Robertson Park and Medeiros Parkway sUAS Surveys for the Sycamore Pilot Implementation Project

June 2024

Prepared By:
San Francisco Estuary Institute

SFEI San Francisco Estuary Institute

In Partnership With:
Alameda County Flood Control and
Water Conservation District, Zone 7

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A Product of **Preparing For The Storm**

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COVER IMAGE CREDITS
Cover photograph is a subset of an orthomosaic collected and produced by SFEI, in April 2024, at Medeiros Park.

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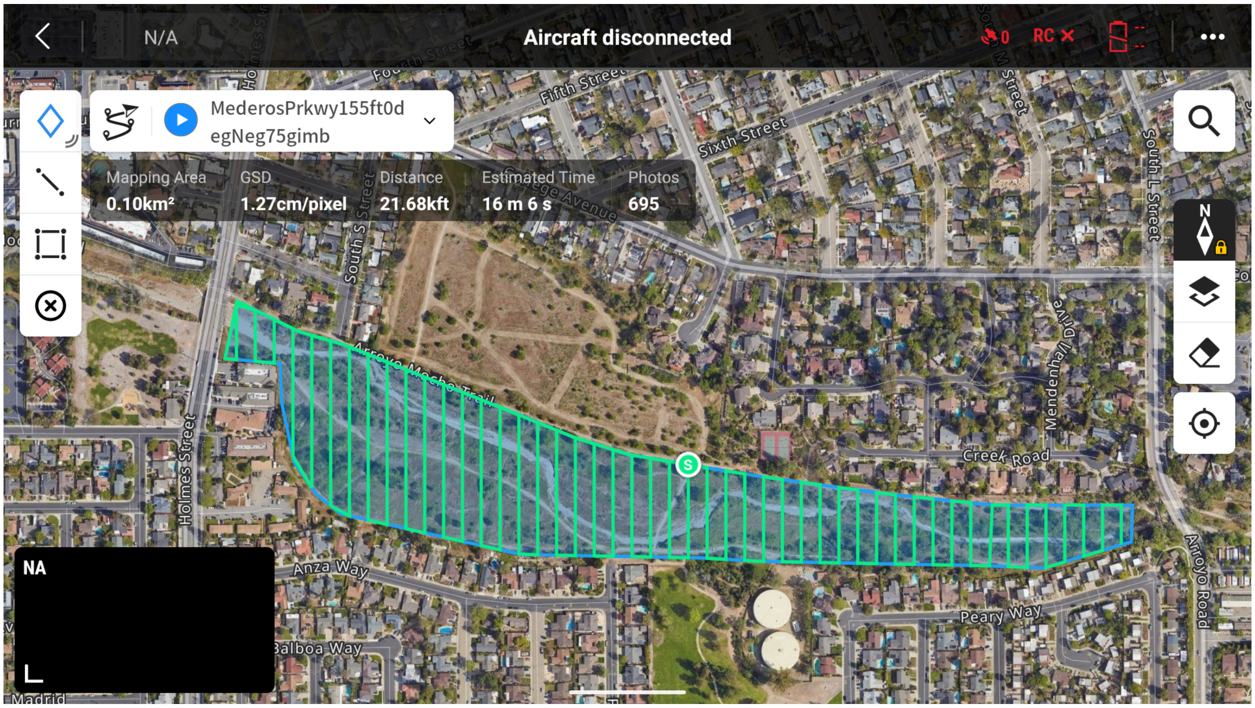
Table of Contents

Introduction

On April 16th, 2024, San Francisco Estuary Institute (SFEI) staff conducted small Unoccupied Aerial System (sUAS) surveys at both Robertson Park and Medeiros Parkway in Livermore-Amador Valley, California. Both flights were conducted using LAANC (Low Altitude Authorization and Notification Capability) approval. Survey flights were conducted at 155 ft above ground level in order to maintain a 0.5 inch ground sampling distance/spatial resolution in imagery products. Flight paths were also conducted in a cross-hatch pattern with a slightly angled camera gimbal angle to provide improved three dimensional and elevation data products as well as to compensate for higher vegetation levels across portions of both locations.

Peter Kauhanen was the Pilot-in-Command for the flights and is a holder of a current FAA Remote Pilot Certificate and conducted operations under FAA 's Small UAS Rule (Part 107) regulation. Kat Palermo was present and acted as a Visual Observer and assisted in maintaining high levels of operational safety.

Below are the flight area and path maps taken as screenshots from the DJI operating system. Note that the flights at Robertson Park (Figures 2 and 3) were broken up into two separate areas of interest in order to easily maintain visual line of sight around the bend in the channel.

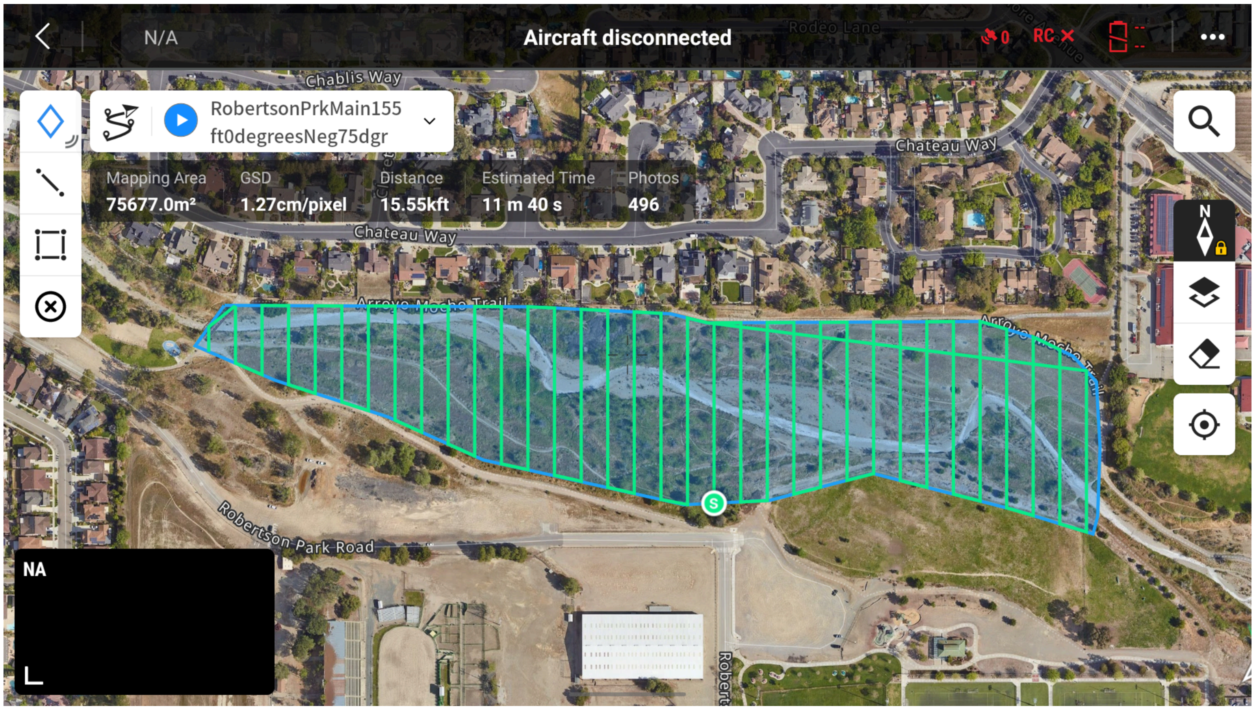


Aircraft disconnected

MederosPrkwy155ft0degNeg75gimb

Mapping Area	GSD	Distance	Estimated Time	Photos
0.10km²	1.27cm/pixel	21.68kft	16 m 6 s	695

