USING STRUCTURE FROM MOTION TO CREATE A HISTORICAL ORTHOMOSAIC OF FLAGSTAFF, ARIZONA FROM 1959

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A Practicum Report

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1. Introduction

1.1 Background: Flagstaff and Andre Faure

The Flagstaff area has been full of resources and a home to many people for a long time. For thousands of years, Flagstaff has been the homeland of many Native American tribes, and in 1848, Arizona became a territory of the United States. Between 1857 and 1860, Lt. Edward Beale explored the area to allow a railroad to come through. Congressional funding enabled the establishment of the transcontinental railroad. By 1882 Flagstaff became a railroad hub with industries such as lumber, ranching, and sheep herding using the railroad to distribute their goods (Discover Flagstaff, 2021).

Route 66 marked Flagstaff's transition to a tourism economy and the start of a population boom. In 1926, Front Street, the road that paralleled the railroad, became Route 66. A new economy emerged with auto shops, hotels, restaurants, and saloons lining Route 66 (City of Flagstaff). By the 1950s, the Arizona Normal College became Northern Arizona University, and Flagstaff's population increased by about 10,000 people (Fig. 1). The need for an urban planner became paramount to accommodate the population growth.

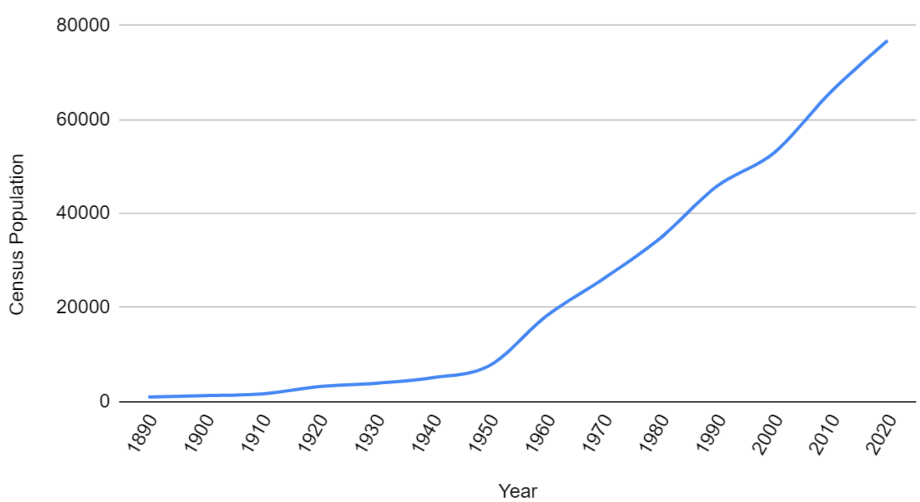

Figure 1. Flagstaff's decennial population from 1890 to 2020. (US Census Bureau)

An urban planner with prior experience in Arizona was referred. Andre M. Faure was born in Paris, France, in 1903 and moved to Erie, Pennsylvania, in 1904 with his family. He attended the University of Pennsylvania Towne School of Engineering, where he held various apprenticeships with planners, gaining valuable field experience. He first worked as a planner for Fairfield County, Connecticut, from 1932 to 1934 and in Montclair, New Jersey, from 1934 to 1940. He moved to Tucson, Arizona, in 1941 and became the planning director for the city of Tucson and Pima county in 1943. In 1947 he left Tucson and took a job with the Federal Housing Administration, where he served as a planning advisor while traveling in nine western states. He returned to work for Tucson and Pima county in 1951 and, after the two departments split, became the planning director for the city of Tucson. He also spent his time on draft reports and plans for the cities of Flagstaff, Williams, Fredonia, and Sedona. He retired in 1968 and continued to work as a private consultant (Andre M. Faure Collection, 1925-1968).

There is potential to learn about future planning needs based on the past. During Andre Faure's time in Arizona, he served as a consultant for the city of Flagstaff and for Coconino County in 1948 and 1958, respectively. He helped draft the city's first zoning ordinance and proposed zoning, regulations, and subdivisions. As part of his planning process, he utilized aerial photographs of Sedona, Williams, and Flagstaff. These photographs are now a part of the Special Collections and Archives Department in the Cline Library at Northern Arizona University. The combination of these photographs with current maps and aerial imagery reveals drastic landscape changes.

1.2 Purpose: Unboxing history

Historical aerial photographs can be used to track land-use change. High-resolution satellites and modern aircraft imagery are widely available online; however, their temporal scale is limited. Most modern satellite imagery only goes back to the early Landsat mission of the 1970s (Morgan et al., 2010). On the other hand, historical aerial photographs provide the longest available record of land-use change. Still, since recently, these photographs have required manual methods to be reconstructed into a landscape of several photos, a process that requires time and expertise (Wulder 1998). The recent development of digital techniques like structure from motion facilitates and enables the efficient reconstruction and analysis of historical landscapes.

1.3 Practicum Objectives

1. Identify Andre M. Faure aerial photographs that cover the City of Flagstaff
2. Scan the selected photographs into digital format at their highest resolution
3. Process the images with Agisoft Metashape using structure from motion for photo alignment and creation of an orthomosaic
4. Georeference the images in a Geographic Information System mapping software
5. Analyze areas of significant change between 1959 and 2021
6. Produce an online product to share with the NAU Cline Library

1.4 Practicum Scope

The guiding principle throughout the process is to create a clean orthomosaic of historical photos that lack camera calibration typically required for traditional photogrammetry. The method should be repeatable for use on other sets of historical photos. Further, this should demonstrate how structure from motion can be an efficient and cost-effective way for others to process historical images for use in a GIS. The methods were broken down into four parts: collecting the photographs, processing the imagery using the software Agisoft Metashape, georeferencing the Metashape output in ArcGIS Pro, and conducting a spatial analysis comparing some of the land-use changes from 1959 to 2021.

The practicum delivers an orthomosaic limited to the area around Flagstaff, Arizona (Fig. 2). The analysis will consist of looking at two areas that have changed significantly since Faure's photos were taken. The Rio de Flag, in what is now the Cheshire neighborhood, and the campus of Northern Arizona University.

