Technical Memorandum

Channel Capacity Report
2025 Restoration Year

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List of Abbreviations and Acronyms

CCAG	Channel Capacity Advisory Group
CCR	Channel Capacity Report
CDEC	California Data Exchange Center
CEQA	California Environmental Quality Act
cfs	cubic feet per second
DWR	Department of Water Resources
FMRs	Flood Management Releases
LSJLD	Lower San Joaquin Levee District
NEPA	National Environmental Policy Act
NOD	Notice of Determination
NRDC	Natural Resources Defense Council
PEIS/R	Program Environmental Impact Statement/Environmental Impact Report
Reclamation	Bureau of Reclamation
Restoration Area	San Joaquin River Restoration Program Restoration Area
RM	river mile
ROD	Record of Decision
SJR	San Joaquin River
SJRRP	San Joaquin River Restoration Program
SMP	Seepage Management Plan
USGS	U.S. Geological Survey
WSE	Water Surface Elevation

Definitions

Channel Capacity Advisory Group (CCAG): The Channel Capacity Advisory Group provides focused input to Reclamation's determination of "then-existing channel capacity" within the Restoration Area.

In-channel capacity: The channel capacity at which the water surface elevation is maintained at or below the elevation of the outside ground (i.e., along the landside levee toe).

Program Environmental Impact Statement/Environmental Impact Report (PEIS/R): The Bureau of Reclamation (Reclamation), as the Federal lead agency under the National Environmental Policy Act (NEPA) and the California Department of Water Resources (DWR), the State lead agency under the California Environmental Quality Act (CEQA), jointly prepared a Program Environmental Impact Statement/Report (PEIS/R) and signed a Record of Decision and Notice of Determination (ROD and NOD), respectively, in 2012 to implement the Settlement.

San Joaquin River Restoration Program (SJRRP): The SJRRP (also abbreviated as Program) was established in late 2006 to restore and maintain fish populations in good condition in the mainstem of the San Joaquin River (SJR) below Friant Dam to the confluence of the Merced River, while reducing or avoiding adverse water supply impacts.

Settlement: In 2006, the SJRRP was established to implement the Stipulation of Settlement in *NRDC, et al., v. Kirk Rodgers, et al*.

Then-existing channel capacity: The channel capacity within the Restoration Area that corresponds to flows that would not significantly increase flood risk from Restoration Flows in the Restoration Area. This annual report will recommend updating then-existing channel capacity based on recently completed evaluations.

1. Introduction

The San Joaquin River Restoration Program (SJRRP) was established in late 2006 to implement a Stipulation of Settlement (Settlement) in *NRDC, et al., v. Kirk Rodgers, et al*. The U.S. Department of the Interior, Bureau of Reclamation (Reclamation), the Federal lead agency under the National Environmental Policy Act (NEPA), and the California Department of Water Resources (DWR), the State lead agency under the California Environmental Quality Act (CEQA), prepared a joint Program Environmental Impact Statement/Report (PEIS/R) to support implementation of the Settlement. The Settlement calls for releases of Restoration Flows, which were initiated in 2014 and are specific volumes of water to be released from Friant Dam during different water year types, according to Exhibit B of the Settlement. Federal authorization for implementing the Settlement is provided in the San Joaquin River Restoration Settlement Act (Act) (Public Law 111-11). Reclamation signed the Record of Decision (ROD)/Notice of Determination (NOD) on September 28, 2012. Both the PEIS/R and the ROD/NOD committed to establishing a Channel Capacity Advisory Group (CCAG) to determine and update estimates of then-existing channel capacities as needed and to maintain Restoration Flows at or below estimates of then-existing channel capacities.

Then-existing channel capacities in the Restoration Area (the San Joaquin River between Friant Dam and the confluence of the Merced River) correspond to flows that would not significantly increase flood risk from Restoration Flows. Then-existing channel capacity is reported in an annual comprehensive Channel Capacity Report (CCR) that is prepared and circulated for public comment. The CCR describes the proposed then-existing channel capacity for the upcoming Restoration Year, and the projects and analyses that were performed to update the capacity from the previous year's CCR.

In this CCR for the 2025 Restoration Year (2025 CCR), the SJRRP is not recommending any increase in then-existing channel capacity, therefore, then-existing channel capacities for all reaches in the Restoration Area remain unchanged from the 2022, 2023, and 2024 CCRs. However, the 2025 CCR includes the latest summary of the bank erosion monitoring that was completed to meet the requirements identified in the PEIS/R to closely monitor erosion and avoid erosion-related impacts resulting from Restoration Flows. The 2025 CCR also includes a summary of studies and monitoring that will be completed the following year. Previous CCRs include more information regarding CCAG roles and responsibilities, technical factors when considering channel capacity, the criteria and evaluation process for determining capacity, as well as the data and analytical tools used to determine channel capacity.

Previous CCRs can be found at the SJRRP website:

Levee Stability / Channel Capacity – San Joaquin River Restoration Program (restoresjr.net)

The 2025 CCR was available for a 60-day public review and comment period from October 18, 2024 to December 17, 2024. No comments were received.

2. Completed Channel Capacity Studies and Related Work

The following sections summarize new technical studies and related work that has been completed at the time of publication of this report. This year's report includes DWR's bank erosion monitoring efforts at critical sites within the Restoration Area considering Restoration Flows; contract deliveries; and the flood management releases (FMRs) in 2019 and 2023.

2.1 Bank Erosion Monitoring Updates

The PEIS/R described the need to "closely monitor erosion and perform maintenance and/or reduce Interim or Restoration Flows as necessary to avoid erosion-related impacts" (SJRRP, 2012b). DWR is taking the lead to monitor bank erosion within the Restoration Area. The goal of the monitoring effort is to identify the locations where erosion occurs and where there are threats of erosion-related impacts. Future efforts may also include identifying the causal mechanisms of erosion at critical erosion sites. The results of the monitoring will assist the SJRRP with the erosion monitoring and reporting that is in the PEIS/R and allow for the development of advance measures to reduce erosion attributed to Restoration Flows. The following sections summarize DWR's previous and ongoing bank erosion monitoring efforts.

2.1.1 Background

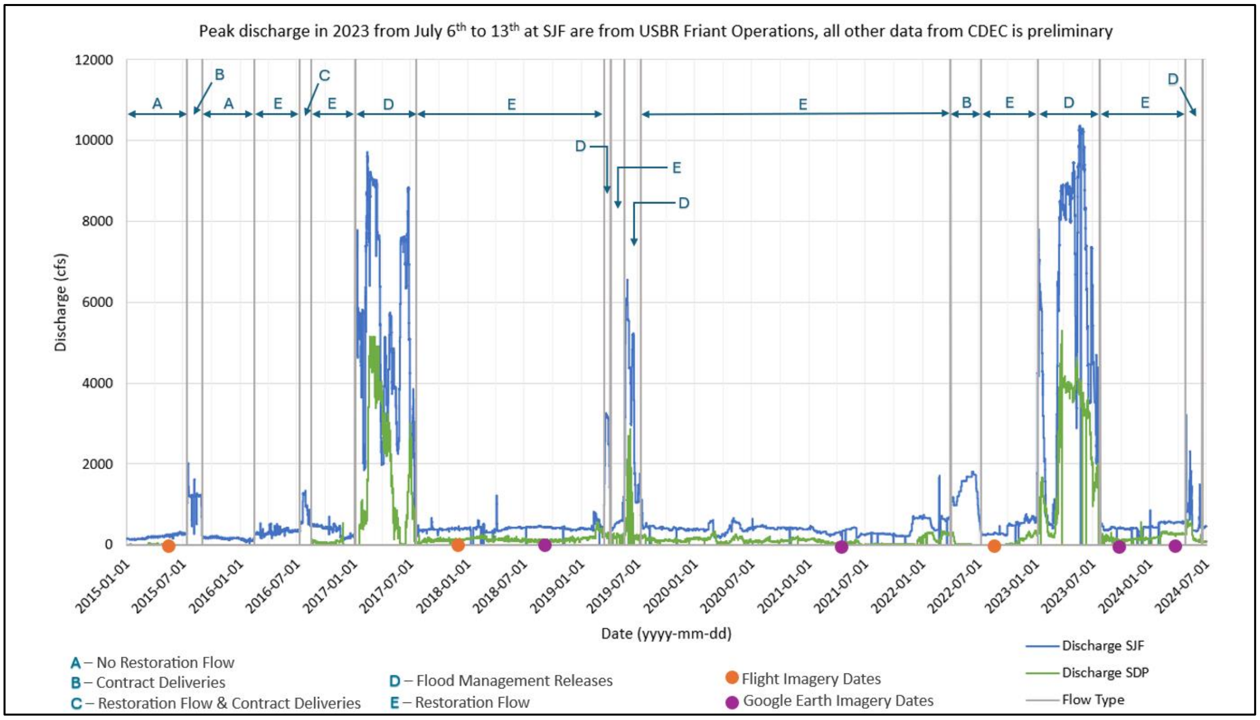
DWR initiated bank erosion monitoring within the Restoration Area and completed a subsequent monitoring report in 2021, which was included in Appendix C of the 2022 CCR. The 2021 monitoring report served as an initial step in identifying and monitoring critical erosion sites. It developed a baseline for future evaluations and recommended monitoring highest threat sites to determine potential causes and changes in erosion patterns related to Restoration Flows. A summary of the 2021 bank erosion monitoring report methodology and initial identification of the critical erosion sites are described in Appendix C of the 2022 CCR. In summary, the 2021 monitoring report concluded that, based on the reviewed aerial imagery, the observed erosion from 2015 to 2017 was mostly caused by the FMRs that occurred between January and July of 2017. It further determined that it is less likely that Restoration Flows caused the erosion because those average daily discharges were smaller in comparison to the FMRs. However, the 2021 monitoring report continued to recommend implementing a long-term erosion monitoring plan that would evaluate the erosion by reach throughout the Restoration Area. The 2021 monitoring report further recommended using remote sensing technology to monitor and detect erosion.

2.1.2 Bank Erosion Monitoring Update (2024)

In 2024, DWR conducted additional bank erosion monitoring to correlate bank erosion patterns and extents to the different types of flow experienced by the SJR from 2019 to 2023. These flow types are Restoration Flows, contract deliveries, and FMRs. The monitoring update focused on the high-threat areas that were identified in the 2021 monitoring report. The 2024 monitoring report also included additional areas of concern identified by the Lower San Joaquin Levee District (LSJLD) as another entity observing erosion for flood control purposes. The goal of the updates was to identify the level of impact of each flow type on the erodible perimeter of the river and bypasses within the Restoration Area. The update used aerial imagery from various sources to track changes in erosion extents over time. Imagery dates were selected based on changes in flow releases from Friant Dam, primarily between Restoration Flows and FMRs. This was done to compare changes in erosion patterns and relative extents between these flow types. Further details regarding the methods used to delineate the erosion can be found in the 2024 erosion monitoring report (Appendix A).

Based on the updated erosion monitoring, Restoration Flows are likely not the cause of most of the erosional impacts, rather, most of the erosion is more likely the result of the FMRs in 2019 and particularly high FMRs in 2023, which had significantly higher flowrates and WSEs. A hydrograph showing the various flow types is shown in Figure 1. During the 2019 FMRs flooding event, FMRs commenced intermittently but mostly in March and June with flows as high as 6,000 cfs. In 2023, FMRs occurred continuously from January to early February and then from early March through most of July. Peak FMRs of 10,000 cfs occurred from mid-May to early June. In general, these flows were much greater than the maximum combined Restoration Flows and contract deliveries of up to 2,000 cfs.