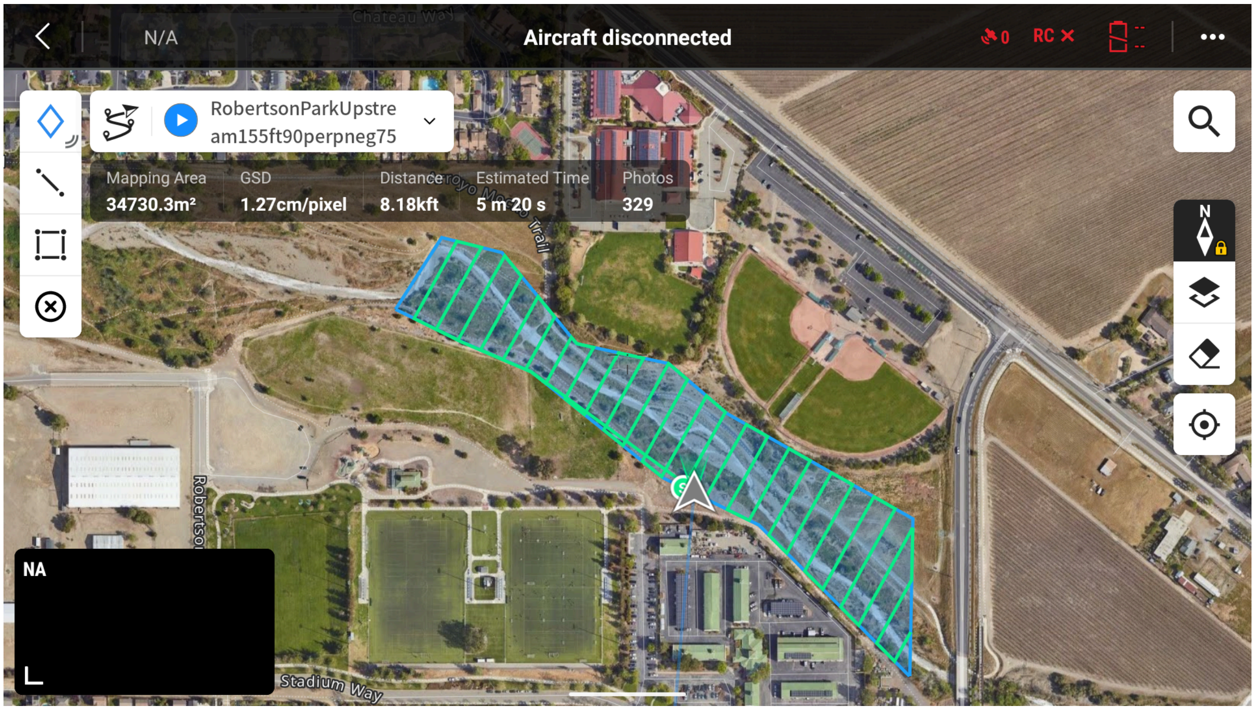
Figure 1. Flight area for Medeiros Parkway for April 16th, 2024 SFEI sUAS survey.



RobertsonPrkMain155
ft0degreesNeg75dgr

Mapping Area 75677.0m^2
GSD 1.27cm/pixel
Distance 15.55kft
Estimated Time 11 m 40 s
Photos 496

Figure 2. Flight area for the first (downstream) of two portions of the Robertson Park survey area for April 16th, 2024 SFEI sUAS survey.



RobertsonParkUpstre
am155ft90perpneg75

Mapping Area 34730.3m^2
GSD 1.27cm/pixel
Distance 8.18kft
Estimated Time 5 m 20 s
Photos 329

Figure 3. Flight area for the second (upstream) of two portions of the Robertson Park survey area for April 16th, 2024 SFEI sUAS survey.

Unoccupied Aerial System Specifications

The Unoccupied Aerial Vehicle (UAV) used for these surveys was the DJI Mavic 3 Enterprise. The specifications for this UAV can be found here: DJI Mavic 3 Enterprise Specs. The sensor is a 4/3 CMOS 20 MP true color camera on a gimbal. The UAV is equipped with a DJI Mavic 3 Enterprise Real Time Kinetic (RTK) Module which enables centimeter-level accuracy. SFEI staff paired the RTK module with the California Real Time Network (CRTN) station P228 (DelValle_CN2005), which was the closest station to the site and within recommended distances.

All processing was completed using Site Scan's services and analyzed by SFEI GIS Specialists.

Products

For each of the two surveys, SFEI provides the following dataset products:

- Orthoimagery (½ inch horizontal spatial resolution) Robertson Park ; Medeiros Parkway
- Elevation Data (from photogrammetry)
    - DSM Robertson Park ; Medeiros Parkway
    - DTM (estimated) Robertson Park ; Medeiros Parkway
- Point cloud (.las) Robertson Park ; Mederos Parkway
- Photos used for processing (~1,200 photos per site) Robertson Park ; Medeiros Parkway
- Processing Report Robertson Park ; Medeiros Parkway

Analysis

Sycamore Plantings Analysis

sUAS Imagery Collection and Sycamore Plantings

Approximately 14 months after the initial sycamore plantings in February 2023 (which included 9 container plants and 100 live stakes), and three months following the replacement plantings in January 2024 (which included 98 stakes and 21 container plants), SFEI conducted a UAS flight operation at the Sycamore Alluvial Woodland restoration sites at Medeiros Parkway and Robertson Park in Livermore, CA for restoration monitoring purposes. Year 1 plantings installed in 2023, were limited in their survival due to large floods that scoured or buried one third of installed container plants and almost two thirds of installed stakes . In Year 2, each non-surviving container plant was replaced at Medeiros Parkway with additional container plants installed across both Medeiros Parkway and Robertson Park (Y1 Annual Report, H. T. Harvey, Y2 Annual Report, H. T. Harvey). The resulting data layers from the UAS flight operation introduce new post-project baseline high-resolution imagery and elevation layers to examine the restoration site and aid in restoration monitoring.

Imagery Analysis and Plant Survival Assessment

To determine how well the 0.5-inch resolution sUAS orthomosaic imagery captured on-the-ground site conditions, SFEI staff performed a comparison with 3-inch aerial imagery produced by Pictometry for the year 2023 (Pictometry International Corp. 2023). The restoration site comparison showed substantial changes including plant status, in-channel debris and geomorphic change.