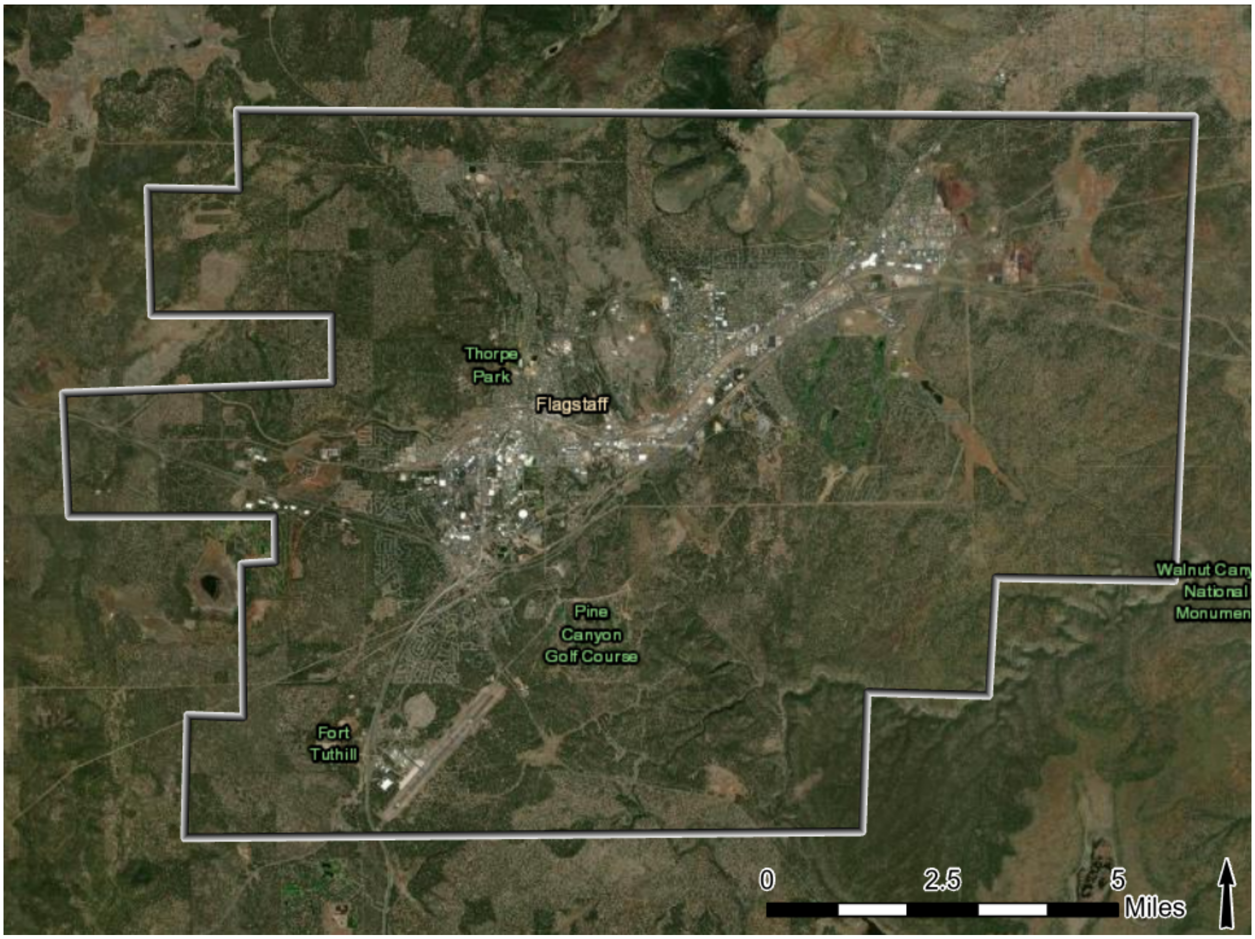

Figure 2: Area covered by Faure's photos around Flagstaff. Approximately 170 square miles.

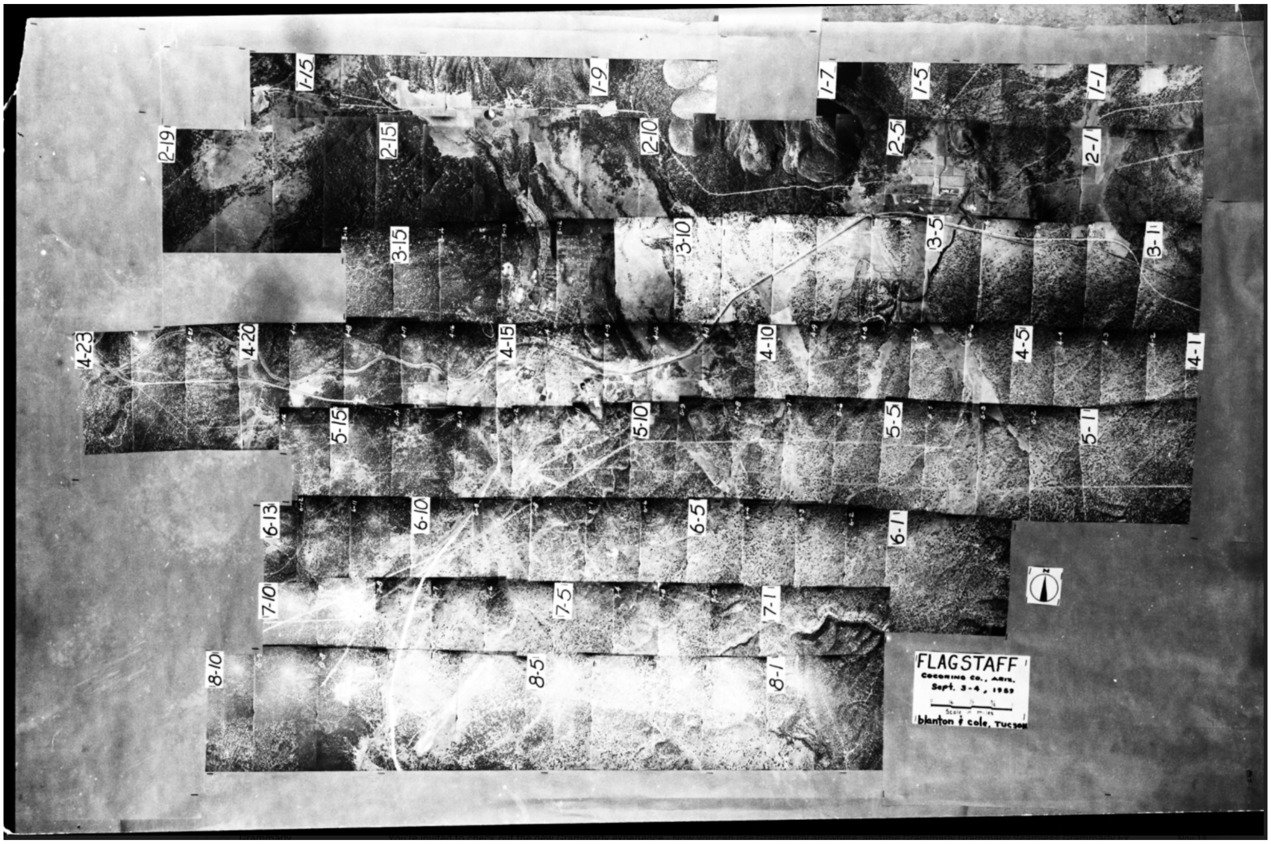

Figure 3: One hundred and twenty one photos mosaiced together on a table.

1.5 Project Justification

Cost and time constraints are likely the reason Faure decided to use aerial photography for his work in 1958 and 1959. Faure took aerial photographs using a film camera mounted to an airplane. While there are no specifics on the camera or aircraft used, the photos indicate professional acquisition; the images contain fiduciary marks that signify a photogrammetric camera, and the 8 x 8-inch print size was common for aerial cameras of that time. In 1958 and 1959, when these photos were ordered, acquired, and used for analysis, they would have been looked at individually or laid on top of and next to each other on a large table. With modern computers and software, these photos can be aligned together in one continuous image.