Based on the 2024 monitoring report, the recent erosion is most likely the result of the high FMRs that occurred in 2019 and 2023. It should be noted that during wet hydrology, Restoration Flows may be accounted for as part of FMRs consistent with the Settlement.



Source: Bank Erosion Monitoring, 2024

Figure 1. San Joaquin River Hydrograph of Mean Daily Discharge at SJF (RM 266.0) and SDP (RM 181.2) Stream Gages.

2.1.3 Recommendations

It is recommended that the SJRRP continue to implement a long-term erosion monitoring plan to evaluate erosion by reach throughout the Restoration Area. This includes applying the recommended future actions using remote sensing technology to monitor and detect erosion. When deemed necessary, future studies may include separate investigations of the processes and flow schedules that cause bank erosion.

3. Then-existing Channel Capacities

The SJRRP has completed comprehensive evaluations of over 60 miles of levees to determine the upper limit of Restoration Flows that can be conveyed in each channel. Evaluations include a drilling program and seepage and stability modeling to evaluate the risk of levee failure. For those levees that have not been evaluated, the SJRRP keeps Restoration Flows below the levees (in-channel) to reduce the risk of a levee failure. This upper limit, which is referred to as “then-existing” channel capacity, is the maximum Restoration Flow that can be conveyed in each reach based on levee capacity. Then-existing channel capacities in the Restoration Area were determined for the 2022 Restoration Year for all of the leveed reaches that can convey Restoration Flows: Reach 2, Reach 3, Reach 4A, and Reach 5 of the San Joaquin River and the Eastside and Mariposa Bypasses, flood bypasses for the San Joaquin River. A Restoration Area map can be found on the SJRRP website:

20130325_SJRRPreaches--scaled.jpg (1855×2560) (restoresjr.net)

There were no findings from studies or projects that occurred in 2024 that would result in changes in channel capacity. Therefore, this year's CCR does not recommend changes to the 2022 then-existing channel capacities (as done in 2023 and 2024). The then-existing channel capacities will remain the same for the 2025 Restoration Year. A summary of how then-existing channel capacity was determined for each reach, and the CCR that describes the study used to determine each reach's capacity, is described below.

For Reach 2A, the lower 2.5 miles of Reach 4A, Reach 4B2, and the Middle Eastside and Mariposa Bypasses, adequate data was available to perform a geotechnical analysis on the levees and these results were used to determine then-existing channel capacity for these reaches. The study details used to determine the then-existing channel capacity for Reach 2A and the lower 2.5 miles of Reach 4A are included in the 2018 CCR. The study details used to determine the then-existing channel capacity for Reach 4B2 and the Mariposa Bypass are included in the 2020 CCR. For the Middle Eastside Bypass, the 2022 CCR was used to update the capacity of the reach after the completion of a levee improvement project in 2020. In-channel capacities are the best estimate of then-existing channel capacities for Reach 2B, Reach 3, portions of Reach 4A, Reach 5, and the Lower Eastside Bypass. The studies used to determine the capacities in these reaches are summarized in the 2017 and 2018 CCRs. A complete discussion of the data and analyses conducted to determine previous then-existing channel capacities can be found in the previous CCRs on the SJRRP website:

Levee Stability / Channel Capacity – San Joaquin River Restoration Program (restoresjr.net)

Table 1 identifies then-existing channel capacities for each reach, and whether the capacity is based on geotechnical data or if Restoration Flows are to remain in-channel. Then-existing channel capacities in Table 1 do not consider limitations to Restoration Flows as it relates to agricultural seepage. For the 2025 Restoration Year, releases of Restoration Flows in Reach 2A, Reach 3, and Reach 4A continue to be limited by agricultural seepage, and not levee stability. Footnotes in Table 1 note current limitations of Restoration Flows based on agricultural seepage. Details of how these seepage limits are determined and limit Restoration Flows are in the *Seepage Management Plan* (SMP), which can be found on the SJRRP website:

Seepage Projects – San Joaquin River Restoration Program (restoresjr.net)

Table 1. 2025 Then-existing Channel Capacity

Reach	Then-existing Channel Capacity (cfs)[1]	Method Used to Determine Then-existing Channel Capacity
Reach 2A	6,000[2]	Geotechnical Assessment
Reach 2B	1,210	In-channel
Reach 3	2,860[3]	In-channel
Reach 4A	2,840[4]	Geotechnical Assessment and In-channel
Reach 4B1	Not Analyzed	--
Reach 4B2	4,300	Geotechnical Assessment
Reach 5	2,350	In-channel
Middle Eastside Bypass	2,600	Geotechnical Assessment
Lower Eastside Bypass	2,890	In-channel
Mariposa Bypass	1,800	Geotechnical Assessment

1 Then-existing channel capacity shown in this table is based on levee stability only and does not consider Restoration Flow limitations related to agricultural seepage.
2 Capacity not assessed for flows greater than 6,000 cfs. Restoration Flows are limited due to agricultural seepage with Reach 2A thresholds being updated in Appendix H of the SMP and published in 2024.
3 Restoration Flows are limited to approximately 850 cfs due to agricultural seepage.
4 Restoration Flows are limited to approximately 500 cfs due to agricultural seepage.

It should be acknowledged that then-existing channel capacities identified in this report do not apply to FMRs and are often much less than the flows the channels will convey during flood events. Flood releases are routed based on a different set of criteria, which can exceed current levee seepage and slope stability criteria (which define then-existing capacity limits).

4. Program Actions

Throughout the implementation of the SJRRP, the maximum downstream extent and rate of Restoration Flows to be released would be limited to then-existing channel capacity, except when agricultural seepage or other constraints (e.g., construction, maintenance, etc.) are more limiting. As channel or structure modifications are completed, corresponding maximum Restoration Flow releases would be increased in accordance with then-existing channel capacity and the release schedule set in the Settlement. There are two projects that the SJRRP is currently working on that could have an effect on site-specific channel capacity. A status update on these projects are as follows:

- **Mendota Pool Bypass and Reach 2B Improvements Project.** The project would route flows and fish around the Mendota Pool to provide volitional fish passage to allow salmon to complete their lifecycle. A fish screen will prevent fish from entering the Mendota Pool when water deliveries are made from Friant Dam to Mendota Pool. The project will also include setback levees to create floodplain habitat and improve channel capacity to at least 4,500 cfs in Reach 2B. In September 2021, the first construction project, the replacement of Mowry Bridge was completed. The bridge replacement will provide a haul route for future construction, operation and maintenance access, and a stable structure for the City of Mendota's municipal water supply line. Several other elements of the project continue in preliminary design, including the setback levees. The major components of this project are scheduled to begin in 2027. A summary of the project can be found at the following website:

Reach 2B and Mendota Pool Bypass – San Joaquin River Restoration Program (restoresjr.net)

- **Arroyo Canal and Sack Dam Improvements Project.** This project is another integral project in restoring salmon to the San Joaquin River and will provide fish passage around Sack Dam and adds a fish screen on the Arroyo Canal to prevent entrainment of juvenile Chinook salmon in the canal. The project will replace the functions of Sack Dam by allowing water to enter the Arroyo Canal and the efficient passing of flows up to 4,500 cfs into Reach 4A, and fish passage. The project is currently at 90% design and construction is scheduled for 2025. A summary of the work completed can be referenced at the following website:

Arroyo Canal Fish Screen and Sack Dam Bypass Project – San Joaquin River Restoration Program (restoresjr.net)

5. Future Program Studies and Monitoring

There are several factors that can impact and limit channel capacity including levee construction or integrity (e.g., insufficient slope stability factor of safety or underseepage factor of safety); flow duration and timing that could saturate the levee and cause instability; erosion of the stream banks that could cause potential levee failure; sedimentation or scouring; ground subsidence; and increased roughness from vegetation. These factors and others were considered in developing SJRRP studies and monitoring to determine then-existing channel capacity. A comprehensive list of studies and monitoring activities of the SJRRP can be found in the 2020 CCR. The following describes the ongoing studies and monitoring activities that may be conducted during the next Restoration Year and included in the 2026 CCR:

- The SJRRP continues to update its hydraulic and sediment transport modeling tools to evaluate the flow, seepage, and structural actions as part of meeting the Restoration Goal of the Settlement, as needed.
- Reclamation, DWR and the U.S. Geological Survey (USGS) continue to operate and maintain several flow and water level stage gages along the San Joaquin River and tributaries between Friant Dam and the Merced confluence. These gages are used to determine the flow and river stage in each reach of the river to ensure that applicable flow releases do not exceed then-existing channel capacity. All of the gages are available online at the California Data Exchange Center (CDEC).
- DWR continues to perform vegetation surveys of Reach 2A and the Middle Eastside Bypass to better assess how vegetation growth may affect channel capacity in the flood system. The monitoring includes photographs and visual descriptions taken along vegetation transects in the channel to understand the general type, heights, and densities of vegetation along these reaches.

6. References

Reclamation (Bureau of Reclamation). 2016. San Joaquin River Restoration Program Environmental Impact Statement/Report – Mendota Pool Bypass and Reach 2B Improvement Project. Available from: Bureau of Reclamation (usbr.gov). Accessed on September 20, 2019.

SJRR (San Joaquin River Restoration Program). 2017. *Technical Memorandum, Channel Capacity Report, 2017 Restoration Year*. Available from: Levee Stability / Channel Capacity – San Joaquin River Restoration Program (restoresjr.net)

SJRR (San Joaquin River Restoration Program). 2018. *Technical Memorandum, Channel Capacity Report, 2018 Restoration Year*. Available from: Levee Stability / Channel Capacity – San Joaquin River Restoration Program (restoresjr.net)

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SJRR (San Joaquin River Restoration Program). 2022. *Technical Memorandum, Channel Capacity Report, 2022 Restoration Year*. Available from: Levee Stability / Channel Capacity – San Joaquin River Restoration Program (restoresjr.net)

SJRR (San Joaquin River Restoration Program). 2023. *Technical Memorandum, Channel Capacity Report, 2023 Restoration Year*. Available from: Levee Stability / Channel Capacity – San Joaquin River Restoration Program (restoresjr.net)

SJRR (San Joaquin River Restoration Program). 2024. *Technical Memorandum, Channel Capacity Report, 2023 Restoration Year*. Available from: Levee Stability / Channel Capacity – San Joaquin River Restoration Program (restoresjr.net)

Appendix A

Bank Erosion Monitoring Report (2024 Update)

July 2024

SAN JOAQUIN RIVER
RESTORATION PROGRAM

State of California
California Natural Resources Agency
DEPARTMENT OF WATER RESOURCES
South Central Region Office

San Joaquin River Restoration Program

Bank Erosion Monitoring Report
(2024 Update)