Figure 4. Pictometry imagery from 2023 at Medeiros Parkway with plantings outlined in red.

Figure 5. UAS orthomosaic imagery from April 2024 SFEI survey at Medeiros Parkway

As seen in the figures above, Pictometry imagery from 2023 (Pictometry International Corp. 2023) shows a string of Year 1 plantings along the edge of the inner floodplain of Arroyo Mocho at Medeiros Parkway (Figure 4). The same area photographed by SFEI's sUAS in April 2024 shows the absence of those plantings (Figure 5). Additionally, one can see changes in gravel bars, the absence of a fallen tree, and new vegetative growth on either side of the open water channel. The imagery provides evidence of high flows from winter storms altering the restoration site and potentially burying or sweeping away a significant portion of Year 1 plantings from 2023. The sUAS imagery collected in April 2024 offers high-resolution imagery to assess the site. Satellite imagery such as from Sentinel-2 and Landsat would not capture all the complexities of the site changes due to their much coarser resolution.

In addition to comparing aerial imagery, SFEI staff explored the use of the sUAS orthomosaic imagery to verify planting location point data and assess plant presence and absence status. With the planting location point data provided by H. T. Harvey and the sUAS orthomosaic imagery, SFEI staff confirmed 73 of the 123 planting location points had a living plant present in April 2024 (see table in Appendix A). The 0.5-inch spatial resolution of the imagery allowed for a detailed look at plants and plant cages throughout the restoration site. The limited number of confirmed plants is due in large part to adjacent vegetation that obscures the view of installed plants. Where protective cages were installed, it was easier to verify the location and status of a specific plant. Plants that did not have a cage or delineated basin were more difficult to assess.

In Figure 6 below, seven planting locations are shown with their status as determined by assessing the sUAS imagery. In this example, all but one planting could be determined as present and surviving.

Figure 6. Examples of Medeiros Parkway planting locations and status. In this example, all but one planting was able to be determined as present and surviving.

Vegetation Indices and Health Assessment

Monitoring restoration plantings through RGB composite images can be further enhanced by the use of vegetation indices. Vegetation indices are mathematical combinations of different spectral bands that amplify the photosynthetic elements of plants, making it easier to assess their survival status while also providing valuable insights into plant health and vigor.

One commonly used vegetation index for 3-band imagery is the Green Leaf Index (GLI). The GLI calculates the ratio of green to red and blue digital numbers per pixel, effectively highlighting the green vegetation in an image (Louhaichi, 2001). This index can significantly improve the detection of individual plantings by enhancing the visibility of green, photosynthetically active plants against the background. This makes it particularly useful for assessing the success of

Sycamore Alluvial Woodland (SAW) restoration projects, where determining the health and survival of newly planted vegetation is crucial. By applying the GLI to the sUAS imagery, practitioners can more accurately identify surviving plants, assess their health, and monitor project success over time. The index helps to differentiate between healthy, photosynthetically active plants and non-photosynthetic elements such as soil, dead vegetation, or other non-living materials. This differentiation is essential for making informed decisions about the management and future planning of restoration efforts. In Figures 7 and 8, SFEI staff illustrate the application of the Green Leaf Index on sUAS imagery for restoration monitoring. The GLI enhances the visibility of the green characteristics of the restoration plantings, making it easier to detect individual plants and assess their condition. Using vegetation indices like the GLI in conjunction with high-resolution sUAS imagery allows for a more detailed and accurate assessment of restoration efforts. This approach not only improves the detection of plantings but also provides valuable data on plant health, enabling better-informed decisions for future restoration activities.

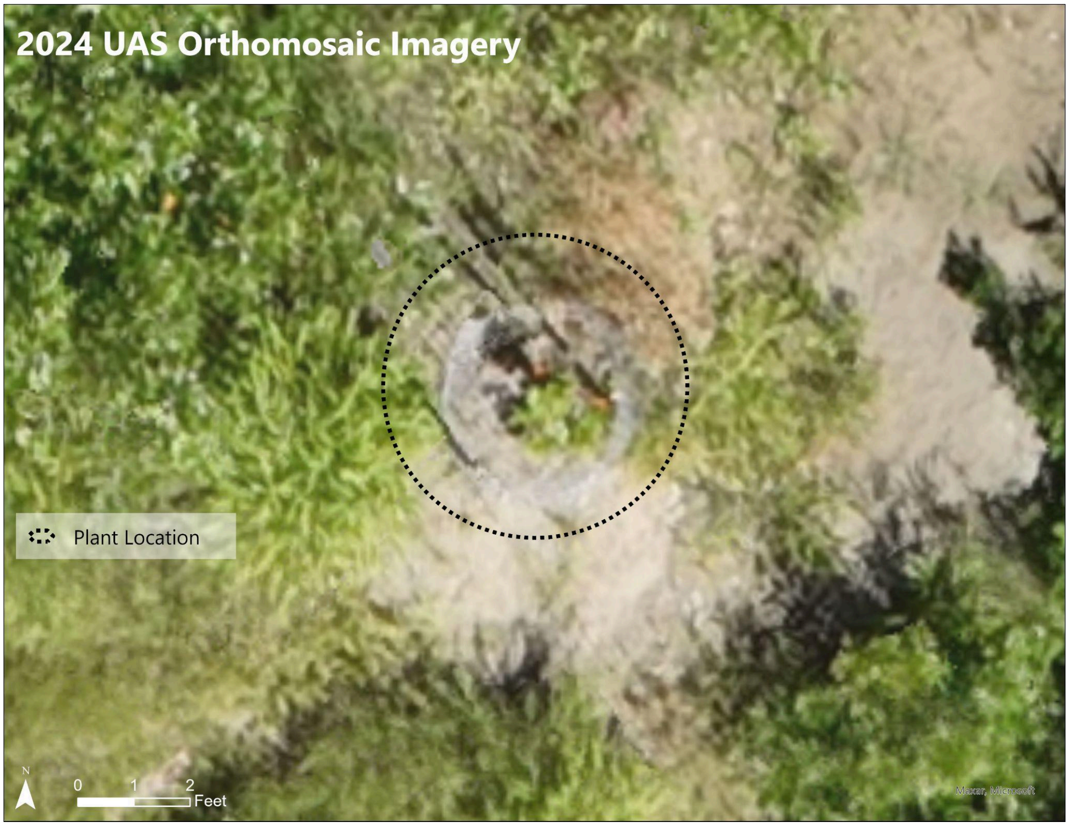


Figure 7. Location of a sycamore planting in the April 2024 SFEI sUAS imagery. This image is in true color and provides a reference for Figure 8.