Cost and time constraints are still relevant today. Photographs decay over time, the paper shrinks, the colors and contrast fade. The images have been scanned into a digital collection already but vary in size, making them difficult to work with for photogrammetry. Having the opportunity to work with scans of the originals allows for them to be used for photogrammetry. Using low-cost, modern software, the photos can be geometrically accurate and then preserved as not just photos but as a usable GIS layer in a timely manner.

The photographs have the potential to tell a visual history of Flagstaff land use over time. Making them more accessible by creating a digital orthomosaic means more people will be able to view the imagery. From citizens interested in the past to current county and city urban planners, the photos will create a dataset that can be applied to tell the history of Flagstaff. By looking at how the city has expanded in the past, current planners can potentially have more information feeding the decision-making process of how they want to develop in the future.

2. Literature Review

2.1 Aerial Photography

French photographer and balloonist Gasper Felix Tournachon, or 'Nadar', took the first known aerial photograph in 1858. (Professional Aerial Photographers Association, 2021). He used a balloon with a large format black and white camera, with a darkroom built into the balloon due to the way images were developed back then. The image no longer exists from that flight, but it caught the attention and interest as others continued to find ways to take aerial photographs.

Equipment was the limiting factor to early aerial imagery as cameras were heavy and required certain conditions for exposure, and lifting the camera off the ground in a controlled manner was not easy. Balloons were first used, and later kites, pigeons, and rockets as technology evolved (Verhoeven, 2009). Wilber Wright was in Italy in 1909 and carried a passenger that took the first known image from a fixed-wing aircraft (Professional Aerial

Photographers Association, 2021). During World War I aerial photographs replaced sketches by aerial observers and saw the manufacturing of cameras, specifically for use in airplanes. Aerial photos were used to make maps of enemy lines, trenches, barbed wire, and weapons placement. After the war, this technology was brought to the private sector and found to be cheaper than conducting ground-based surveys (Crawford, 1926).

The quality and resolution of an aerial photograph are directly related to the camera and film used to capture the images (Morgan et al., 2010). Large format cameras with long focal lengths were typically used. A possible camera from the time that Faure could have used was the Fairchild T-11 with a 9 inch (230 mm) negative format, a 6-inch lens, and a 152.4mm focal length (Perez et al., 2014). This camera was in production from 1951 to 1954 and had over 1100 produced, so it would have been widely available. A camera like this could have recorded up to 600 rolls of film with a high spatial resolution.

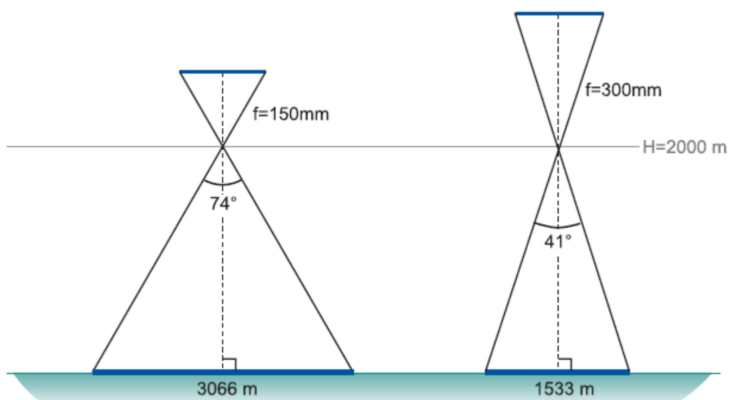

Figure 4: Focal length determines the field of view for the captured image.

Image from Bakker et al., 2009

Because aerial photos are typically taken as a series of photographs, most flights have specific procedures. The aircraft will fly a predetermined flight path that either follows east-west or north-south directions. At the end of each pass, a 180-degree turn is made, the following pass is made above or below the previous one (Fig. 5). The flight pattern is followed until all the images are collected (Paine et al., 2012). During each pass, the photos will be numbered to keep them organized and know which photo goes next to each other. Each photo overlaps 50-60% along the flight line and 15-30% between flight lines (Fig. 6).

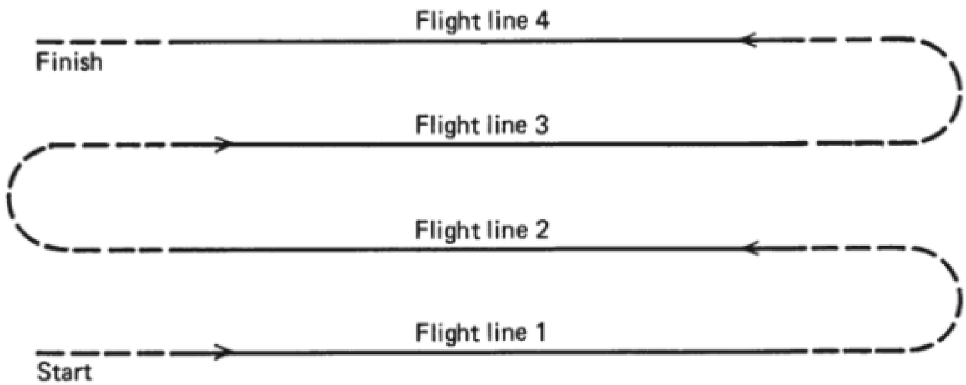

Figure 5: Example flight path used for aerial photo collection. Image from Paine et al. 2012

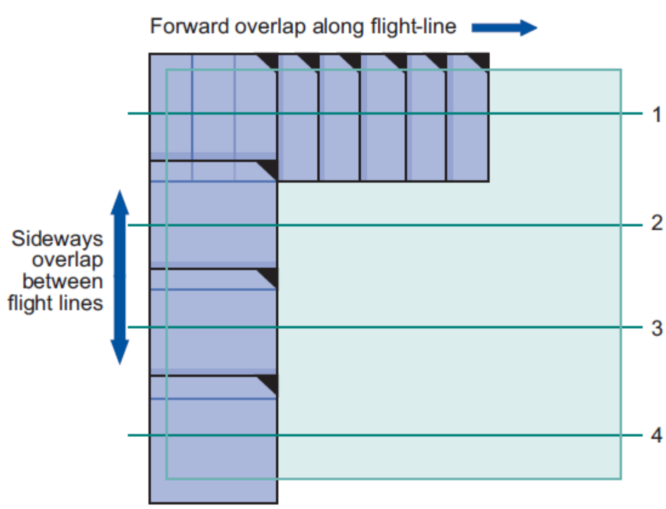

Figure 6: Example of photos overlapping with flight lines. Image from Bakker et al.,2009

Additional data will be collected either on one piece of film that will stay with the collection of photos or on each photo. Each photo, at minimum, will have a set of fiducial markings that indicate reference points for each photograph. These markings are used to correct photo distortion using the interior orientation process. Other data for the images could be the time captured, altitudes, frame number, focal length, among other things (Fig. 7). This data is used to determine the scale of the image, making distance and area calculation possible.