July 2024

DRAFT

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Acronyms and Abbreviations

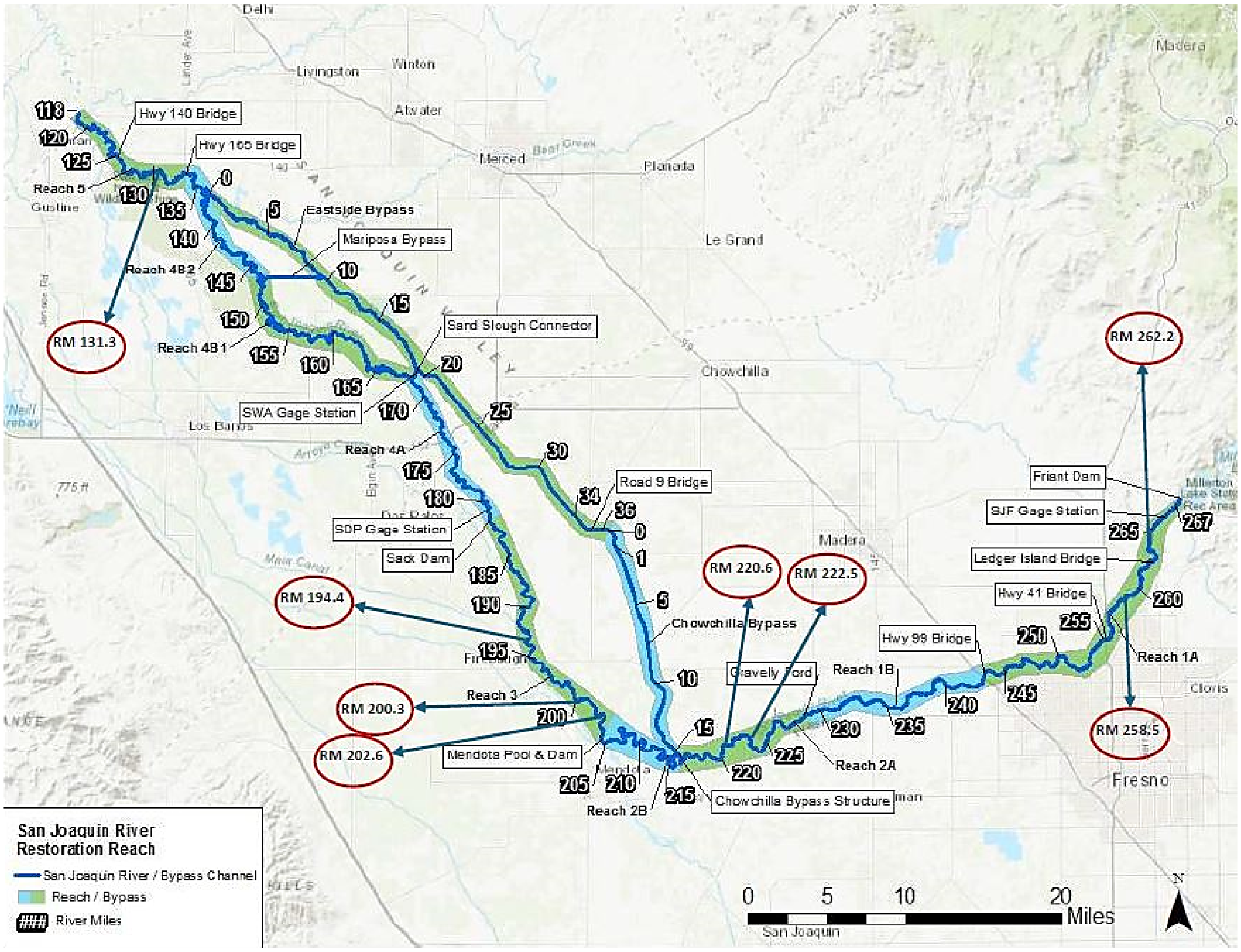
CALOES	California Governor's Office of Emergency Services
CCC	California Conservation Corps
cfs	Cubic feet per second
DWR	California Department of Water Resources
EOS	Office of Emergency Services
FOC	Flood Operations Center
LSJLD	Lower San Joaquin Levee District
PEIS/R	Program environmental impact statement/report
Restoration Area	San Joaquin River between Friant Dam and the Merced River confluence
RM	River mile
SDP	San Joaquin River Gage near Dos Palos
SJF	San Joaquin River Gage below Friant
SJRRP	San Joaquin River Restoration Program

1.0 Introduction

The San Joaquin River Restoration Program (SJRRP or Program) was established to meet two goals; one of which is to restore a self-sustaining, naturally reproducing salmon fishery back to the San Joaquin River (SJR). Restoration Flows now maintain a connected river channel from Friant Dam to the confluence with the Merced River except during critically dry water years. The SJRRP, in collaboration with federal and state agencies, developed a Program Environmental Impact Statement/Report (PEIS/R) to identify and minimize the impacts of the Program, including the need to "monitor erosion and perform maintenance and/or reduce Interim and Restoration Flows as necessary to avoid erosion-related impacts" (San Joaquin River Restoration Program 2012). The California Department of Water Resources (DWR) took lead in identifying and monitoring bank erosion within the Restoration Area (Figure 1) and completed a bank erosion monitoring report in 2021. This erosion monitoring can help better inform the Program and other entities on potential erosion resulting from Restoration Flows.

The 2021 report served as an initial step in identifying and monitoring critical erosion sites. It developed a baseline for future evaluations and recommended monitoring highest threat sites to determine potential causes and changes in erosion patterns related to Restoration Flows. This report provides an update to the 2021 report and evaluates eight high-threat erosion sites that were identified in the previous report. This update uses aerial imagery before and after flood management releases in 2019 and 2023 to relate erosion extents to the different flow types released from Friant Dam. In addition to the sites previously identified by DWR, this report also includes a cursory review of flood-threat sites identified in 2023 by the Lower San Joaquin Levee District (LSJLD) as another entity observing erosion for flood control purposes.

Figure 1 San Joaquin River Study Area by Reach and High Threat Site Locations Identified by DWR in 2021



2.0 Background

Flows released from Friant Dam are categorized as three primary flow types. These include Restoration Flows, contract deliveries, and flood management releases. During a wet year type, Restoration Flows may be already accounted for in flood management releases consistent with the Settlement. The magnitude and duration of each flow-type has the potential to cause erosion based on the geotechnical conditions of the riverbank and applied hydraulic force. To simplify identifying and monitoring erosion sites, DWR used aerial imagery to track erosion throughout the Restoration Area and compared flow releases to help determine when erosion occurred. With this approach, DWR performed a comprehensive evaluation of bank erosion along the SJR and flood bypass system in 2021 that was built upon the foundation of the 2010 Tetra Tech study, and the 2016 DWR pilot study. The 2021 report identified vulnerable areas where monitoring for erosion should be continued to ensure the protection of nearby infrastructure and property to support the assessment of the potential effects of Restoration Flows.

In the 2021 report, DWR reviewed 268 locations for the presence of erosion utilizing aerial imagery from 2015 to 2017. Fifty locations showed signs of bank erosion after 2017 flood management releases. High-, medium-, and low-threat classifications were assigned to each site based on their proximity to infrastructure. Eight sites were classified as high-threat, and twenty-two sites were classified as medium-threat. The cause of erosion related to flow-type was uncertain because all flow types were present between the aerial imagery dates that were used. However, DWR assumed that the erosion shown in the 2021 report was most likely a response to flood management releases occurring between January and July 2017; and was less likely caused by Restoration Flows because daily averages were small in comparison (California Department of Water Resources 2021).

DWR has committed to continue monitoring erosion in these areas to ensure that the SJRRP actions avoid significant erosion-related impacts. This commitment involves a long-term erosion monitoring plan that continues to evolve as data-gaps are assessed and remote sensing technology improves over time. Periodic reports will provide an evaluation of erosional areas recommended for monitoring from the last report update and provide new recommendations, if any. This report follows a recommendation from the 2021 report to monitor high-threat sites and improve the understanding of how Restoration Flows, contract deliveries, and flood management releases affect erosion sites in the Restoration Area.

3.0 Methods

The following describes delineation methods, site nomenclature, and threat classifications used for this report. Aerial imagery from various sources were used to track changes in erosion extents over time. Imagery dates were selected based on changes in flow releases from Friant Dam, primarily between Restoration Flows and flood management releases. This was done to compare changes in erosion patterns and relative extents between these flow types. This report focuses on the high-threat sites from the 2021 report, and includes additional areas identified by the LSJLD where erosion was apparent on aerial imagery.

Aerial Imagery Bank Delineations: In general, this method of delineation is the process of outlining the top of the riverbank or the edge of the water on aerial photos. After the delineation is completed, they are compared to determine if there were any changes over time. These changes could suggest bank erosion or deposition. Based upon imagery available for each site, either high-resolution aerial photos from 2022 or Google Earth imagery from 2018 to 2024 were used for delineation. Delineations are limited by overhanging vegetation, shadows, flow inundation, and pixel resolution. These limitations made it difficult to identify the exact bankline to determine how much erosion occurred at some sites. However, for the purpose of this monitoring it is sufficient for determining whether significant erosion did occur.

River Mile and Levee Mile Stationing: This report refers to the location of the sites using River Miles (RMs) and levee miles. RMs start at zero in the Sacramento-San Joaquin Delta and end 267 miles upstream just below Friant Dam. The levee miles for the Eastside Bypass start at the downstream end of the bypass at the confluence of the San Joaquin River and count upstream from zero to 36.

Threat Classification: The risk of erosion to structures (which is defined as human-made additions within the study area), was determined by calculating a threat ratio as described in the 2021 report. This ratio is the distance to the nearest structure divided by the distance of lateral erosion measured between the photoset dates. A smaller threat-ratio value means a more significant threat from erosion at that site. Sites with threat ratios lower than 3.0 were determined as critical and designated as a high threat. Sites that showed erosion but had a threat ratio between 3 and 10 were designated as a medium threat. The sites that showed no perceptible erosion from 2015 were designated as a low threat.

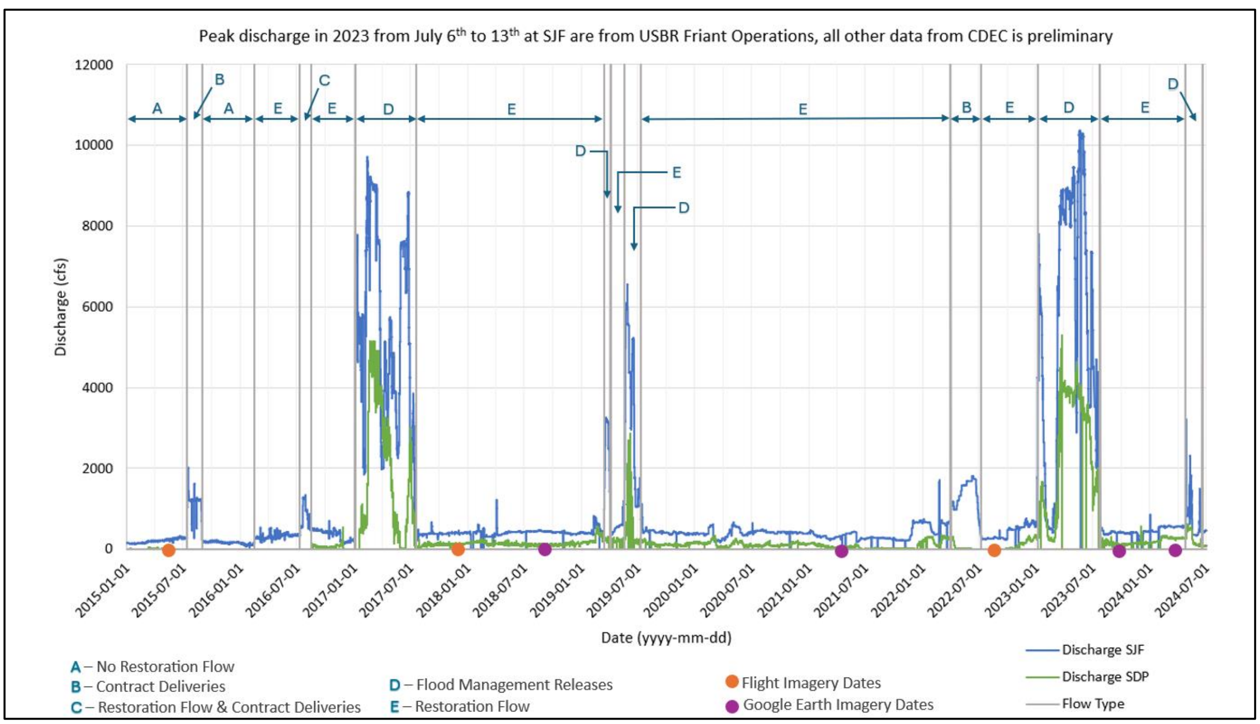
$$Threat\ Ratio = \frac{distance\ to\ nearest\ structure}{lateral\ erosion\ distance\ between\ photoset\ dates}$$

3.1 Hydrograph Data

Flow types play a crucial role in understanding the relative flow magnitudes between the photoset dates. DWR identified three key flow categories: Restoration Flows, contract deliveries, and flood management releases. The information for each flow category was collected from the California Data Exchange Center (CDEC) and the SJRRP (www.restoreSJR.net).