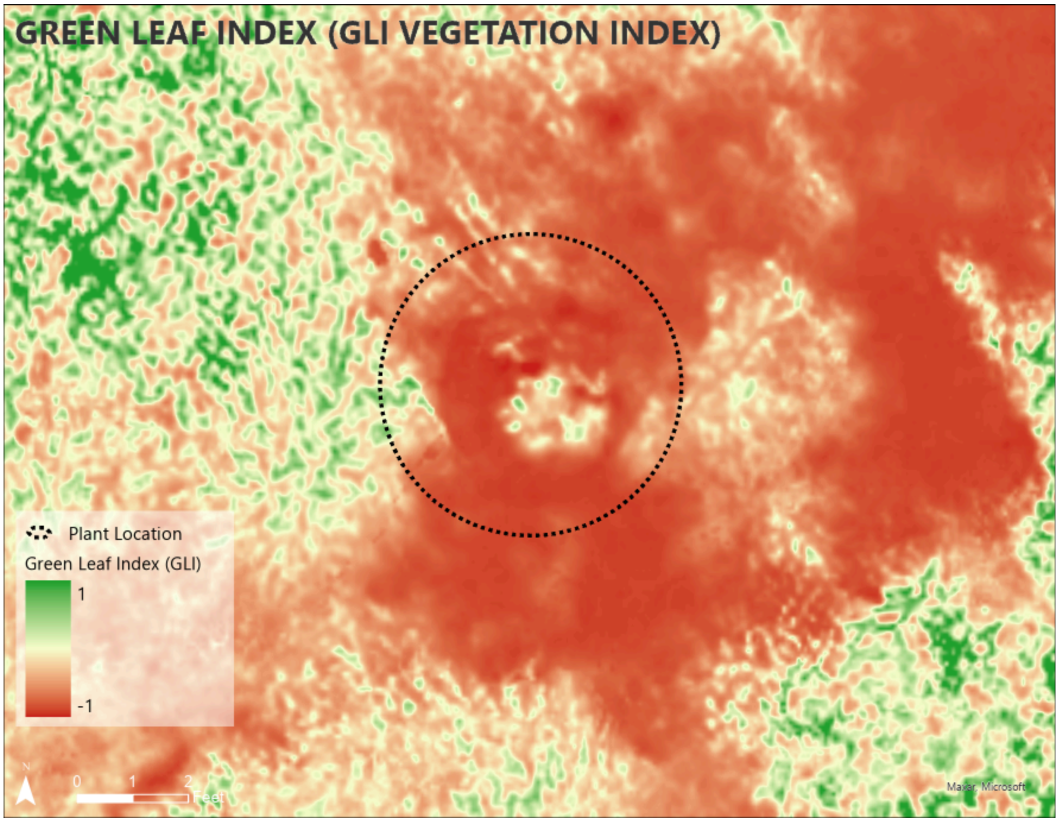


Figure 8. Example of the derived Green Leaf Index using the sUAS 3-band (RGB) orthomosaic imagery. Vegetation indices can help assess greenness of restoration plantings, allowing for insight into the status and health of plantings.

Vegetation Height Assessment

Deriving a vegetation height raster, also known as a canopy height model or normalized digital surface model, can provide further information for restoration monitoring. Beyond assessing greenness, evaluating vegetative growth can provide insight into the health and development of plantings by representing vertical structure. Vegetation height rasters are derived by subtracting the values of a digital terrain model (DTM) which represents the bare ground surface, from a digital surface model (DSM) which represents the height of all objects on the surface. High resolution DTMs and DSMs are produced from the sUAS imagery after the flight operation.
In Figure 10, the vegetation height raster, derived from the sUAS elevation layers, demonstrates the ability to assess vegetation height information, even for plantings within protective cages. This high-resolution data provides a detailed representation of the vertical structure of the vegetation, which is crucial for identifying individual plants and assessing their growth over time.

Figure 9. Location of a sycamore planting in the April 2024 SFEI sUAS imagery and Medeiros Park. This image is in true color and provides a reference for Figure 10.

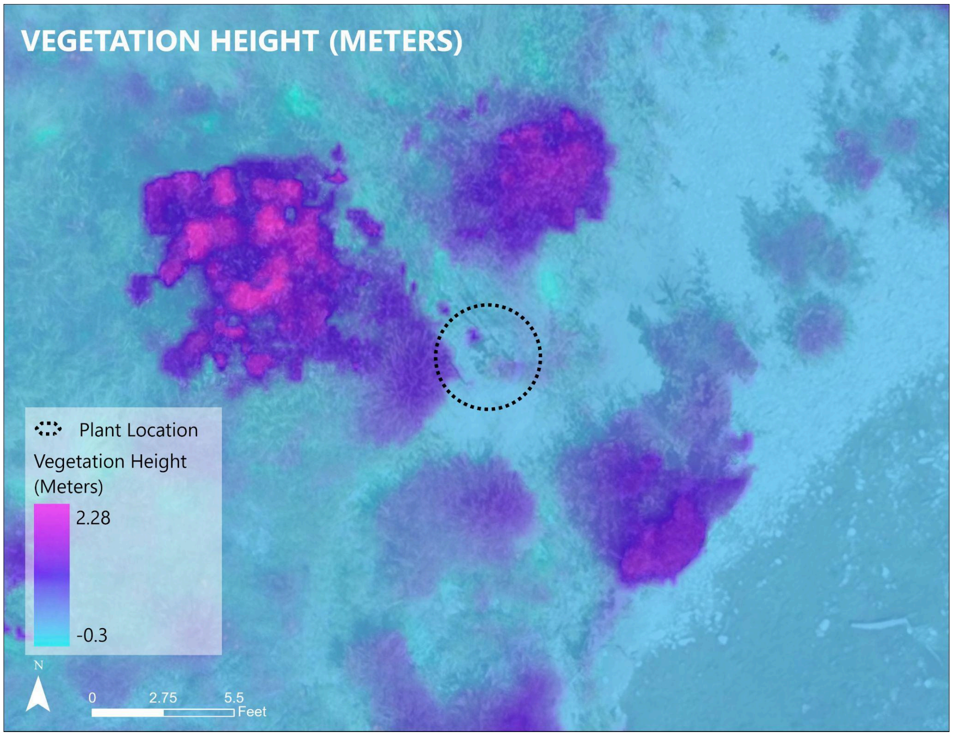


Figure 10. An example of the derived Vegetation Height layer using the sUAS elevation layers. Vegetation height can help assess growth of restoration plantings, which can be helpful for monitoring growth over time.

Additionally, the vegetation height raster allows for a comprehensive assessment of the restoration area and greater SAW habitat. It enables the identification of areas where plantings are thriving and areas where additional intervention may be necessary. By comparing vegetation height across different areas and time periods, practitioners can gain insights into the broader impacts of restoration efforts, such as changes in habitat structure and biodiversity.This targeted approach helps in making informed decisions about resource allocation, ensuring that efforts are focused on areas that need the most attention.

Recommendations, Benefits and Limitations

sUAS imagery can be an important tool for both planning and monitoring SAW restoration projects. It is useful not only to provide a synoptic view of a project site and the changing conditions, but provides a dataset that can be mined to investigate the status of issues as they arise. With high-resolution sUAS imagery and elevation layers, practitioners can efficiently assess restoration planting survival and health in a dynamic habitat.