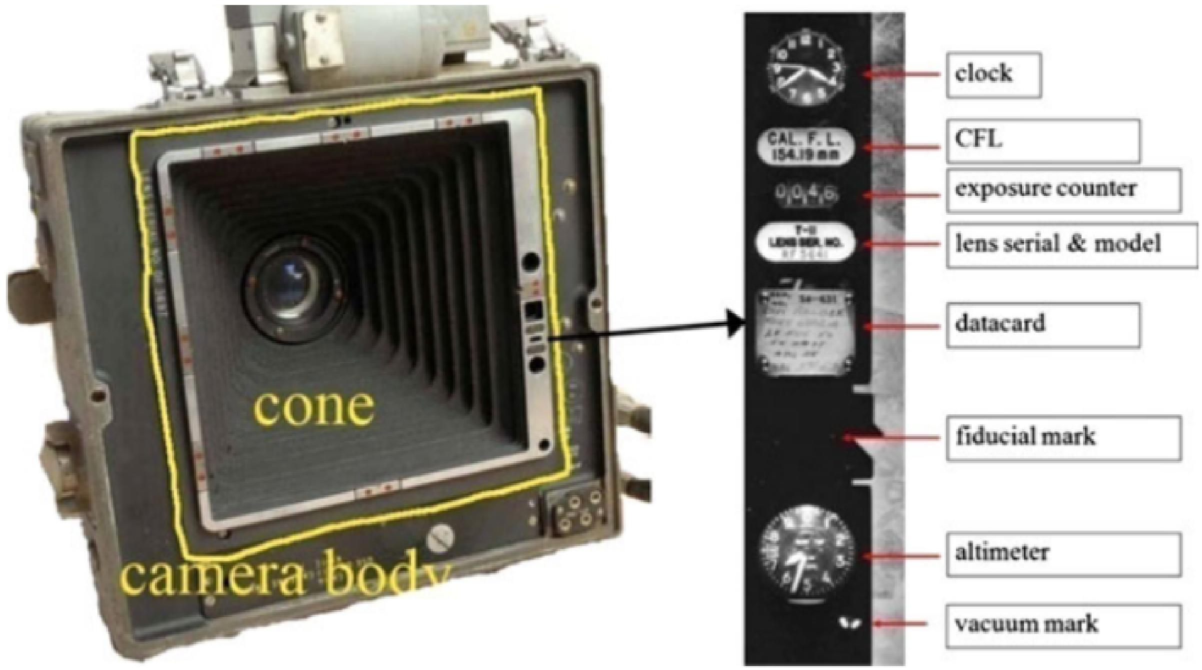

Figure 7: Example of a camera body used for aerial photography and information that would be included and printed on the images. Image from: Pérez et al. 2014

2.2 Digitizing aerial photographs

Film photographs can be digitized by scanning (Wolf and Dewitt, 2000). Some photogrammetric-specific scanners are big and expensive, but other high-quality scanners can produce products suitable for interpretation needs. Images can lose resolution, color, or tone in the scanning process, so it is crucial to have a high-quality scanner that can maintain the resolution of the original imagery. It is essential to balance the resolution with needed outputs. Too low of a resolution will cause missing data, and too high resolution creates a very large file size (Morgan et al., 2014).

2.3 Photographic errors

Geometric and radiometric errors can limit photograph use. Errors can occur during the capturing and digitizing of photographs (Morgan et al., 2014). Geometric errors are those created from distortion or displacement. Distortion refers to lens distortion such as a fish-eye effect, film or print shrinkage in old photographs, or atmospheric refraction of light. Displacement can be caused by the curvature of the earth, the tilt of the camera, the tilt of the aircraft, or extreme topographical features. Radiometric errors refer to those caused by the camera or the environment. The camera can have reflectance, poor exposure, or be poorly attached to the aircraft. The environment can cause errors in the form of clouds, the angle of the sun, or atmospheric haze. (Paine et al., 2012).

Table 1. This table presents common photographic errors. Table from Paine et al. 2012

Type of error	Systematic	Random
Geometric		
Distortion	Lens distortion (more common on old photographs)[a] Image motion compensation (typically occurs on high spatial resolution photographs)	Film or print shrinkage (occurs on historic photographs or film)[a] Atmospheric refraction of light[a]
Displacement	Earth curvature[a]	Topographic/relief displacement (more obvious in mountainous areas) Tilt displacement (especially problematic for oblique photographs) Detector error (roll, crab/yaw, pitch)[a] Typically affects older aerial photographs
Radiometric		
Sensor	Exposure falloff Sensing geometry	Bidirectional reflectance (e.g., hot spot effects and mutual shadowing)
Environment	Atmospheric (haze)	Clouds Sun angle (worse for photographs taken off solar noon)

a. Errors generally considered to be negligible or accounted for during processing.

2.4 Photo alignment and orthorectification

Georeferencing is the process of defining the image's location. The method consists of using map coordinates and assigning a coordinate system to the map frame (Overview of

Georeferencing—ArcGIS Pro | Documentation, 2021). This process enables the imagery to be viewed, queried, and analyzed with other geographic data.

A mosaic is a series of photographs stitched together to match the detail of all of the adjacent photographs. For example, there are one hundred and twenty-one photographs used in this project. A landscape is created by aligning all of the photographs while utilizing the standard overlap they have. Instead of viewing one photograph at a time, the entirety of the collection can be viewed in a seamless mosaic across the Flagstaff area.

Orthorecitifying corrects geometric displacement. Orthorectification manipulates a photograph by adding x, y, and z coordinates (Lillesand et al., 2015) compared to georeferencing that only looks at x and y horizontal coordinates (Morgan et al., 2014). Orthorectifying a single aerial image can be a time-consuming endeavor even when there is aircraft and camera information; it can take even longer when there is no information. The Cline Library Special Collections has all the photos Andre M. Faure took, but they are not spatially referenced, have no camera information, and exist only as single images. The most information there is about a single image is the legal description within the photo area. Some of the images are not oriented north. Because aligning and orthorectifying a large number of images can be time-consuming and complex, and due to the lack of camera information, there have been relatively few land use studies using historical aerial photographs (Nita et al., 2018).

2.3 Structure from Motion

Structure from motion utilizes matching features to align photos and orthorectify a scene or landscape. By looking at overlapping images with points that exist in multiple images, points are aligned and given depth through stereo pairing. The algorithm used can efficiently produce a reconstruction of a series of images. It works best with images with a high degree of overlap across a large scene viewed from many different positions (Westoby et al., 2012). This is done by having a moving sensor across a fixed feature. In this project, the moving sensor is the camera on an aircraft flying over a fixed landscape (Fig. 8).