The hydrograph data used for this analysis is a continuation of the one created for the 2021 report and adds flow releases through April 2024 as shown in Figure 2. The vertical gray lines show when flow types changed with the flow types labeled at the top of the chart. Imagery dates are also identified at the bottom of the chart.

Figure 2 San Joaquin River Hydrograph of Mean Daily Discharge at SJF (RM 266.0) and SDP (RM 181.2) Stream Gages



Since the last update in 2021, flood management releases occurred in 2019, spanning from March 15th to April 5th, May 19th to July 11th, and again in 2023 from January 8th to February 5th and from March 8th to July 26th. Restoration Flows covered most of the remaining duration through 2024 except for a 3-month period in 2022 when Restoration Flows were reduced for contract deliveries and for temperature management of the reservoir. Specific flow types, the number of days released, and their start and end date since 2017 are summarized in Table 1.

Table 1 Flow Releases

Start Date	End Date	Days	Flow Type
8/1/2017	3/15/2019	591	Restoration
3/15/2019	4/5/2019	21	Flood management release
4/5/2019	5/19/2019	44	Restoration
5/19/2019	7/11/2019	53	Flood management release
7/11/2019	4/1/2022	995	Restoration
4/1/2022	7/8/2022	98	Contract deliveries
7/8/2022	1/5/2023	181	Restoration
1/5/2023	2/6/2023	32	Flood management release
2/6/2023	3/8/2023	30	Restoration
3/8/2023	7/27/2023	141	Flood management release
7/27/2023	5/1/2024	280	Restoration

Following the 2017 flood management releases, additional flood management releases were made for 247 days, contract deliveries for 98 days, and Restoration Flows for 2,121 days. While these flow characteristics provide insight into relative erosion, they alone do not determine erosion causes definitively. Further data and analyses are necessary to identify the exact factors contributing to erosion during this period.

4.0 Results

This report builds upon the 2017 findings as well as includes additional sites identified as possible areas of concern by the LSJLD as the agency that manages the flood control system. To evaluate previously identified high threat sites, DWR used aerial imagery from April 2015, December 2017, August 2018, April 2021, September 2022, October 2023, and February 2024. Comparison of the newer imagery with past delineations identified those sites with erosion following significant flow events. The magnitude of erosion varied between sites. The results, detailed in Table 2, provide an update on erosion at the previously identified high threat sites. The table also shows the maximum distance of lateral erosion and the minimum distance to the nearest infrastructure over time. This includes delineations for the post-2017 flood management releases from the previous report and new delineations before and after flood management releases in 2019 and 2023. The distances shown in Table 2 are not always measured at the same location. The minimum and maximum distances varied year by year based on site-specific erosion trends and location.

Table 2 Erosion at Previously Identified High Threat Sites

River Mile	2015 to 2017		2017 to 2018		2018 to 2021/2022		2021/2022 to 2023/2024	
	Maximum Lateral Erosion (feet)	Minimum Distance to Structure (feet)	Maximum Lateral Erosion (feet)	Minimum Distance to Structure (feet)	Maximum Lateral Erosion (feet)	Minimum Distance to Structure (feet)	Maximum Lateral Erosion (feet)	Minimum Distance to Structure (feet)
262.20	55	85	10	82	17	81	21	68
258.50	10	0	1	0	12	0	15	0
222.50	140	45	0	45	72	40	10	40
220.60	37	75	8	71	19	60	ND[1]	ND[1]
202.60	20	33	5	33	4	33	10	33
200.30	55	3	2	3	8	3	21	3
194.4	12	24	ND[1]	ND[1]	4	16	9	16
131.30	11	0	ND[1]	ND[1]	9	0	18	0

[1] Not Determined

Significant flow events appear to influence erosion patterns observed in aerial imagery. The duration between the 2017 and 2018 imageries experienced only Restoration Flows, resulting in relatively lower erosion extents in a few areas compared to erosion observed after flood management releases. Imagery was not available for all sites around the 2021/2022 timeframe; therefore, some sites used 2021 imagery to assess pre-2023 flood management releases and other sites used imagery from 2022. Between the 2018 and 2021 imageries, Restoration Flows continued, but had a 74-day break for flood management releases in 2019, which peaked up to 6,500 cubic feet per second (cfs). For those sites that used imagery in 2022, it includes the continuation of Restoration Flows and 98 days of contract deliveries from April to July 2022.

Post-2023 flood management releases were assessed using available imagery either from 2023 or 2024. Significant flood management releases over a period of 173 days occurred between January and July 2023, with peak flows up to 10,000 cfs. The erosion observed in this period is likely related to these significant flood management releases. Site-specific changes at each high-threat site identified in the 2021 report are further described in the following section.

4.1 Previous High Threat Sites Update (2024)

RM 262.20

The site is located in Reach 1A at the southern end of Ledger Island and features an unprotected riverbank that was identified in a previous report as a high-threat area due to its proximity to a gravel mining pit separated by an eroding bank (Figure 3). From 2015 to 2017, a maximum lateral erosion of 55 feet was observed, reducing the minimum distance to the structure to 85 feet. Most of the erosion during this period occurred around the middle of the eroding bank and was likely due to flood management releases in 2017. In August 2018, using Google Earth imagery, the maximum lateral erosion between 2017 and 2018 was measured at 10 feet at a different location, and the minimum distance to the structure slightly reduced to 82 feet. Most of the erosion during this period shifted to the upstream end of the site in an area away from the minimum distance to the gravel pit. By April 2021, Google Earth imagery showed additional erosion at the upstream area up to 17 feet, with the minimum distance to the structure further reduced to 81 feet. The latest imagery from October 2023 showed additional erosion throughout the entire extent of the eroding bank up to 21 feet from 2021, with the minimum distance to the structure reduced to 68 feet.

Most of the erosion continued towards the upstream end of the site and relatively less erosion downstream where it is closer to the gravel pit. The erosion trends observed at this site appear to be influenced by the different flow types over the years. Between 2017 and 2018, additional erosion was relatively less as a result of Restoration Flows and appeared to occur only at the upstream area of the site. This erosion trend continued through 2021 as Restoration Flows continued along with 74 days of flood control releases with peak flows up to 6,500 cfs in 2019. Based on these observations, most of the additional erosion up to 2023 that impacts the minimum distance to the structure is assumed to occur because of the 2023 flood management releases where substantial flood control flows were released for 173 days, with peak flows up to 10,000 cfs. Following this flood event, erosion was observed throughout the entire extent leading to an erosion pattern similar to what was observed after the 2017 flood. Monitoring at this site showed distinct differences in erosion trends based on flow type, where erosion from Restoration Flows is relatively less and focused only on the upstream half of the site compared to the magnitude and extent of erosion after a significant flood event.

RM 258.50

This site is located near Owl Hollow within Reach 1A and features an unprotected riverbank with an embankment dirt road as the nearest threatened structure, separating a gravel mining pit from the river (Figure 4). In 2017, the maximum lateral erosion was 10 feet and began to erode into the dirt road. In August 2018, significant erosion was not observed with continuous Restoration Flows, but by April 2021, erosion increased an additional 12 feet at the downstream end following Restoration Flows and 74 days of flood control releases in 2019. Additional erosion between this timeframe was likely caused by flood management releases based on trends observed at this site during Restoration Flows between 2017 and 2018. Additional erosion of up to 15 feet was observed after the 2023 flood. Erosion trends at this site appear to be largely influenced by flood management releases where most of the changes were observed; minor erosion was observed during Restoration Flows.

RM 222.50

This site is located within Reach 2A and is a threat to a levee with farm buildings and an orchard beyond it (Figure 5). Between 2015 and 2017, the maximum lateral erosion was 140 feet, with the minimum distance to the levee at 45 feet, primarily around the middle section. In August 2018, no significant erosion was observed. In September 2022, an additional 72 feet of erosion was observed, particularly at the upstream area and the minimum distance to the structure reduced to 40 feet. By October 2023, an additional 10 feet of erosion was observed; however, the minimum distance to the levee did not change because erosion occurred at the upstream end further away from the levee. This site was protected by the LSJLD during the 2023 flood where rock slope protection was placed along the eroding bank. The erosion trends at this site appear to be influenced by varying flow types; Restoration Flows between 2017 and 2018 caused minimal erosion, while flood management releases from 2019 and 2023 had a considerable impact on erosion patterns.

RM 220.60

This site is located within Reach 2A, with the nearest threatened structure being a levee and row crops beyond it (Figure 6). Between 2015 and 2017, the maximum lateral erosion was recorded at 37 feet with the most significant erosion observed around the middle of the site; and the minimum distance to the levee was equal to 75 feet. In August 2018, Google Earth imagery showed additional erosion up to 8 feet, but the minimum distance to the structure remained unchanged at 75 feet. Erosion occurred only at a few locations, but a majority of the site remained unchanged during this period. By September 2022, additional erosion up to 19 feet was observed throughout the site, reducing the minimum distance to the levee to 60 feet. During this period, uniform erosion along the entire bankline was observed. The 2019 flood control releases are believed to have contributed to new erosion observed up to 2022. Erosion after the 2023 flood was not delineated because the bankline was not clear in the imagery. In general, this site shows a uniform erosion trend along the bankline after major flood releases and relatively less erosion during periods of Restoration Flows.

RM 202.60

This site is located within Reach 3 and features a sparsely vegetated riverbank without any bank protection (Figure 7). The nearest threatened structure is a service road along a canal. From 2015 to 2017, the site experienced a maximum lateral erosion of 20 feet, reducing the minimum distance to the structure to 33 feet. Most of the erosion occurred at the downstream end. In August 2018, additional erosion up to 5 feet was observed, but occurred away from the minimum distance to the service road, leaving that distance unchanged. By 2022, an additional 4 feet of erosion was observed again at the downstream end and not impacting the minimum distance to the road. Following the 2023 flood, an additional 10 feet of erosion was observed at the downstream end. These changes can be attributed to varied flow types where erosion appears to be expanding downstream more after a flood event compared to Restoration Flows.