To maximize the value of sUAS data products for monitoring, it is crucial to conduct surveys at the optimal time. Timing sUAS flights to coincide with the best environmental conditions for capturing restoration plantings can yield significantly better results. Practitioners are recommended to consider the phenology of the restoration plantings and surrounding vegetation to capture contrast within the imagery. Additionally, timing flight operations to occur at approximately solar noon helps eliminate shadows within the imagery, further enhancing data quality.

When done strategically, high-resolution imagery and elevation layers from sUAS surveys provide a more accurate representation of current on-the-ground conditions for monitoring restoration plantings. Beyond imagery and elevation layers, practitioners can derive vegetation indices and vegetation height layers, which are particularly useful for monitoring plant health and planning subsequent phases of planting or replacement plantings.

However, there are limitations to using high resolution UAS data for restoration monitoring. New growth can still be hard to detect, particularly on smaller plantings, and may require on the ground visual inspection to assess foliage on the lower stem. New plant recruitment would also be difficult to assess given the visual limitations of using aerial imagery for plant identification.

Overall, sUAS imagery and elevation layers enhance the ability to monitor and evaluate SAW restoration projects, offering a detailed view of plant growth and health. Drone flights offer a method of obtaining high-frequency monitoring data at a relatively low cost. By following best practices for flight surveys and analysis, practitioners can effectively leverage this technology to support successful restoration efforts.

Hydrogeomorphic Analysis

Comparison between the pre-implementation 2020 data (Pictometry International Corp. 2020) and the most recent 2024 sUAS survey reveals substantial developments and changes in the channel path and topography. One way sUAS surveys can be leveraged to analyze and record these changes is through virtual cross sections. Cross sections of elevation data over time can help demonstrate the changes that can be assessed by using data products from the sUAS surveys, as seen below in Figure 11. Figure 11 uses an elevation cross section over two years of elevation data, 2021 and 2024, to illustrate a significant change in the channel topography along a cross section of Arroyo Mocho in Medeiros Park.

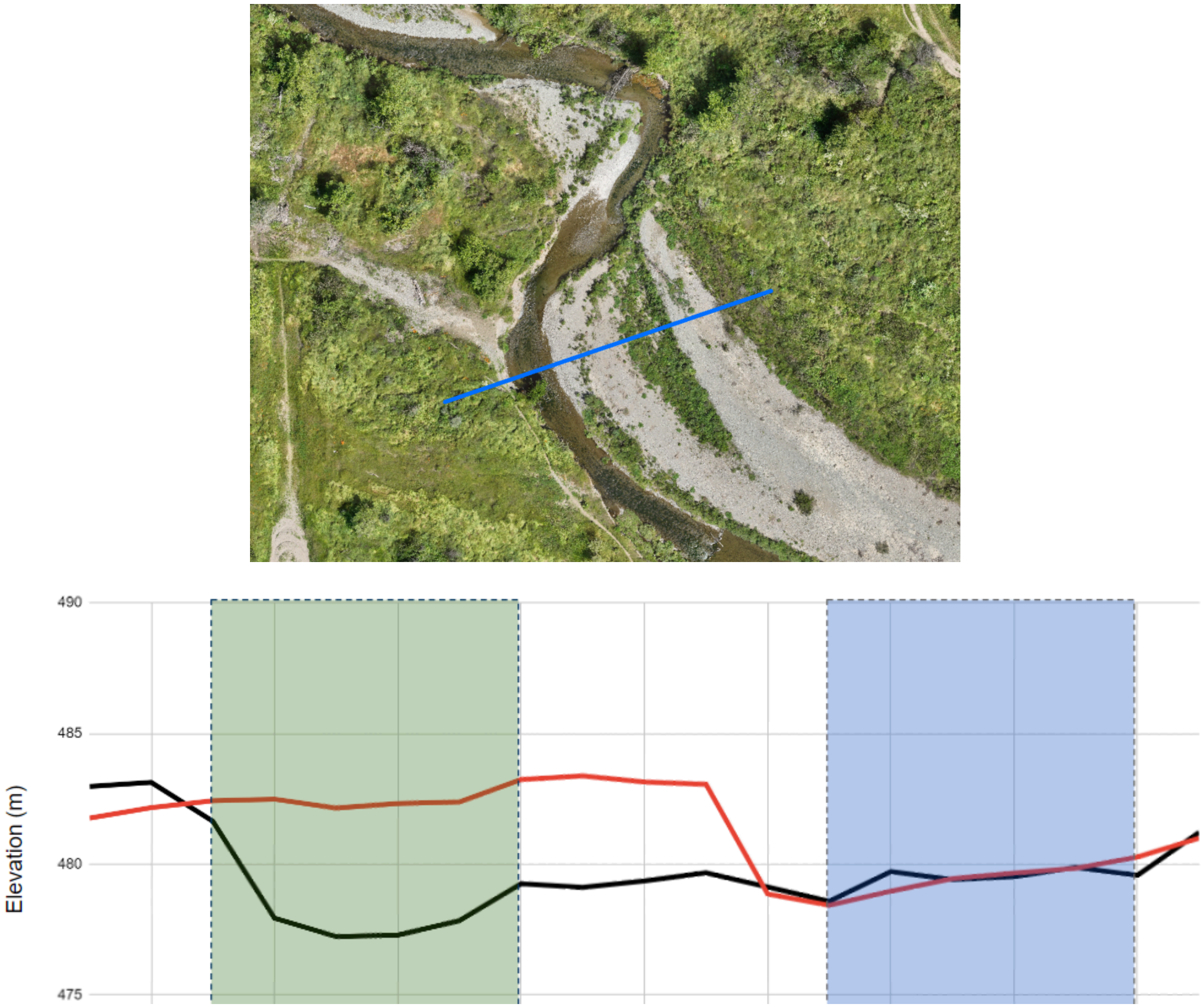


Figure 11. Elevation cross-sections of the USGS 2021 Alameda County LiDAR (red) compared to the SFEI 2024 sUAS-derived DTM (black). The blue rectangle represents the Active Channel zone previously delineated, and the green rectangle shows the active channel as it appears in the 2024 sUAS imagery and DTM.

Furthermore, sUAS elevation data can be used to delineate and update hydromorphic zone boundaries so that they retain accuracy throughout a restoration project. For this study, zones were delineated by hand in 2020 and confirmed through field work. The digitization was done using NAIP imagery from 2016. At the time of the plantings, which took place in 2023 and 2024, the zones had been digitized on imagery that was eight years old and confirmed by field work that had happened four years prior. Figure 12 underscores the importance of delineating important elevation-based boundaries using up-to-date elevation data. The low flow channel boundary, shown below in blue across Medeiros Park, no longer accurately reflects the channel path, and planting decisions based on these outdated borders may impact the survival rate of each plant.