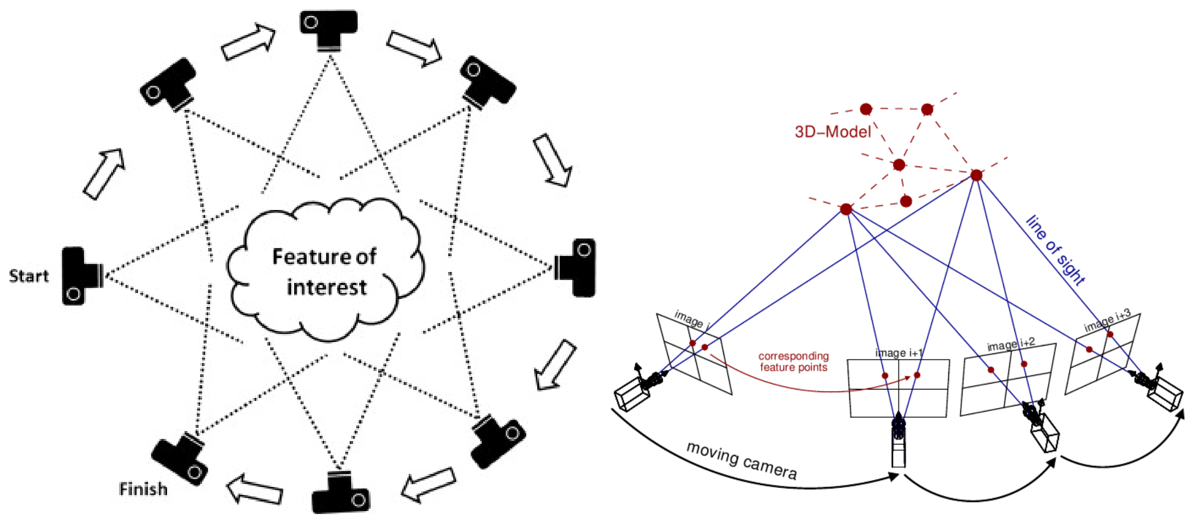

Figure 8: Structure from Motion (SfM). Instead of a single stereo pair, SfM requires multiple, overlapping photographs as inputs to feature extraction and 3-D reconstruction algorithms. Source: Westoby (2012) and Theia-sfm.org (2016)

Traditional photogrammetric methods rely on a series of known ground control points and known elevation (Westoby et al., 2012). Structure from motion does not need ground control points or elevation; images are aligned, and geometry is reconstructed based on matching points in overlapping images (Peterson, 2012). These points are tracked from image to image and provide estimates for camera location and coordinates which are defined using non-linear least-squares minimization (Snavely 2008).

With no ground control points, there is no scale or orientation in the structure from motion reconstruction (Westoby et al., 2012). The images are aligned in a 3-D space that needs to be referenced later. This is done by exporting the structure from motion result as an image and importing it into GIS software. From there, visual reference points can be assigned, such as building corners, roads, or other features that remain constant from the historical imagery to the present imagery.

3. Methods

3.1 Photograph collection

The Cline Library has a repository of historical documents. The Cline Library Special Collections and Archives on the campus of Northern Arizona University has historical documents of Northern Arizona, Flagstaff, and the Colorado Plateau, among others. These documents consist of maps, newspapers, letters, interviews, films, and photographs. Some collections' items have been digitized, but others are only available in a physical format. This is the case of Andre M. Faure's photo collection. The staff at the Cline library were immensely helpful with this project, scanning each image at 800 dpi and sharing them via Google drive. The scanning resolution was determined by the library as capturing the resolution of the parent image while using excess disk space. Each image was black and white and 8 x 8 inches in size (Fig. 9) for a total of 121 photos requiring about 42.9 GB in disc space.

Figure 9: Example of aerial photo image as obtained from the Cline Library Special Collections. Image location is over the west side of Flagstaff.

3.2 Image processing

The software Agisoft Metashape (version 1.7, 2021) was used for image processing. Photos were aligned through feature detection and placed into the workspace in Metashape called a “chunk” (Fig. 10).

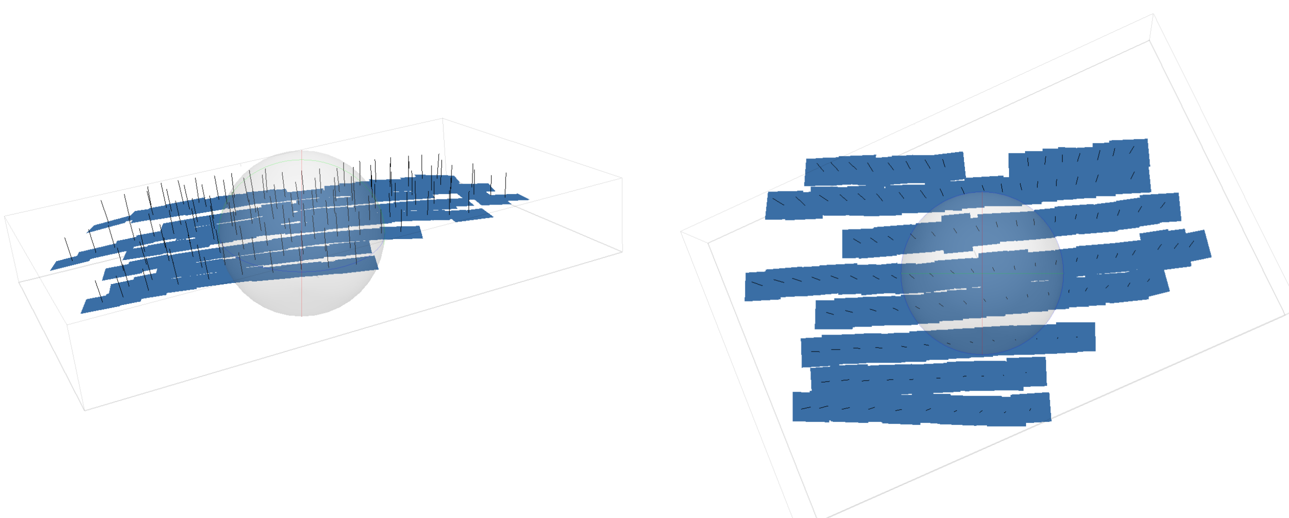

Figure 10: Photo alignment in Metashape and initial alignment inside the chunk.

Photos were inspected to see if any were incorrectly aligned. Once photos were verified for placement, a mask was placed on the black edge of each photo so it would not be detected in further steps (Fig. 11). Black edges of photos can be counted in the software as meaningful pixels and affect the end mosaic by appearing as black streaks or as invalid markers. The mask maintains a consistent image size that works best with structure from motion while making the black edge and fiduciary marks irrelevant during processing.

Figure 11: An example of a masked photo. The black edges are still visible but the whit line between the image and black edge effectively cuts the balck edge off from further processes.