RM 200.30

This site is in Reach 3 and depicts vegetation loss and no bank protection (Figure 8). As identified in the previous report, the nearest structure threatened is a service road and row crops just south of the site. The 2017 bankline delineation for this site is uncertain in some areas because of overhanging vegetation and shadows caused by them. Due to this reason the 2017 delineation crosses over the delineations for 2018 and 2022 banklines.

From 2015 to 2017, the site experienced a maximum lateral erosion of 55 feet, with a minimum distance to the structure at 3 feet. By August 2018, additional erosion was observed up to 2 feet at the downstream end, not impacting the minimum distance to the structure. By 2022, additional erosion up to 8 feet continued at the downstream end. The latest imagery from February 2024 shows additional erosion up to 21 feet throughout the site following the 2023 flood. Erosion observed between 2022 and 2024 is likely caused by the 2023 flood. For this site, the effect of Restoration Flows between 2017 and 2018 is not clear due to uncertainties of the 2017 bankline delineation, but considerable erosion was observed between 2018 and 2024 along the upstream and downstream ends, which is likely due to flood management releases.

RM 194.40

This site is in Reach 3 within the city of Firebaugh and depicts light vegetation with riprap serving as bank protection (Figure 9). The nearest threatened structure is a residential neighborhood. Bankline delineations for this site are uncertain because of vegetation growth, image resolution, and flow inundation. Based on these delineations, it may be assumed that there is up to 20 feet of erosion between 2015 and 2024; however, changes are not apparent and because of the riprap, there should be minor changes. Additional data collection and site visits will need to be conducted to further assess changes in erosion and impacts to nearby infrastructure.

RM 131.30

This site is located in Reach 5 and features a 430-foot-long barren bank that is actively eroding and encroaching within the side slope of a levee. Between 2015 and 2017, the site experienced up to 11 feet of erosion, which continued to increase an additional 9 feet by 2022; and by February 2024, the upstream area eroded an additional 18 feet. Google Earth imagery for 2024 does not cover the full extent of this site and further evaluation will be needed to identify the extent of erosion downstream. Most of the additional erosion observed in 2022 and 2024 are likely caused by flood management releases in 2019 and 2023. After communicating with the LSJLD, this site may no longer be classified as a high-threat site because the area is within the Great Valley Grasslands State Park where they have begun breaching the levee to flood native ground and restore floodplain habitat.

Figure 3 San Joaquin River Reach 1, RM 262.2; Threat Ratio 1.15, Threat Level: High

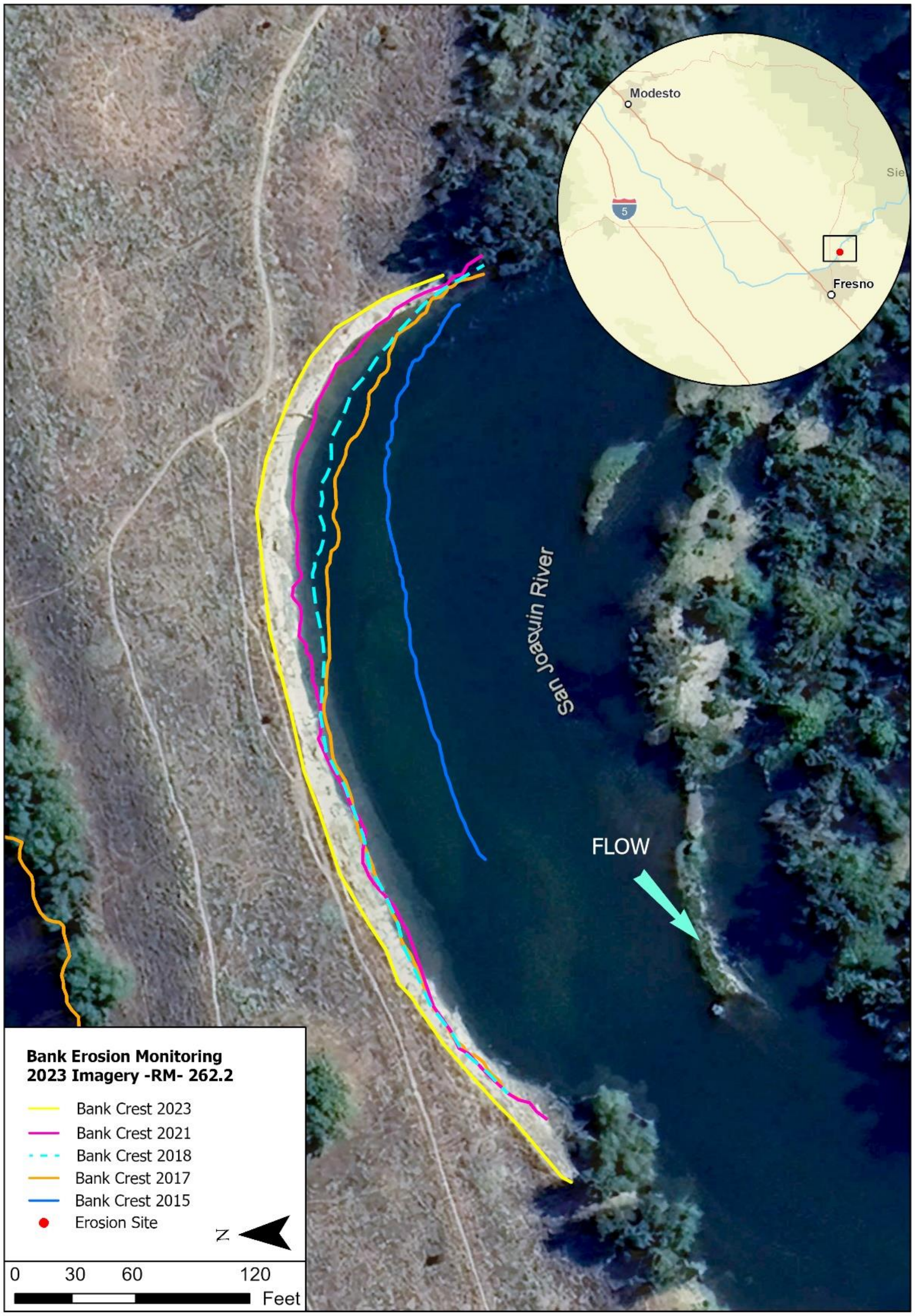


Figure 4 San Joaquin River Reach 1, RM 258.5; Threat Ratio 0.0, Threat Level: High

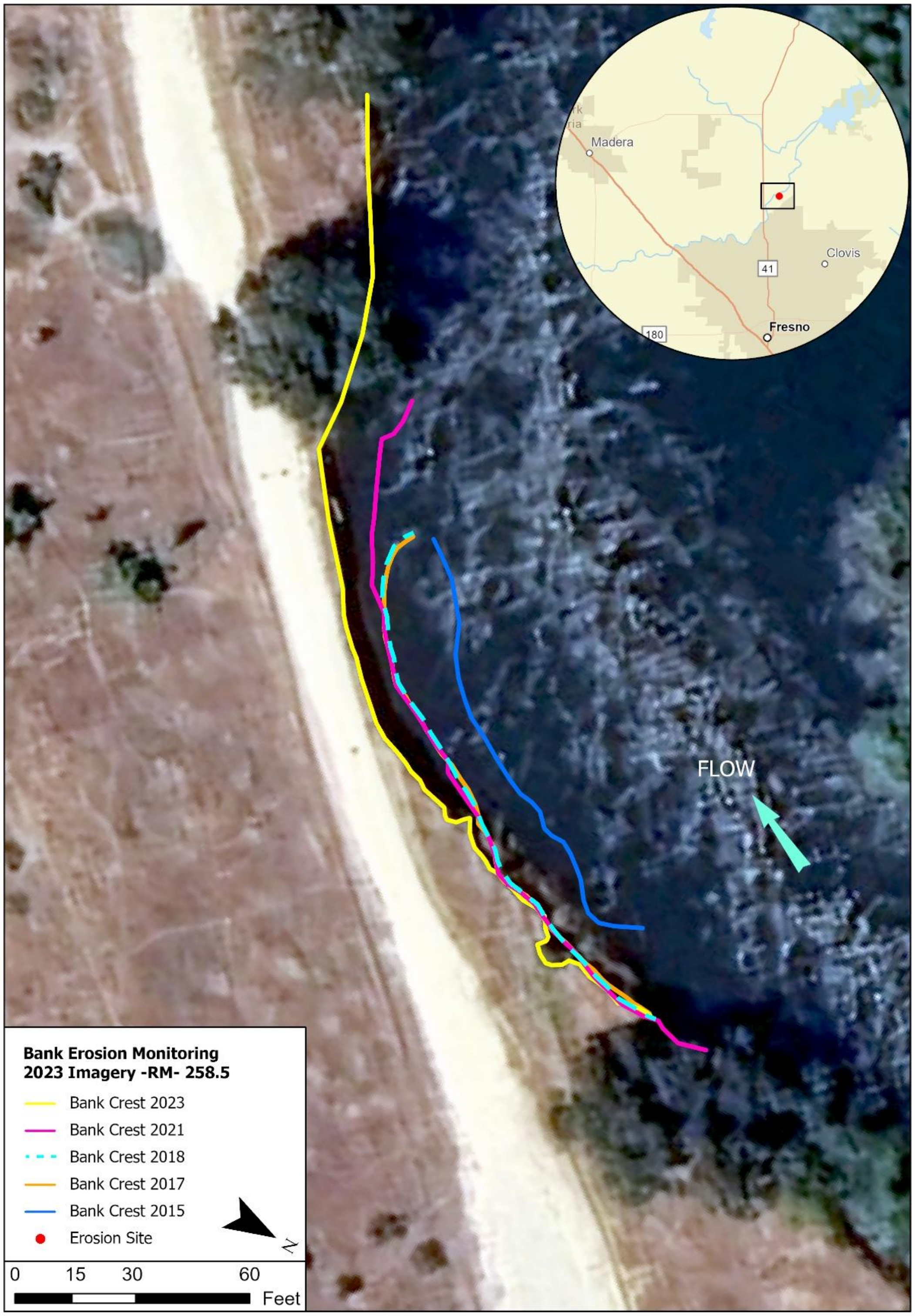


Figure 5 San Joaquin River Reach 2A, RM 222.5; Threat Ratio 0.29, Threat Level: High