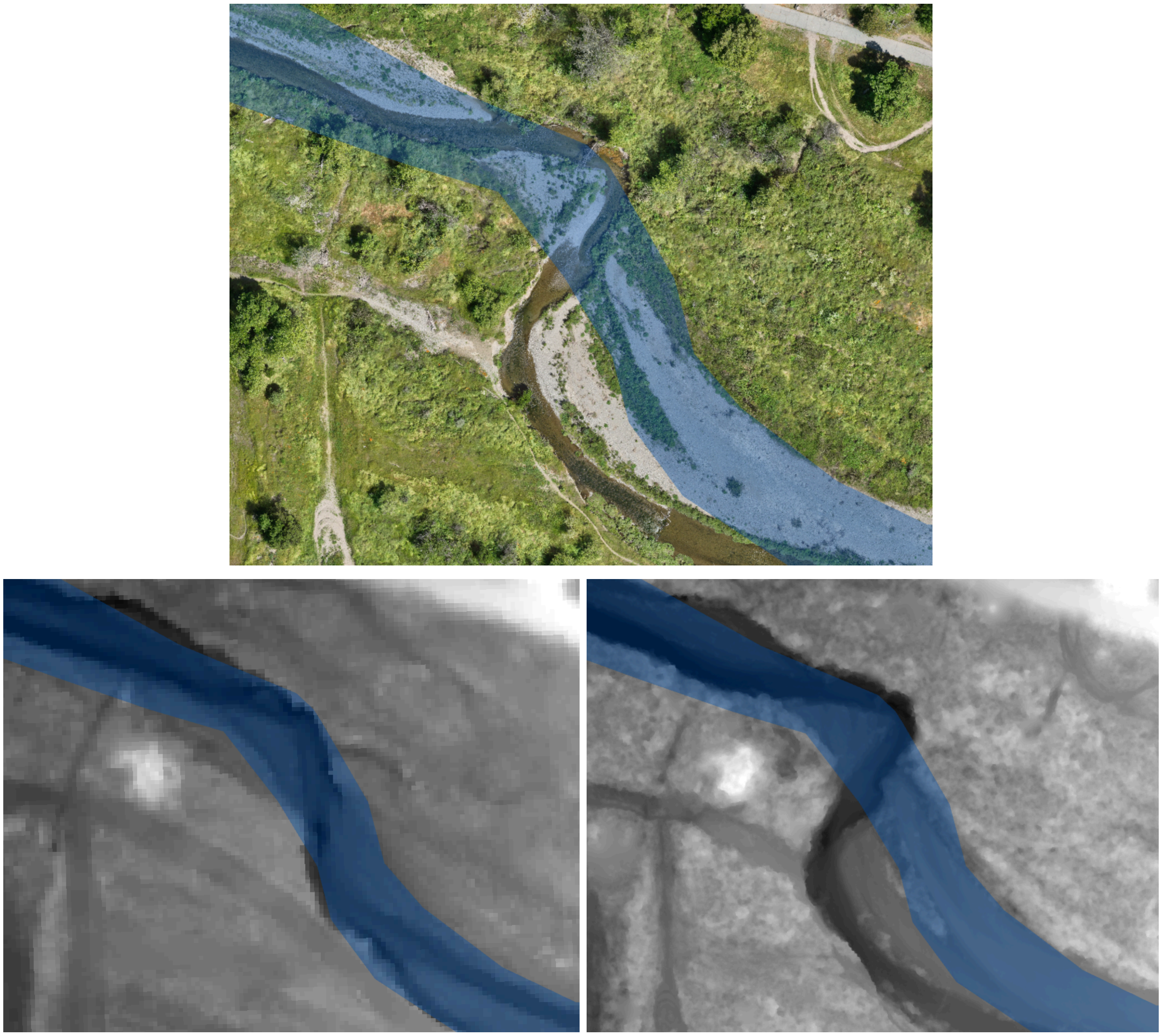


Figure 12. Medeiros Park. The Active Channel zone shown in blue, overlaid on the 2021 USGS Alameda County LiDAR (left) compared to the 2024 SFEI sUAS-derived photogrammetry based DSM (right) and the 2024 SFEI sUAS orthomosaic (top).

Temporal Resolution and Flexibility

sUAS surveys are particularly well suited for monitoring smaller-scale restoration projects as they can be deployed quickly and at specific times, ensuring timely data collection. This is particularly important for riparian restoration projects, where these dynamic habitats can rapidly change their channel paths and topography due to natural events or human activities. The ability to capture high-resolution, up-to-date imagery and elevation data allows for accurate monitoring of these dynamic environments, facilitating the assessment of a project’s restored vegetation health and hydrogeomorphic status. Furthermore, the relatively inexpensive cost of collecting data with a sUAS vs a plane mounted sensor allows for more frequent data collection and a more complete view of the change that occurs at a project location. This strength can be visualized with the example below, which shows a segment of the Arroyo Mocho that shifted significantly from the time of the 2021 Alameda County LiDAR flight and the SFEI sUAS flight.

Spatial Resolution

sUAS-based data collections can be used to generate high resolution elevation data. These datasets can be derived from true color cameras using photogrammetry processing (like the 2024 sUAS survey for this project) or by using UAV-based LiDAR sensors. Photogrammetry-based elevation data can provide the benefits of being cost effective while providing detailed elevation data, but lacks the high density laser return outputs of LiDAR that is often used to create highly accurate bare earth or DTM datasets. Most publicly available LiDAR datasets, such as those from the USGS 3D Elevation Program (3DEP), are collected using plane mounted LiDAR. While such LiDAR datasets can have higher spatial resolution and detail, they are expensive and are often used to produce lower spatial resolution products that are appropriate for county scale projects. UAVs can operate at significantly lower altitudes than planes, enabling them to capture data with finer resolution. In the study area, the best available USGS LiDAR has a spatial resolution of 1 m, significantly lower than the 0.065 m resolution of UAS-derived DEMs. Figure 13 draws a side-by-side comparison of the best available USGS LiDAR and the sUAS elevation data, illustrating the volume of detail lost with a spatial resolution that is over 15 times lower than that of the sUAS data.