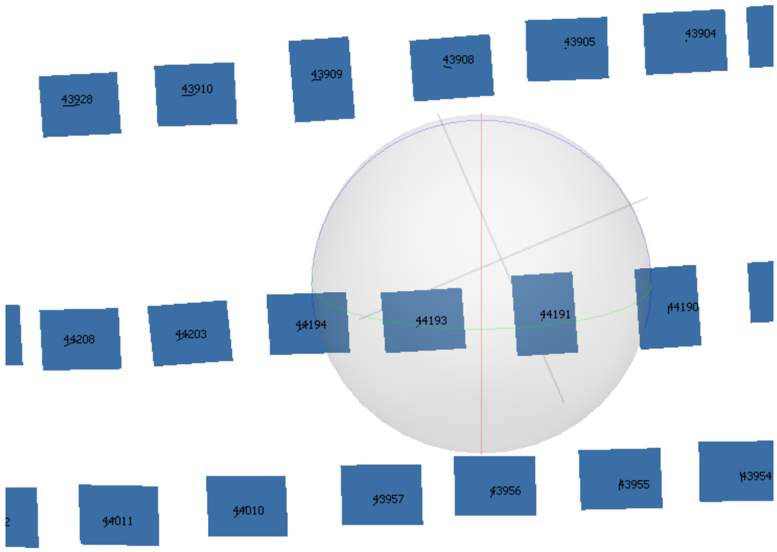

Figure 12: Zoom in to the initial alignment revealing that some scanned images have different orientations but are in the correct placement. Image 43909, the third image from the top left, illustrates a vertical orientation.

Photos were then given manual markers to help with alignment. The markers serve to identify the same point that appears in different photos. The same point exists in multiple photos due to the overlapping of the images. The software does a good job of finding matching points but the end product is made better by providing some manual markers. An effort was made to have at least one marker in each photo. A total of 67 markers were used through the area covered (Fig. 13). The number of markers was not planned. It was the result of having at least one marker in every photo and marking easily identifiable points. In urban areas, constructed features such as streets, building corners, rooflines, and fences were used as markers. As the images covered more rural areas, some dirt roads or water tanks from cattle grazing were used. Features with significant height were avoided as distortion, lighting, and shadows were not consistent from image to image.

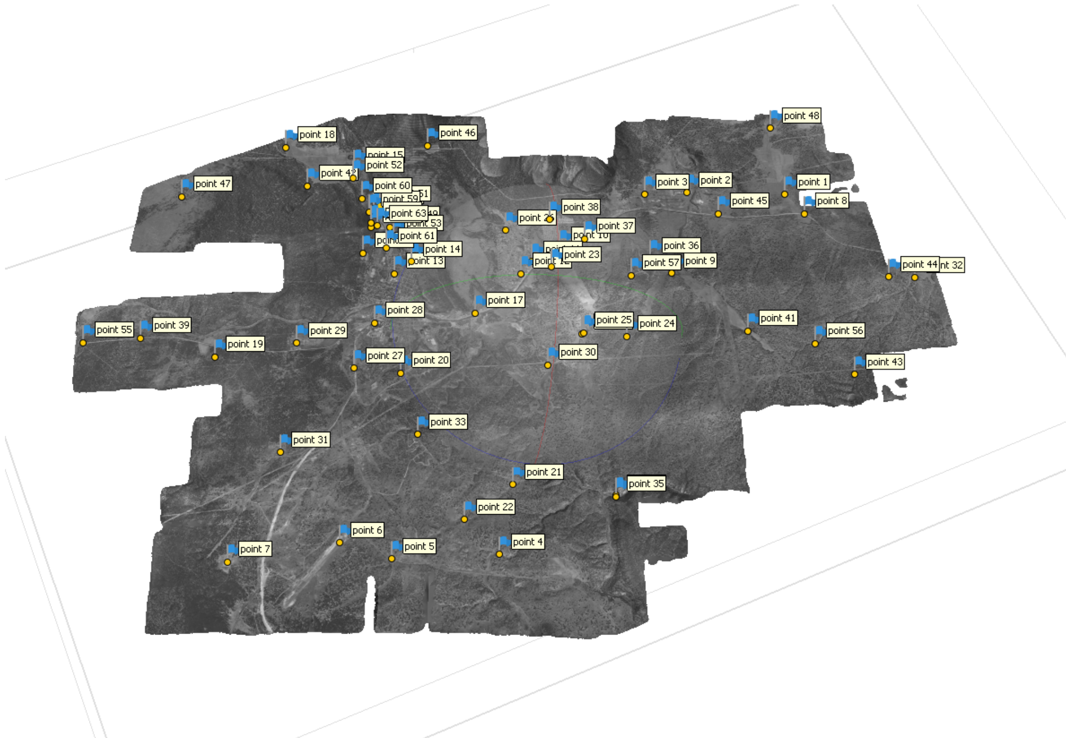

Figure 13: Using 67 markers to reference the images together.

Alignment of the masked photos was done with high accuracy, a key point limit of 40,000, and a tie point limit of 10,000. Key points are a point on the photograph that the algorithm determines to be an important feature typically based on contrast or texture. Tie points are matches of points between images that are used to generate three-dimensions relative positioning. By setting the limits you are setting the quality of the output and cost of computation. Stationary tie points were excluded. These parameters were selected because they work with the original resolution with no upscaling or downscaling.

With no camera information, a point cloud was generated (Fig. 14). The dense point cloud is based on depth maps calculated using stereo matching. Depth maps are calculated using overlapping image pairs. Combined depth maps generated for each camera are transformed into partial dense point clouds, which are then merged into a final dense point cloud with additional noise filtering steps applied in the overlapping regions. The normals in the partial dense point clouds are calculated using plane fitting to the pixel neighborhood in the combined depth maps, and the colors are sampled from the images. (Agisoft Metashape User Manual, 2021). The parameters for building the dense cloud were high quality with mild depth filtering.

Figure 14. This is the dense point cloud. Some of the points fell below the main surface and can be deleted entirely or removed with manual markers.

The mesh was built using dense cloud data with an arbitrary surface type. A high face count was used, and interpolation was enabled. Using the dense point cloud results in higher quality output. The arbitrary surface type was used because the images have many surfaces from buildings to land cover. This takes more memory but yields a better result for this purpose. Interpolation was used to fill any holes that existed in the dense cloud while a high face count was used to help in the final visualization. The texture was run using the model.

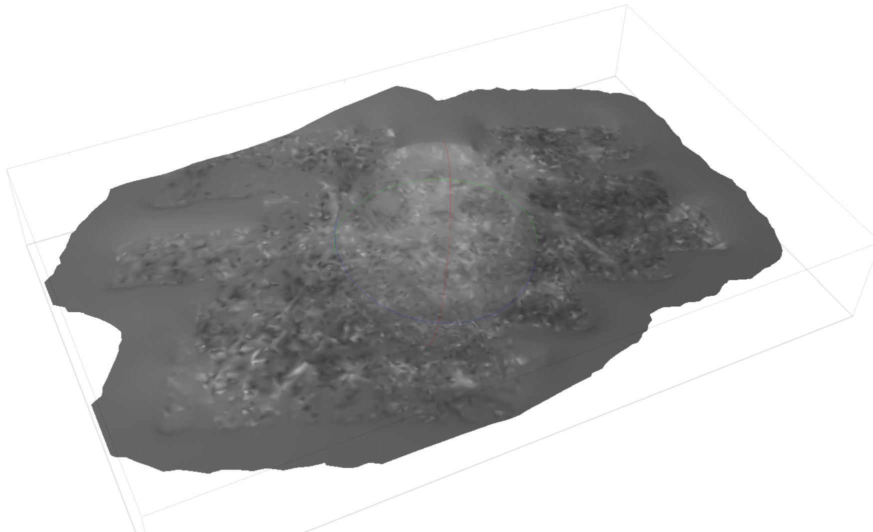

Figure 15: Building the Mesh

A tiled model was built using depth maps and high quality. The default pixel size was used as well as the tile size as there was no camera reference at this point. This time a medium face count was used to save some processing time with minimal effects on the result.