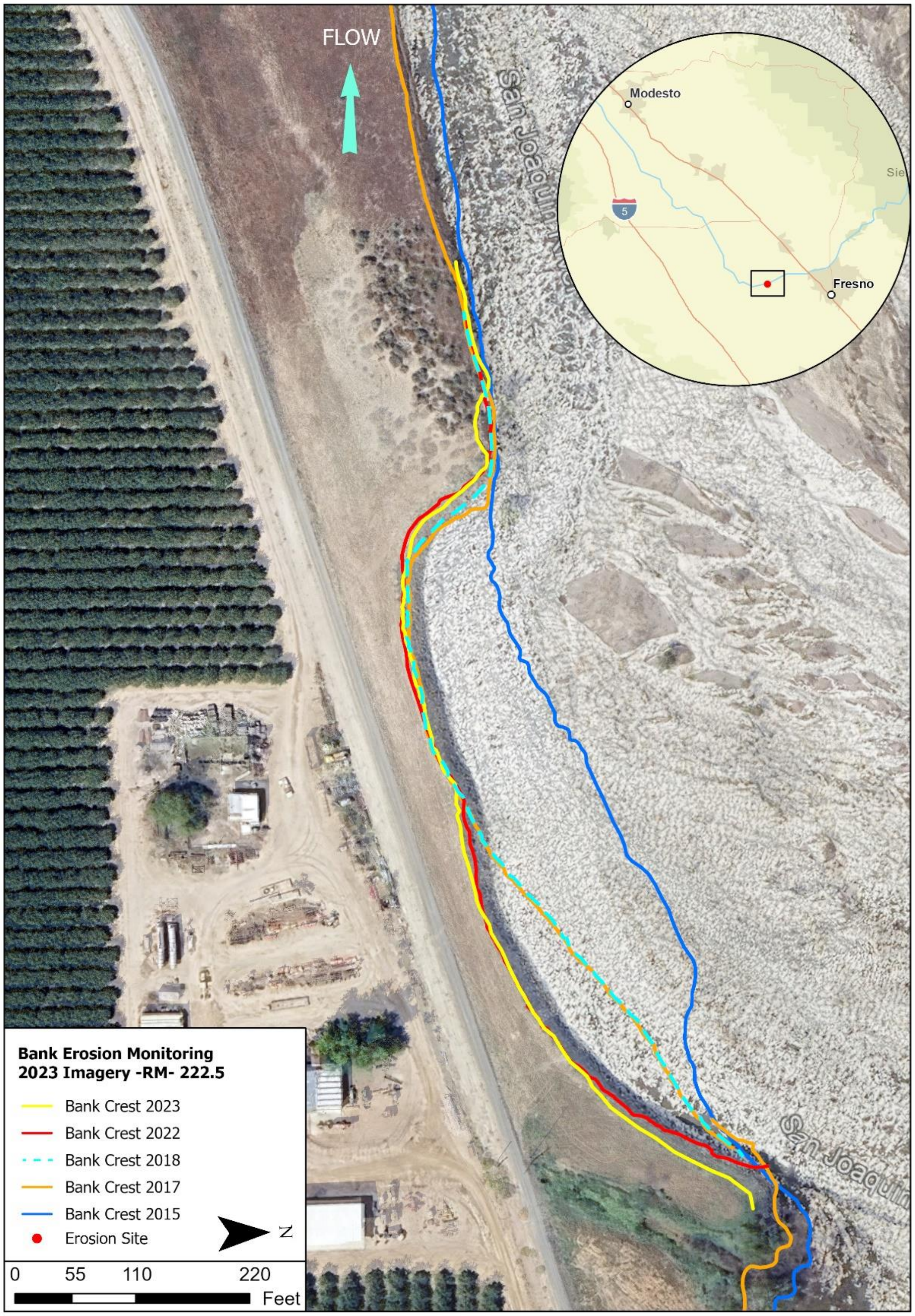


Figure 6 San Joaquin River Reach 2A, RM 220.6; Threat Ratio 0.67, Threat Level: High

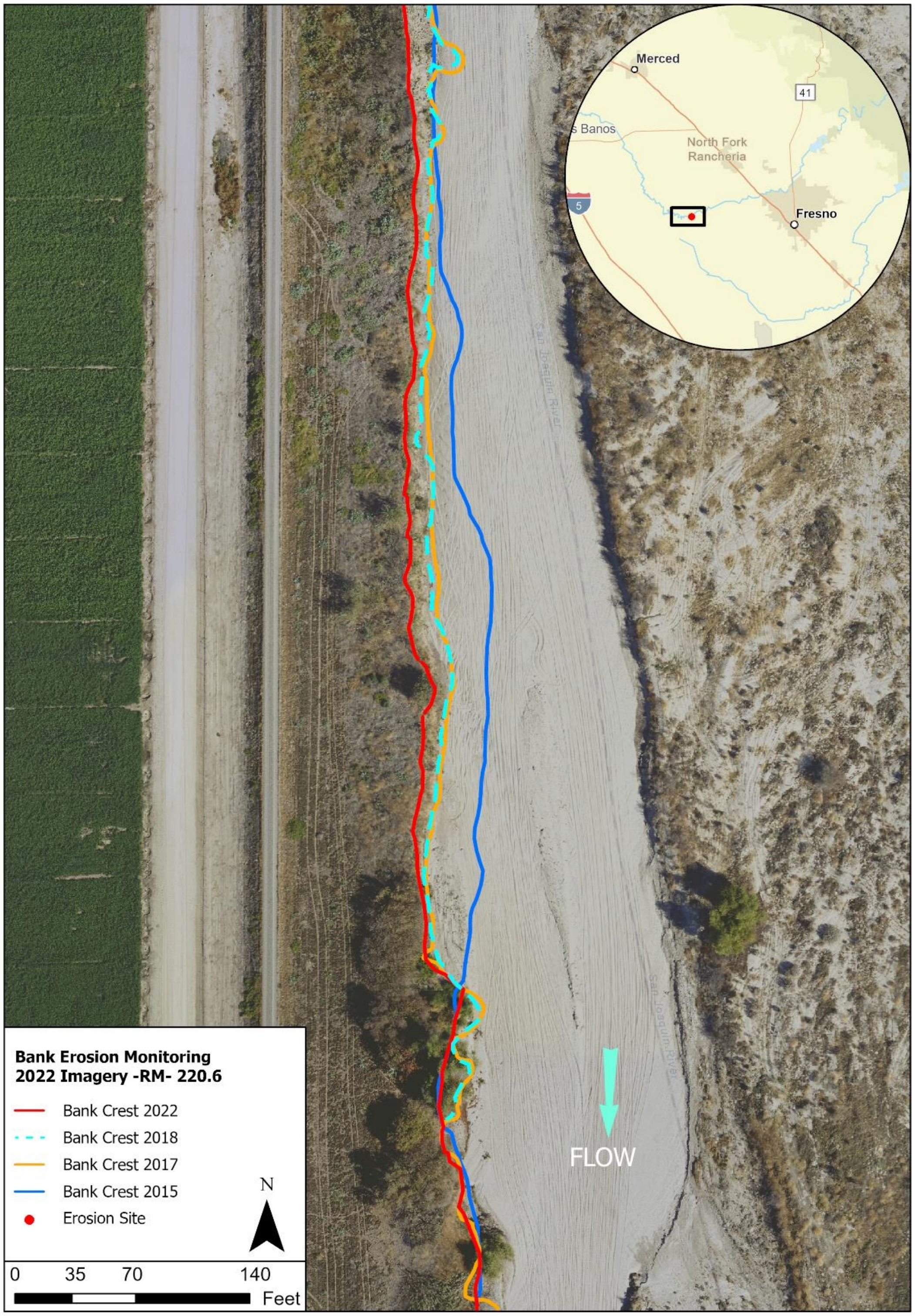


Figure 7 San Joaquin River Reach 3, RM 202.6; Threat Ratio 1.1, Threat Level: High

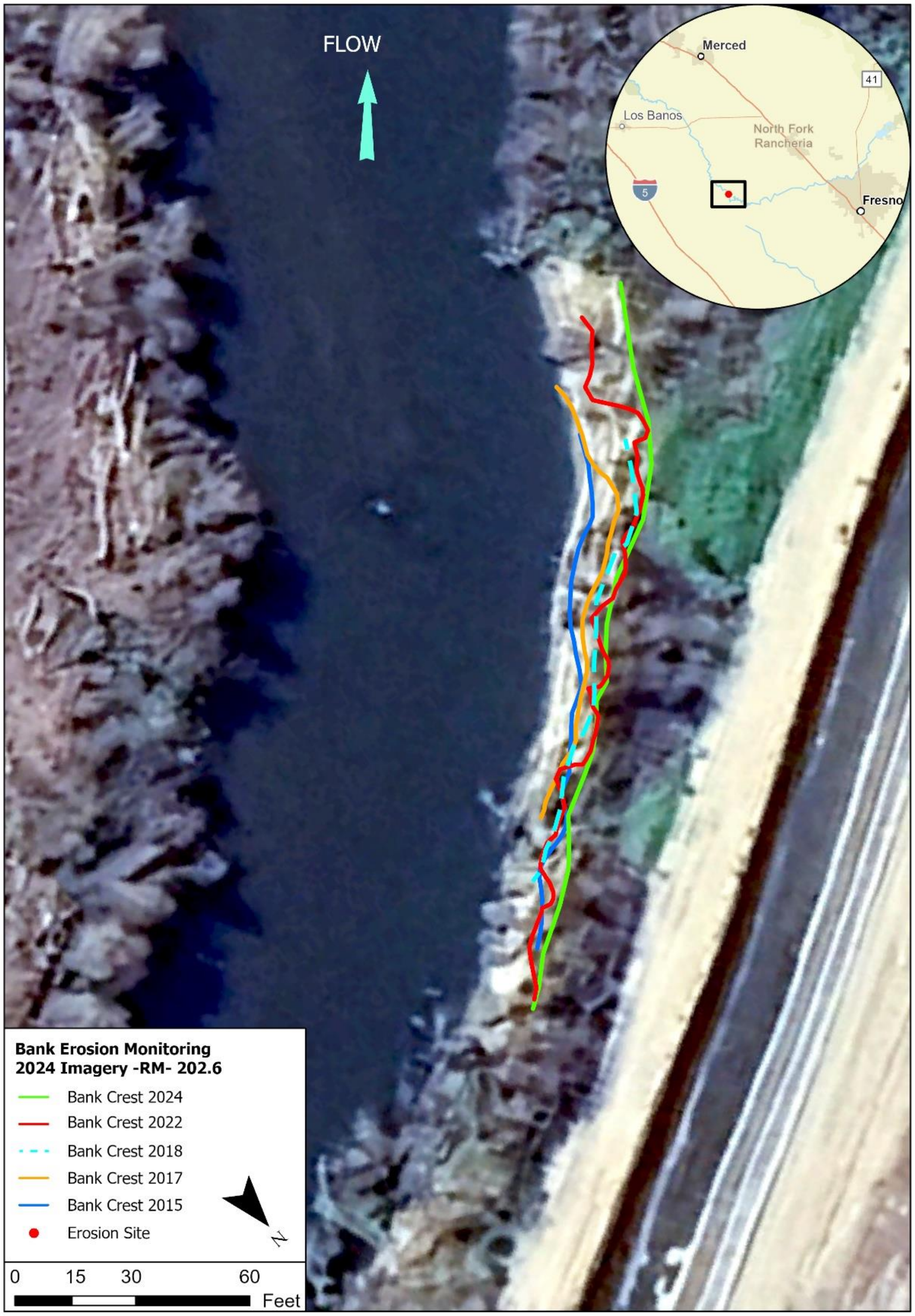


Figure 8 San Joaquin River Reach 3, RM 200.3; Threat Ratio 0.0, Threat Level: High