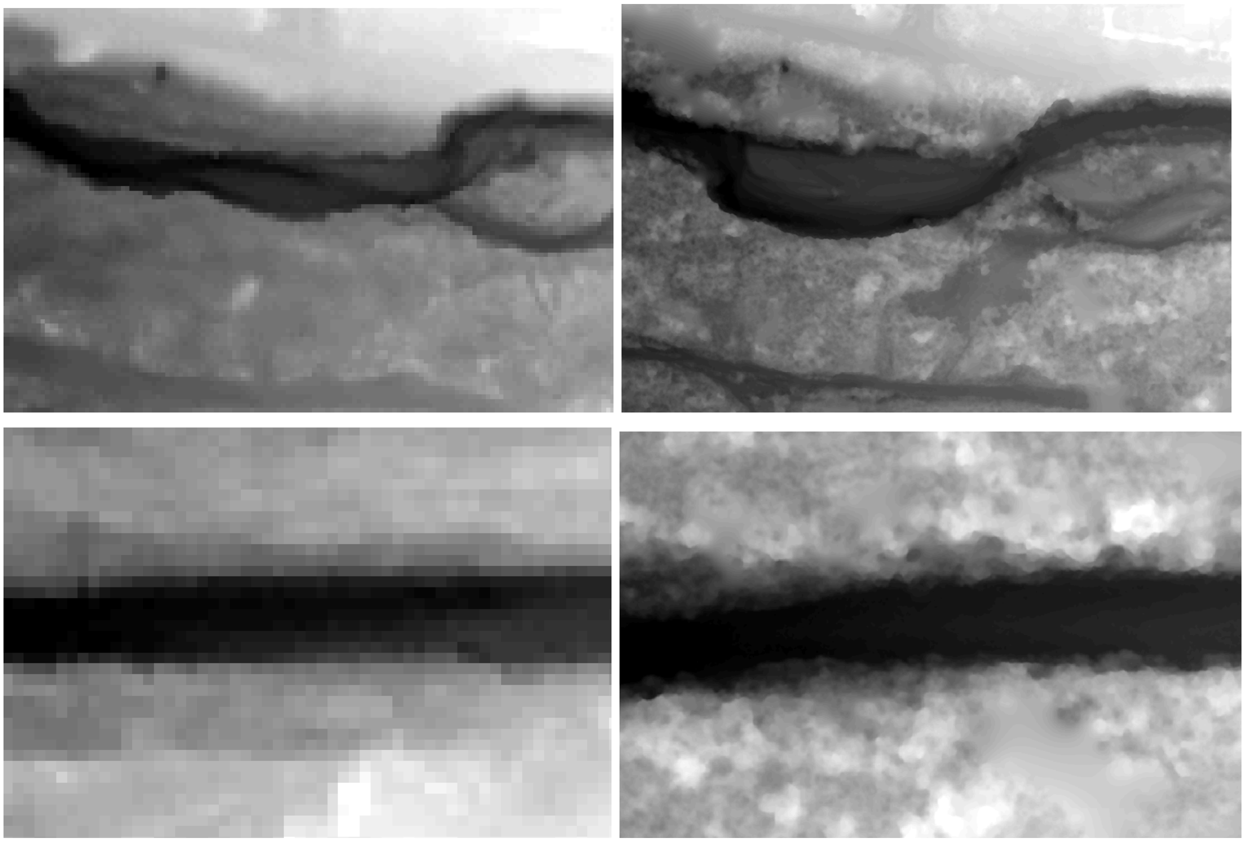


Figure 13. A comparison of the 1m resolution USGS 2021 Alameda County lidar (left) and the 0.065m resolution SFEI 2024 UAS-derived DSM.

Additionally, the USGS LiDAR dataset for Alameda County lacks a Canopy Height Model (CHM), essential for measuring vegetation height and monitoring the health and growth of planting restoration projects. The alternative Meta Global Canopy Height Map, with a 1 m resolution, is generated using imagery rather than LiDAR and has a mean error of 2.8 meters, making it unsuitable for accurately sensing the health of individual plants. Figure 14 provides a comparison Meta Global Canopy Height Map with the sUAS derived CHM along a site in Medeiros Park. While large-scale datasets are valuable for broad area projects, monitoring targeted restoration projects benefits substantially from the precise topographic information provided by high-resolution UAS-based elevation data.

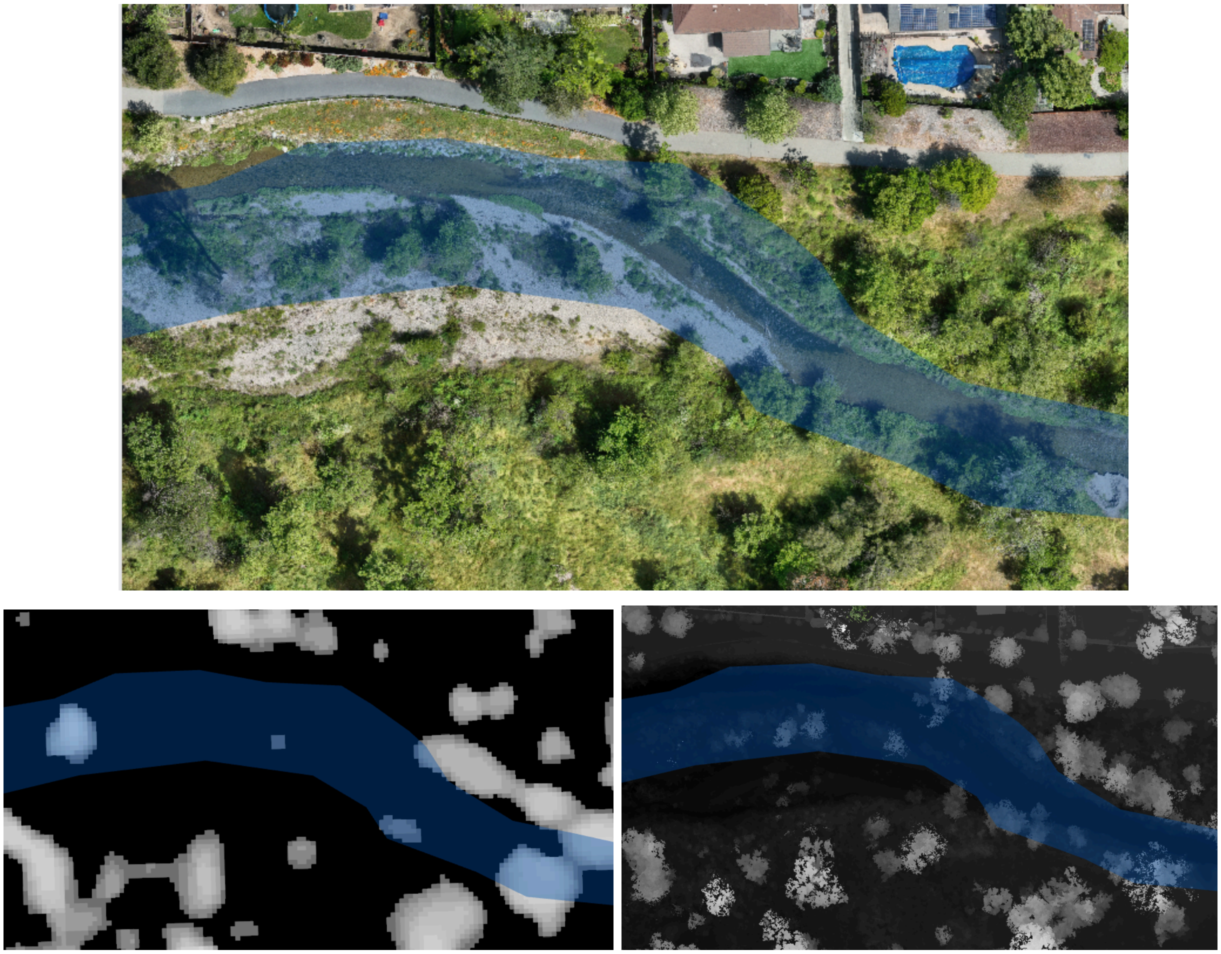


Figure 14. A comparison of the highest resolution Canopy Height Model (CHM) available, 2024 SFEI sUAS orthoimagery (top), the Meta Global Canopy Height Map (left) and the SFEI UAS-derived CHM (right). Both are shown with the Active Channel zone overlay in blue.