Once complete, the outputs were used to build the orthomosaic . No projection or coordinate system was used. Hole filling was turned on to help make a seamless mosaic image. Pixel sizes were left as default, and the final orthomosaic was exported as a tiff (Fig. 16).

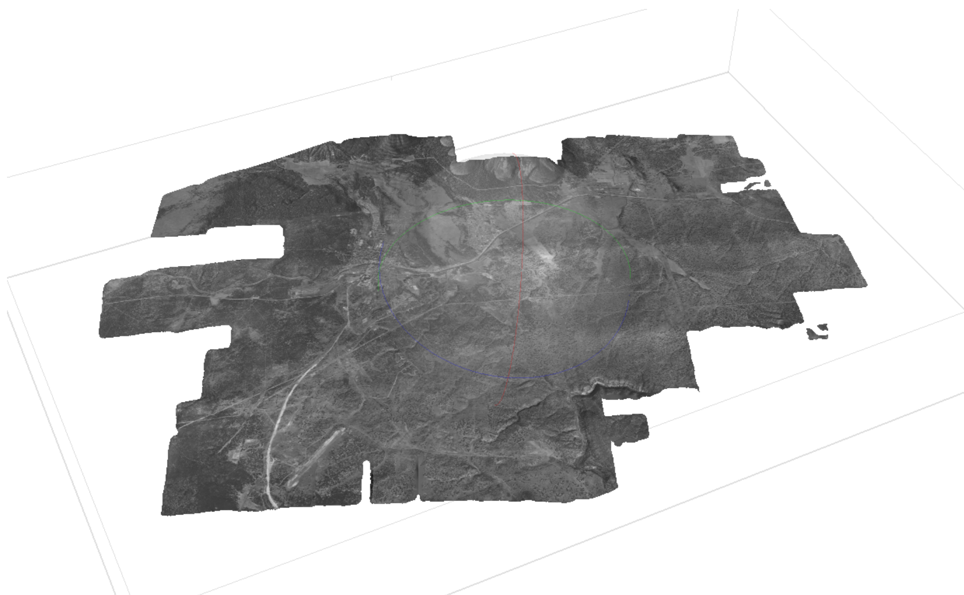

Figure 16: The final orthomosaic inside the chunk.

3.3 Georeferencing the orthomosaic

The historical images in the Faure collection did not have spatial reference information, so they needed to be georeferenced. Because orthorectifying a large number of images can be time-consuming and complex, and due to the lack of camera information, there have been relatively few land-use studies in northern Arizona using historical aerial photographs (Nita et al., 2018). An alternative for orthorectifying the Faure photos is the use of Structure from Motion (Ullman 1979). The process started importing the tiff images into ArcGIS Pro version 2.8. Natural color NAIP imagery was added from the ESRI Living Atlas. The resolution of this imagery is 1 meter or better, and its spatial reference was WGS 1984 Web Mercator. This is not a great reference for analysis, as mercator maps can distort shape and size, but will be used as a first step and later for web products.

Attempts were made to project the NAIP imagery to NAD 1983 UTM zone 12N, but the tool failed. This may be a limitation of the computer being used for image processing. The base map was changed to the imagery base map used in ESRI software. This imagery is produced from inputs from various partners but ranges from 0.3 to 0.03 meters in resolution.

Two georeferenced images were produced of the Faure orthomosaic. One in WGS 1984 Web Mercator and one in NAD 1983 UTM Zone 12 N. The NAD 1983 was used for all spatial calculations and analysis.

A total of eighteen control points were used and second-order polynomial transformation (Fig. 17). This led to a minimal amount of distortion, considering the size of the area covered. The total RMS errors:

Forward: 11.55 m

Inverse: 9.73 m

Forward-Inverse: 1.59 m

Source X	Source Y	X Map	Y Map	Residual X	Residual Y	Residual
-12,428,335.22	4,191,458.91	-12,428,333.03	4,191,461.43	1.50	-8.23	8.37
-12,424,847.84	4,192,537.25	-12,424,770.72	4,192,572.06	-8.15	9.67	12.64
-12,415,955.24	4,193,631.24	-12,415,436.73	4,193,507.54	-5.29	1.22	5.43
-12,416,423.32	4,196,688.33	-12,415,862.36	4,196,848.10	-2.44	-13.21	13.43
-12,418,697.64	4,197,140.97	-12,418,326.18	4,197,401.09	-26.70	4.86	27.14
-12,417,076.26	4,197,114.03	-12,416,554.97	4,197,346.34	3.06	5.05	5.90
-12,416,684.05	4,197,176.18	-12,416,108.74	4,197,403.83	26.58	2.13	26.66
-12,429,983.17	4,196,379.67	-12,430,206.35	4,196,508.15	2.10	-2.15	3.00
-12,430,134.64	4,195,605.20	-12,430,321.85	4,195,709.77	3.29	1.15	3.48
-12,434,528.89	4,190,067.26	-12,434,556.78	4,190,034.65	-5.97	5.72	8.26
-12,430,166.94	4,189,885.52	-12,430,168.39	4,189,867.59	-0.78	-4.45	4.52
-12,429,187.50	4,190,918.24	-12,429,192.35	4,190,917.73	1.05	-1.02	1.47
-12,429,208.17	4,190,953.35	-12,429,217.07	4,190,952.60	-2.07	-1.98	2.86
-12,429,279.69	4,190,536.04	-12,429,279.68	4,190,528.80	1.04	-0.80	1.31
-12,428,854.28	4,190,808.20	-12,428,854.84	4,190,804.75	-1.77	-0.84	1.96
-12,428,618.59	4,190,715.67	-12,428,612.64	4,190,706.48	-0.40	-3.60	3.62
-12,428,526.40	4,189,198.93	-12,428,489.52	4,189,169.64	16.99	6.98	18.37
-12,432,937.20	4,182,060.71	-12,432,905.87	4,182,135.97	-2.08	-0.49	2.14

Table 2: Table of the eighteen control points.