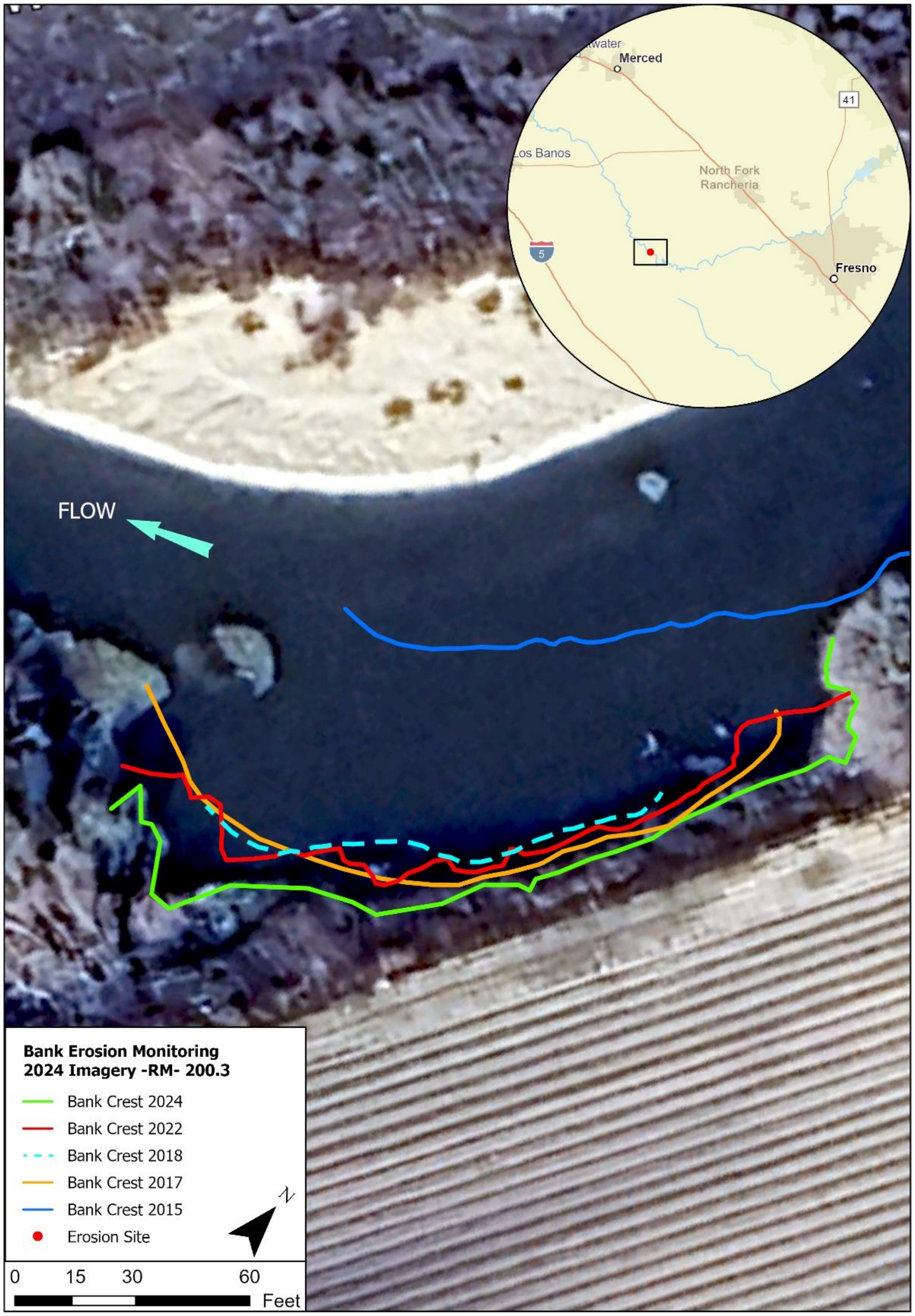


Figure 9 San Joaquin River Reach 3, RM 194.4, Threat Ratio 1.38, Threat Level: High

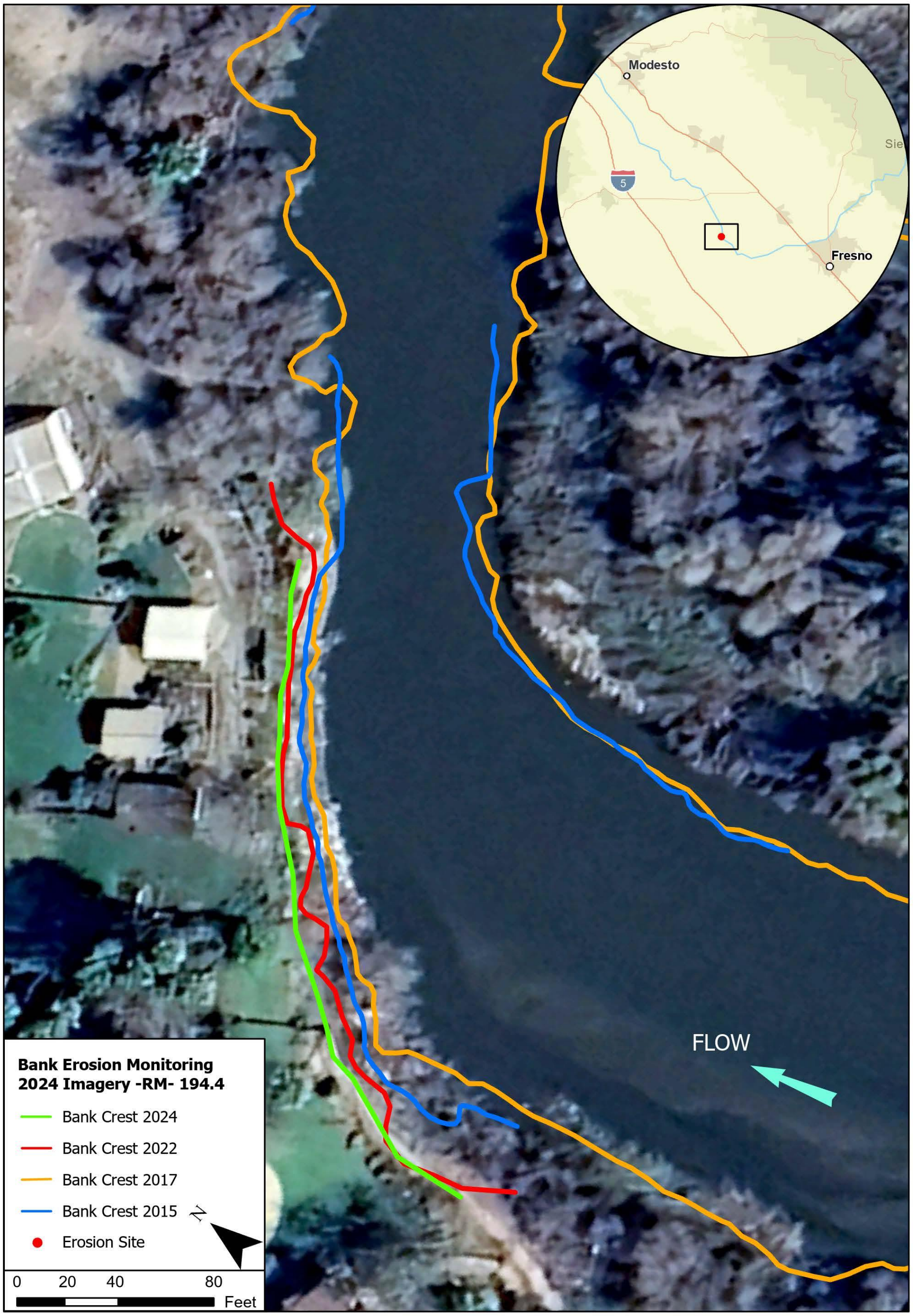
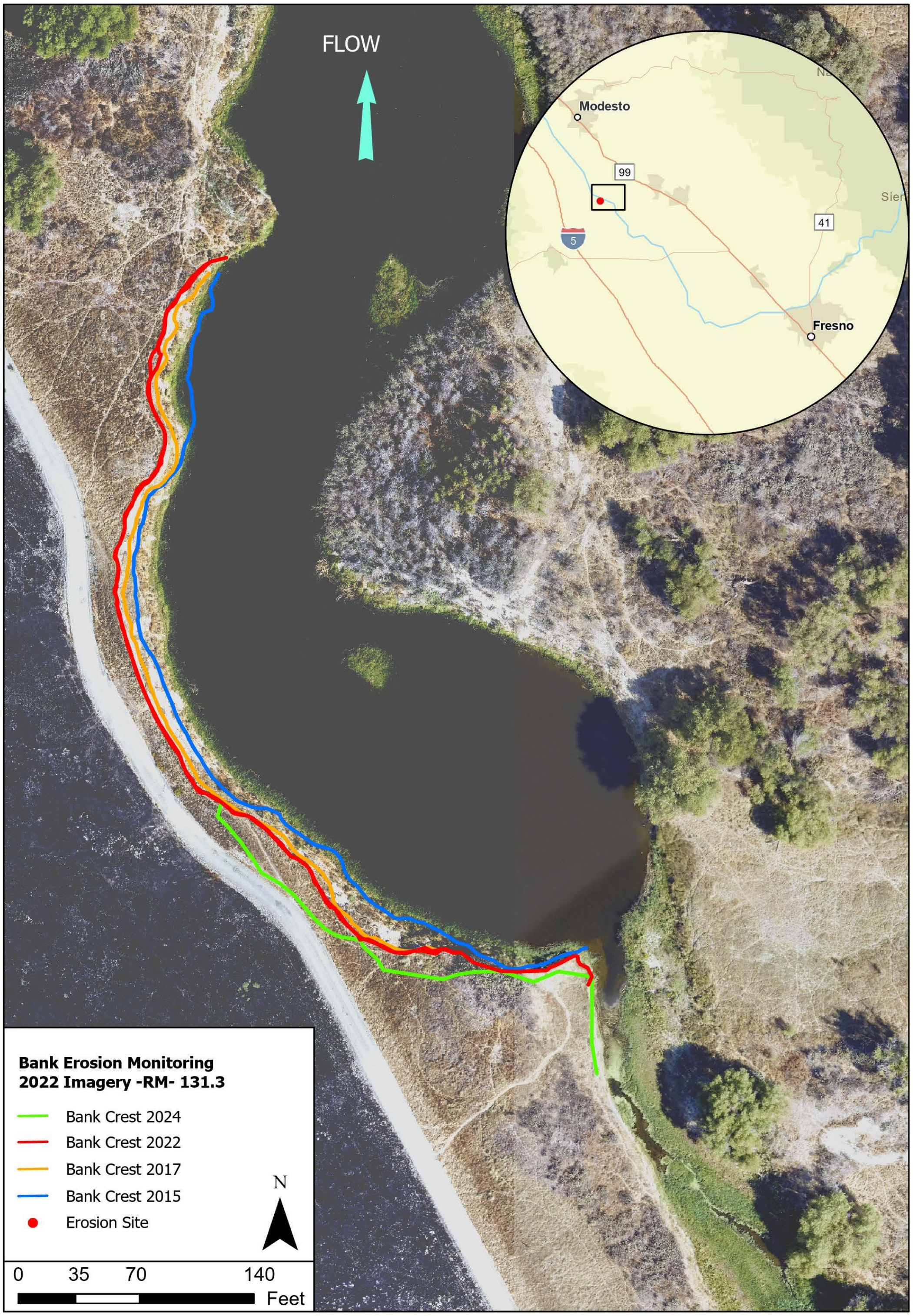


Figure 10 San Joaquin River Reach 5, RM 131.3; Threat Ratio 0.0, Threat Level: High



4.2 Lower San Joaquin Levee District Flood Threat Sites

During the 2023 flood management releases, as part of their ongoing monitoring efforts for flood control purposes, the LSJLD identified existing and potential flood-threat sites along several reaches including: 2A, 2B, 3, 4A, Middle Eastside Bypass (MESB), and Upper Eastside Bypass (UESB). A number of sites were identified with various issues, including erosion, boils, and seepage. Some of these sites are listed in Table 3 along with the LSJLD descriptions, DWR's threat classifications from 2017, and updated classification using available imagery from either 2023 or 2024. The table does not include all sites identified by the LSJLD but focuses exclusively on erosion-related threats; other issues such as seepage and boils were not included.