Discussion

The use of sUAS presents an opportunity to improve the efficiency, quality and timeliness of data to support riparian restoration projects. Using imagery and elevation data from sUAS can support planning and analysis for restoration and management practices. The changes observed along the Arroyo Mocho over just four years underscore the importance of up-to-date elevation and imagery data. Tasks such as delineating hydromorphic zones benefit greatly from up-to-date data, and sUAS surveys can be used to corroborate and check field-based data collections, such as cross sections, facilitating more informed restoration planning. sUAS surveys also provide valuable communication materials for the public and managers, offering high-resolution visuals to document the status of a site over time. This time-series style data can be revisited to address new questions that arise.

In the future, sUAS surveys could play an increasingly vital role in planning and monitoring riparian vegetation restoration. One promising application is the use of sUAS for detailed modeling and monitoring of channel migration and sediment erosion/deposition. For instance, comparing elevation data from 2019-2021 to that of 2024 reveals significant shifts in sections of the Arroyo Mocho, including areas with restoration plantings. sUAS surveys are well-suited for such projects due to their relatively low-cost deployment paired with their ability to capture high spatial resolution data and imagery, crucial for monitoring and modeling channel migration rates.

sUAS surveys may also be useful in monitoring sites after flooding or other disturbances. For example, between December 2022 and March 2023, the Arroyo Mocho experienced two major storm events that led to substantial bank erosion. Quick sUAS deployment could provide updated data to support efficient reaction and restoration plan adjustments to these events. Furthermore, changes in channel structure as a result of natural migration or other site disturbances could be used to estimate sediment erosion. sUAS may be used to improve sediment load models and calculations. Integrated into comprehensive management plans, sUAS survey data can support adaptive strategies that respond to real-time environmental changes, ultimately enhancing the efficacy and sustainability of riparian restoration projects.

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Appendix A.

2023 Pictometry (above) and the 2024 sUAS imagery (below) in Medeiros Park.

2023 Pictometry (above) and 2024 sUAS imagery (below) in Robertson Park.

Appendix B.

Point Data Table with Planting Status as Determined by sUAS Orthomosaic Imagery

Object ID	Year Installed	Propagule Type	Geomorphic Zone	Status in April 2024 sUAS Imagery
1	2023	Stake	Outer edge of inner floodplain	Present
2	2023	Stake	Inner floodplain	Unknown
3	2023	Seedling	Upper floodplain	Unknown
4	2023	Seedling	Upper floodplain	Present
5	2023	Seedling	High Upper floodplain	Present
6	2023	Seedling	Upper floodplain	Present
7	2023	Stake	Side of main channel	Unknown
8	2024	Seedling	Upper floodplain	Present
9	2024	Seedling	Upper floodplain	Present
10	2024	Stake	Inner floodplain	Unknown
11	2024	Stake	Inner floodplain	Present
12	2024	Stake	Inner floodplain	Present
13	2024	Stake	Inner floodplain	Present
14	2024	Seedling	Inner floodplain	Present
15	2024	Seedling	Inner floodplain	Present
16	2024	Seedling	Inner floodplain	Present
17	2024	Stake	Inner floodplain	Present
18	2024	Stake	Inner floodplain	Present
19	2024	Stake	Inner floodplain	Present
20	2024	Stake	Inner floodplain	Present
21	2024	Seedling	Inner floodplain	Unknown
22	2024	Stake	Inner floodplain	Present
23	2024	Seedling	Inner floodplain	Present
24	2024	Stake	Inner floodplain	Present

25	2024	Stake	Inner floodplain	Present
26	2024	Stake	Inner floodplain	Present
27	2024	Stake	Active channel	Unknown
28	2024	Stake	Active channel	Unknown
29	2024	Stake	Active channel	Unknown
30	2024	Stake	Active channel	Unknown
31	2024	Stake	Active channel	Present
32	2024	Stake	Active channel	Unknown
33	2024	Stake	Active channel	Present
34	2024	Stake	Active channel	Unknown
35	2024	Stake	Active channel	Present
36	2024	Stake	Active channel	Unknown
37	2024	Seedling	Active channel	Unknown
38	2024	Stake	Active channel	Unknown
39	2024	Stake	Active channel	Unknown
40	2024	Stake	Active channel	Present
41	2024	Stake	Active channel	Unknown
42	2024	Stake	Active channel	Present
43	2024	Stake	Active channel	Present
44	2024	Stake	Active channel	Present
45	2024	Stake	Active channel	Present
46	2024	Seedling	Active channel	Present
47	2024	Stake	Active channel	Present
48	2024	Stake	Active channel	Unknown
49	2024	Stake	Active channel	Present
50	2024	Seedling	Active channel	Present
51	2024	Stake	Active channel	Present
52	2024	Stake	Active channel	Present

53	2024	Stake	Active channel	Present
54	2024	Stake	Active channel	Present
55	2024	Stake	Active channel	Unknown
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57	2024	Stake	Active channel	Present
58	2024	Stake	Active channel	Unknown
59	2024	Stake	Active channel	Present
60	2024	Stake	Active channel	Unknown
61	2024	Stake	Active channel	Present
62	2024	Stake	Active channel	Present
63	2024	Stake	Active channel	Unknown
64	2024	Stake	Active channel	Unknown
65	2024	Stake	Outer floodplain	Present
66	2024	Seedling	Outer floodplain	Present
67	2024	Seedling	Outer floodplain	Present
68	2024	Seedling	Outer floodplain	Present
69	2024	Seedling	Outer floodplain	Present
70	2024	Seedling	Outer floodplain	Unknown
71	2024	Seedling	Active channel	Present
72	2024	Seedling	Active channel	Unknown
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81	2024	Seedling	Active channel	Unknown
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94	2024	Stake	Active channel	Unknown
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96	2024	Stake	Active channel	Unknown
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111	2024	Stake	Inner floodplain	Unknown
112	2024	Stake	Inner floodplain	Unknown
113	2024	Stake	Inner floodplain	Unknown
114	2024	Stake	Inner floodplain	Unknown
115	2024	Stake	Inner floodplain	Unknown
116	2024	Stake	Inner floodplain	Unknown
117	2024	Stake	Inner floodplain	Unknown
118	2024	Stake	Inner floodplain	Unknown
119	2024	Stake	Active channel	Unknown
120	2024	Stake	Active channel	Unknown
121	2024	Stake	Active channel	Unknown
122	2024	Stake	Inner floodplain	Unknown
123	2024	Stake	Active channel	Unknown