *Landsat 7 and 8* satellites. In order to analyze the time-series of NDVI derived across all Landsat satellites for the period of record, a bias-correction factor of -0.05, derived from literature review (Li et al., 2014; Flood, 2014: and Ke et al., 2015), was used to transform all *Landsat 8* NDVI estimates such that all historical NDVI estimates could be analyzed collectively (Roy et al., 2016).

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[9] Earthexplorer Link

[10] Landsat Link

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# Appendix B

## Mann-Kendall Analysis of NDVI

## B.1 Introduction

The Mann-Kendall statistical trend test (Mann-Kendall test) was performed on the average growing--season NDVI metrics (NDVI) for the period of 1984 to 2020 for all 15 areas where NDVI are analyzed for the *Annual Report of the Prado Basin Habitat Sustainability Committee Water Year 2020*. The Mann--Kendall test was utilized to evaluate whether the average growing-season NDVI increased, decreased, or remained stable over time.

## B.2 Methods

The Mann-Kendall test is a non-parametric statistical trend test. It is analogous to parametric trend testing such as regression (linear regression) except the data do not need to have a particular probability distribution (normal) and be accurately described by a particular measure of centrally tendency (mean, standard deviation, etc.) (Helsel and Hirsch, 2002).

To perform the test, the NDVI values are ordered chronologically and the signs (+/–) are recorded for all of the possible differences between a given NDVI value and every NDVI value that preceded it in the time series. The Mann-Kendall test statistic **S** is defined as the number of positive differences (+) minus the number of negative differences (–). From **S** and the number of NDVI values, **n**, the **τ** coefficient (analogous to the **r** correlation coefficient in linear associations) is then calculated. The **τ** coefficient represents the strength of the monotonic relationship between time and NVDI values with a possible range of -1 to 1. A perfect positive trend would yield a **τ** coefficient equal to 1, and a perfect negative trend would yield a **τ** coefficient equal to -1.

The Mann-Kendall test utilizes the null hypothesis that there is no trend. If the **S** test statistic and **τ** coefficient are significantly different than zero, the null hypothesis is rejected, and a trend exists. The level of statistical significance is expressed as a p-value between 0 and 1. The smaller the p-value the stronger the evidence that the null hypothesis should be rejected. In this study, a p-value of less than or equal to 0.05 was used to determine if a trend existed. In summary, the three possible outcomes of the test are

- Increasing trend (p-value $\leq 0.05$, $\tau > 0$)
- No trend (p-value $> 0.05$)
- Decreasing trend (p-value $\leq 0.05$, $\tau < 0$)

## B.4 Data Analysis and Results

The Mann-Kendall **S** test statistic, **τ** coefficient and p-value were computed for average-growing season NDVI from 1984 to 2020 for the 15 areas in Prado Basin, using the python package pyMannKendall (Hussain, 2019). Table B-1 through B-3 lists the results of the Mann-Kendall test for the three time periods of interest: 1984 through 2020; 1984 through 2006; and 2007 through 2020.

**Table B-1. 1984 to 2021**

| Area | n (number of NDVI values) | S Test Statistic | τ coefficient | p-value | Trend |
|---|---|---|---|---|---|
| Riparian Vegetation Extent | 37 | 110 | 0.17 | 1.54E-01 | No Trend |
| Chino Creek Area | 37 | 414 | 0.62 | 6.61E-08 | Increasing |
| Mill Creek Area | 37 | -32 | -0.05 | 6.85E-01 | No Trend |
| CC-1 | 38 | 349 | 0.50 | 1.21E-05 | Increasing |
| CC-2 | 38 | 493 | 0.70 | 6.20E-10 | Increasing |
| CC-3 | 38 | 453 | 0.64 | 1.33E-08 | Increasing |
| CC-4 | 38 | 269 | 0.38 | 7.54E-04 | Increasing |
| MC-1 | 38 | 339 | 0.48 | 2.14E-05 | Increasing |
| MC-2 | 38 | 87 | 0.12 | 2.80E-01 | No Trend |
| MC-3 | 38 | 91 | 0.13 | 2.58E-01 | No Trend |
| MC-4 | 38 | 213 | 0.30 | 7.69E-03 | Increasing |
| SAR-1 | 38 | -97 | -0.14 | 2.27E-01 | No Trend |
| SAR-2 | 38 | -59 | -0.08 | 4.66E-01 | No Trend |
| SAR-3 | 38 | 217 | 0.31 | 6.62E-03 | Increasing |
| LP | 38 | 207 | 0.29 | 9.60E-03 | Increasing |

**Table B-2. 1984 to 2006**

| Area | n (number of NDVI values) | S Test Statistic | τ coefficient | p-value | Trend |
|---|---|---|---|---|---|
| Riparian Vegetation Extent | 23 | 33 | 0.13 | 3.98E-01 | No Trend |
| Chino Creek Area | 23 | 99 | 0.39 | 9.65E-03 | Increasing |
| Mill Creek Area | 23 | -97 | -0.38 | 1.12E-02 | Decreasing |
| CC-1 | 23 | 49 | 0.19 | 2.05E-01 | No Trend |
| CC-2 | 23 | 137 | 0.54 | 3.28E-04 | Increasing |
| CC-3 | 23 | 143 | 0.57 | 1.77E-04 | Increasing |
| CC-4 | 23 | 19 | 0.08 | 6.35E-01 | No Trend |
| MC-1 | 23 | 33 | 0.13 | 3.98E-01 | No Trend |
| MC-2 | 23 | -53 | -0.21 | 1.70E-01 | No Trend |
| MC-3 | 23 | -47 | -0.19 | 2.24E-01 | No Trend |
| MC-4 | 23 | 13 | 0.05 | 7.51E-01 | No Trend |
| SAR-1 | 23 | 1 | 0.00 | 1.00E+00 | No Trend |
| SAR-2 | 23 | -119 | -0.47 | 1.83E-03 | Decreasing |
| SAR-3 | 23 | -55 | -0.22 | 1.54E-01 | No Trend |
| LP | 23 | -37 | -0.15 | 3.42E-01 | No Trend |

**Table B-3. 2007 to 2021**

| Area | n (number of NDVI values) | S Test Statistic | τ coefficient | p-value | Trend |
|---|---|---|---|---|---|
| Riparian Vegetation Extent | 14 | 3 | 0.03 | 9.13E-01 | No Trend |
| Chino Creek Area | 14 | 35 | 0.38 | 6.27E-02 | No Trend |
| Mill Creek Area | 14 | 29 | 0.32 | 1.25E-01 | No Trend |
| CC-1 | 15 | 25 | 0.24 | 2.35E-01 | No Trend |
| CC-2 | 15 | 63 | 0.60 | 2.15E-03 | Increasing |
| CC-3 | 15 | 43 | 0.41 | 3.77E-02 | Increasing |
| CC-4 | 15 | 41 | 0.39 | 4.78E-02 | Increasing |
| MC-1 | 15 | 61 | 0.58 | 2.99E-03 | Increasing |
| MC-2 | 15 | 49 | 0.47 | 1.75E-02 | Increasing |
| MC-3 | 15 | 45 | 0.43 | 2.94E-02 | Increasing |
| MC-4 | 15 | -1 | -0.01 | 1.00E+00 | No Trend |
| SAR-1 | 15 | 77 | 0.73 | 1.69E-04 | Increasing |
| SAR-2 | 15 | 43 | 0.41 | 3.77E-02 | Increasing |
| SAR-3 | 15 | 51 | 0.49 | 1.33E-02 | Increasing |
| LP | 15 | 29 | 0.28 | 1.66E-01 | No Trend |

## B.5 References

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