Table 3 Threat Classifications for Levee District Sites

RM	Reach	Levee District Flood Threat Label	DWR 2017 Threat Classification	DWR 2023/2024 Threat Classification
225.4	2A	Site 7 Erosion	Low	High
222.5	2A	Site 1 Erosion	High	High
220.6	2A	Flooding Threat High	High	High
219.8	2A	Flooding Threat High	Low	Medium
219.3-left bank/levee	2A	Flooding Threat High	Low	Unclear[1]
219.3-right bank/levee	2A	Flooding Threat High	Not Determined	Unclear[1]
218.5	2A	Flooding Threat High	Low	Unclear[1]
218.4	2A	Flooding Threat High	Not Determined	Unclear[1]
217.5-left bank/levee	2A	Flooding Threat High	Low	Unclear[1]
217.5-right bank/levee	2A	Flooding Threat High	Not Determined	Unclear[1]
217	2A	Flooding Threat High	Low	Unclear[1]
216.2	2A	Flooding Threat High	Low	Unclear[1]
209.5	2B	Flooding Threat High	Low	Low
196.8	3	Flooding Threat High	Low	Low
196.15	3	Flooding Threat High	Low	Low
194.9 (left bank/levee)	3	Flooding Threat High	Not Determined	High
194.9 (right bank/levee)	3	Flooding Threat High	Low	Low
194.55	3	Flooding Threat High	Low	Low
194.4	3	Flooding Threat High	High	High
193	3	Flooding Threat High	Not Determined	Unclear[1]
192.8	3	SJR Private Levee Break	Not Determined	Unclear[1]
183.3	3	Flooding Threat High	Low	Low
180.5	4A	Flooding Threat High	Low	Low
177.6	4A	Flooding Threat High	Low	Unclear[1]

RM	Reach	Levee District Flood Threat Label	DWR 2017 Threat Classification	DWR 2023/2024 Threat Classification
168.4	4A	Flooding Threat High	Not Determined	Unclear[1]
16.3	MESB	Flooding Threat High	Not Determined	Unclear[1]
16.3	MESB	Site 10, Wave Wash	Not Determined	High
16.2	MESB	Flooding Threat High	Not Determined	Unclear[1]
15	MESB	Flooding Threat High	Not Determined	Unclear[1]
15	MESB	Site 3 Erosion Site	Low	High
Avenue 18.5 bridge	UESB	Site 6, Bridge Foundation Erosion	Not Determined	High
Washington Road bridge	UESB	Site 11, Bridge Closed	Not Determined	Unclear[1]

[1] Flow/inundation, imagery or vegetation makes it difficult to calculate the extent of erosion and classify the threat level.

A total of 32 LSJLD sites were identified by DWR as having potential erosion threats. To validate their significance, the sites were cross-referenced with the results from the previous erosion report conducted in 2021. 19 out of the 32 sites had been previously identified by DWR in the 2021 report, falling under a range of threat classifications between low, medium, and high. Threat ratios and classifications were updated where recent aerial imagery was available in Google Earth between 2023 and 2024 to review changes after the 2023 flood. However, the delineations for several sites were unclear due to inundation extents in the imagery making erosion observations challenging. While half of these sites remain uncertain regarding erosion, a few are apparent erosion sites. Sites from the LSJLD list classified as either medium- or high-threat after the 2023 flood are further described in the following section.

RM 225.4 (Threat Classification - High)

Located in Reach 2A along the right bank, this site is labeled "Site 7, Erosion" by the LSJLD and identified by DWR as a low threat site in 2017. Critical observations were made during a site visit in March 2023 by the LSJLD. The nearest threatened structure is a levee positioned 25 feet away, with an orchard beyond it. Notably, a maximum of 56 feet of lateral erosion along the river-right bank line during the 2023 flood. This erosion encroached into the levee prism. In response, California Governor's Office of Emergency Services (CALOES) with assistance from the adjacent landowner, installed 3,500 tons of rock to stabilize the erosion site. Despite this protective measure, the calculated threat ratio for this site is equal to 0.45 and is a new high threat site that should be monitored to ensure that the rock protection is stable and assess if erosion continues beyond its extent.

RM 222.5 (Threat Classification - High)

Located in Reach 2A along the left bank, this threat site was previously identified and discussed in Section 4.1 High Threat Sites Update (2024).

RM 220.6 (Threat Classification - High)

This threat site is located in Reach 2A along the right bank and was previously identified and discussed in Section 4.1 High Threat Sites Update (2024).

RM 194.9 (left) (Threat Classification - High)

This site is located in Reach 3 at RM 194.9 along the left bank line. The LSJLD labeled this site as a high flooding threat, but it was unclear whether the threat was erosion related. We assumed the threat was a concern to Riverside Park in the town of Firebaugh and assessed erosion around it. This site was not identified by DWR in 2017, but recent observations have shown some erosion after the 2023 flood. Erosion was observed along the left bank near the upstream end of the site, approximately 350 feet from the bridge crossing on 13th Street. Given that the park appears to be situated on the floodplain, we considered the threatened infrastructure to be the park itself and labeled this site as a high threat since erosion is occurring along the park boundaries. Additional information is needed to further assess the threat level and determine whether monitoring should continue for this site.

RM 194.4 (Threat Classification - High)

This site is located in Reach 3 and was previously identified and discussed in Section 4.1 High Threat Sites Update (2024).

RM 16.3 (Threat Classification - High)

Located in the MESB at RM 16.3, this site is labeled "Site 10, Wave Wash" by the LSJLD. It was not identified by DWR in 2017. This site is along a levee improvement project completed by DWR in 2020. On March 28, 2023, the LSJLD reported wave wash damage on the levees to the Flood Operations Center (FOC). By March 30th, California Conservation Corps (CCC) crews responded and began wave wash protection efforts. Flow inundation in recent aerial imagery complicates direct observation of erosion damage. However, data collection and site visits were conducted at this site and erosion was observed along the levee prism classifying this site as a high threat.

RM 15 (Threat Classification - High)

Located in the MESB, this site is labeled “Site 3, Erosion Site” by the LSJLD. It was not identified by DWR in 2017. In January 2023, DWR FOC reported that the levee was failing due to erosion. By April 2023, CALOES had initiated a rock contract to address the issue. Based on 2024 imagery (Google Earth), we observed approximately 23 feet of lateral erosion since 2017 that began eroding into the levee toe and classifying this site as a high threat. Although rock slope protection was added to protect the levee, this site should be monitored to ensure the stability of the protections and assess whether erosion continues beyond its extent.

Avenue 18.5 Bridge (Threat Classification - High)

Located in the UESB, this site is labeled “Site 6, Bridge Foundation Erosion” by the LSJLD. It was not identified by DWR in 2017. During the 2023 flood, erosion was visibly impacting the bridge embankment. Consequently, the bridge was closed after being reported to Madera County Office of Emergency Services (EOS) and the Public Works department in January 2023. The threat level is assumed to be high due to the significant impact on the bridge embankment.

RM 219.8 (Threat Classification - Medium)

Located in Reach 2A, this site is labeled "Flooding Threat High" by the LSJLD. It was previously identified by DWR as a low threat in 2017. The nearest threatened structure is a levee positioned 82 feet away. Lateral erosion was measured to be 13.5 feet between 2015 and 2024, with a minimum distance to the levee measured to be 82 feet. The resulting threat ratio is equal to 6.1 after the 2023 flood, classifying this site as medium threat.

5.0 Conclusion and Recommendations

Building on past assessments, this update tries to distinguish erosion patterns between different flow types including Restoration Flows, contract deliveries and flood management releases. This was conducted using aerial imagery before and after flood events in 2019 and 2023 and focuses primarily on the high-threat sites identified in the 2021 bank erosion monitoring report, but also includes a cursory review of threatened sites identified by the LSJLD during the 2023 flood management releases. The LSJLD sites provide insight on the need to monitor additional sites for new erosion and previously identified sites that may have worsening conditions and threat classifications. This 2024 Bank Erosion Monitoring Report marks another step forward in our efforts to understand and monitor erosion within the Restoration Area. By following these recommendations, the Program can collect better data to inform and address any potential erosion threats resulting from Restoration Flows. Continual monitoring will improve the understanding of how Restoration Flows, contract deliveries, and flood management releases effect the erodible perimeter of the river and bypasses. Further monitoring and analysis will be necessary to understand the causal mechanisms of erosion in the Restoration Area and to confirm that Restoration Flows are not causing erosion-related impacts.

Review of the aerial photos indicate that the previously identified high-threat sites have undergone notable changes, with some experiencing worsening conditions. The magnitude of erosion varied per site but generally shows less erosion during Restoration Flows in comparison to significantly higher flood management releases. Specifically, sites at RM 262.20 and 258.50 showed little to no erosion during the Restoration Flow period between 2017 and 2018, and more erosion in comparison following flood management releases in 2019 and 2023. These high-flow events appear to be a significant factor contributing to additional erosion at these sites. Similar trends were observed at RM 222.5, and 220.60. Some sites such as RM 202.60 exhibited consistent erosion trends despite the flow type. Overall, although most of the additional erosion observed could be linked to higher flows during flood management releases, erosion patterns are largely dependent on specific site conditions where hydraulic, geotechnical, and vegetation conditions vary and impacts how erosion changes over time.

Insights from the LSJLD have emphasized the importance of monitoring not only high-threat sites but also medium- and low-threat sites identified in the previous report, and potentially new sites that were not yet identified. The dynamic nature of erosion could lead to worsening threat classifications over time and include new erosion sites, as evidenced by some sites identified by the LSJLD during the 2023 flood management releases. Therefore, it is important to periodically evaluate these sites to detect early signs of high-threat erosion and coordinate with the appropriate entities for preventative measures if necessary.

Based on these observations, the following actions are recommended prior to the next report to further understand how Restoration Flows, contract deliveries, and flood management releases affect erosion sites in the Restoration Area:

1. Continued Monitoring of High-Risk Sites: Focused attention should be maintained on high-risk sites identified in this report to protect critical infrastructure and property. Monitoring should be enhanced with advanced methods such as aerial imagery and detailed surveys, which have proven effective in mapping riverbanks and detecting signs of erosion.

2. Periodic Evaluation of Medium and Low-Threat Sites: It is essential to occasionally monitor medium and low-threat sites to assess whether they have worsened. This proactive approach will help identify new high-threat sites early and implement timely mitigation measures if necessary.

3. Integration of Multiple Monitoring Resources and Techniques: The Program should seek monitoring data from other entities conducting or responsible for erosion monitoring. A combination of monitoring methods, including drone surveillance and detailed field surveys should be employed to gain a comprehensive understanding of erosion trends. These techniques will allow for better correlation of erosion patterns with different flow types.

4. Long-Term Monitoring Plan Development: Establishing a long-term monitoring plan is crucial for tracking erosion trends over time. This plan should include regular data collection and analysis to assess the impacts of various flow conditions on bank erosion.

In conclusion, DWR recommends continuing to implement a long-term erosion monitoring plan that would evaluate the causal mechanisms by reach throughout the Restoration Area to reduce or avoid erosion-related Restoration Flow impacts in the Restoration Area. This includes applying the methods outlined above by using remote sensing technology to monitor and detect erosion. When deemed necessary, future studies may include separate investigations of the processes and flow schedules that cause bank erosion.

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