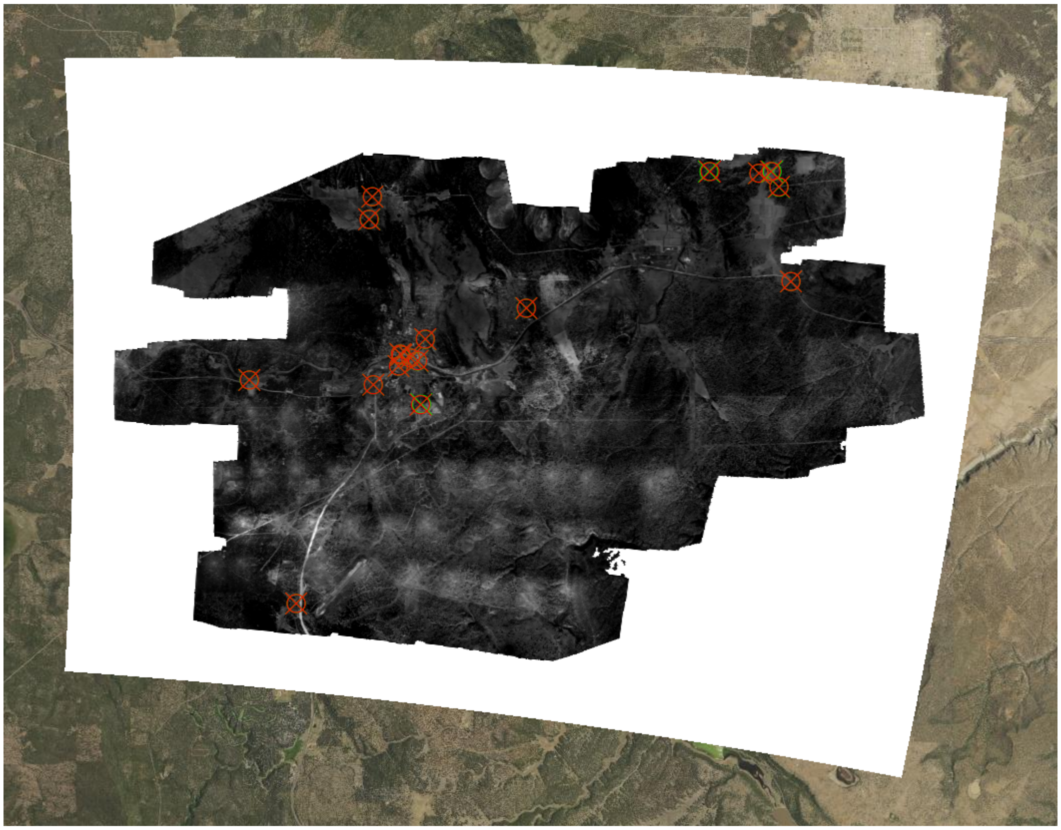

Figure 17: Control points.

3.4 Spatial Analysis

3.4.1 Cheshire and Rio de Flag

The Rio de Flag is a small river that runs through Flagstaff. It starts at the base of the San Francisco Peaks to the north and runs south-easterly through town. The river has been straightened as it has been developed around, and there is nowhere more evident than in the

Cheshire neighborhood (Fig.18).

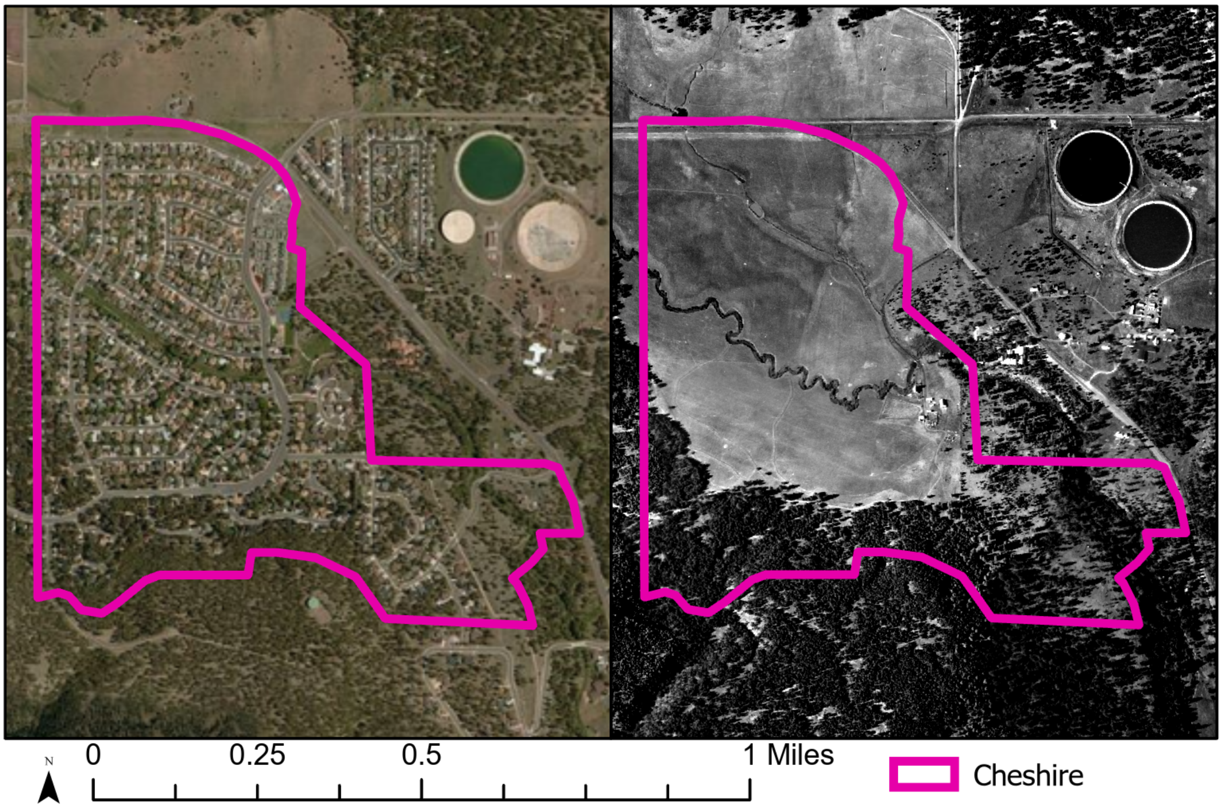

Figure 18: The image on the left shows the current Cheshire neighborhood, the image on the right shows the same location in 1959 when the neighborhood was not yet built.

The Rio de Flag has gone from a twisty river to an almost straight river on its route through Cheshire. The Rio de Flag was a meandering river carrying water through a wetland in what is now known as the Cheshire neighborhood. With the development of Cheshire, the wetland was drained, and the river was straightened. The straightening of rivers is typically done to speed up water evacuation and reduce flooding, in this case, to build a neighborhood. The digitization of the 1959 and 2021 Rio de Flag allowed for analyzing its flow length and sinuosity coefficient through the Cheshire neighborhood. The sinuosity coefficient is an index of the degree of deviation from a straight line. To calculate the sinuosity coefficient, the 1959 length was divided by the 2021 length . The resulting analysis determined that the Rio de Flag flow length was 5,788 feet in 1959 and 4,141 feet in 2021. In 1959 the sinuosity coefficient was 1.4, on the high end of the definition of a twisty river (Fig. 19).

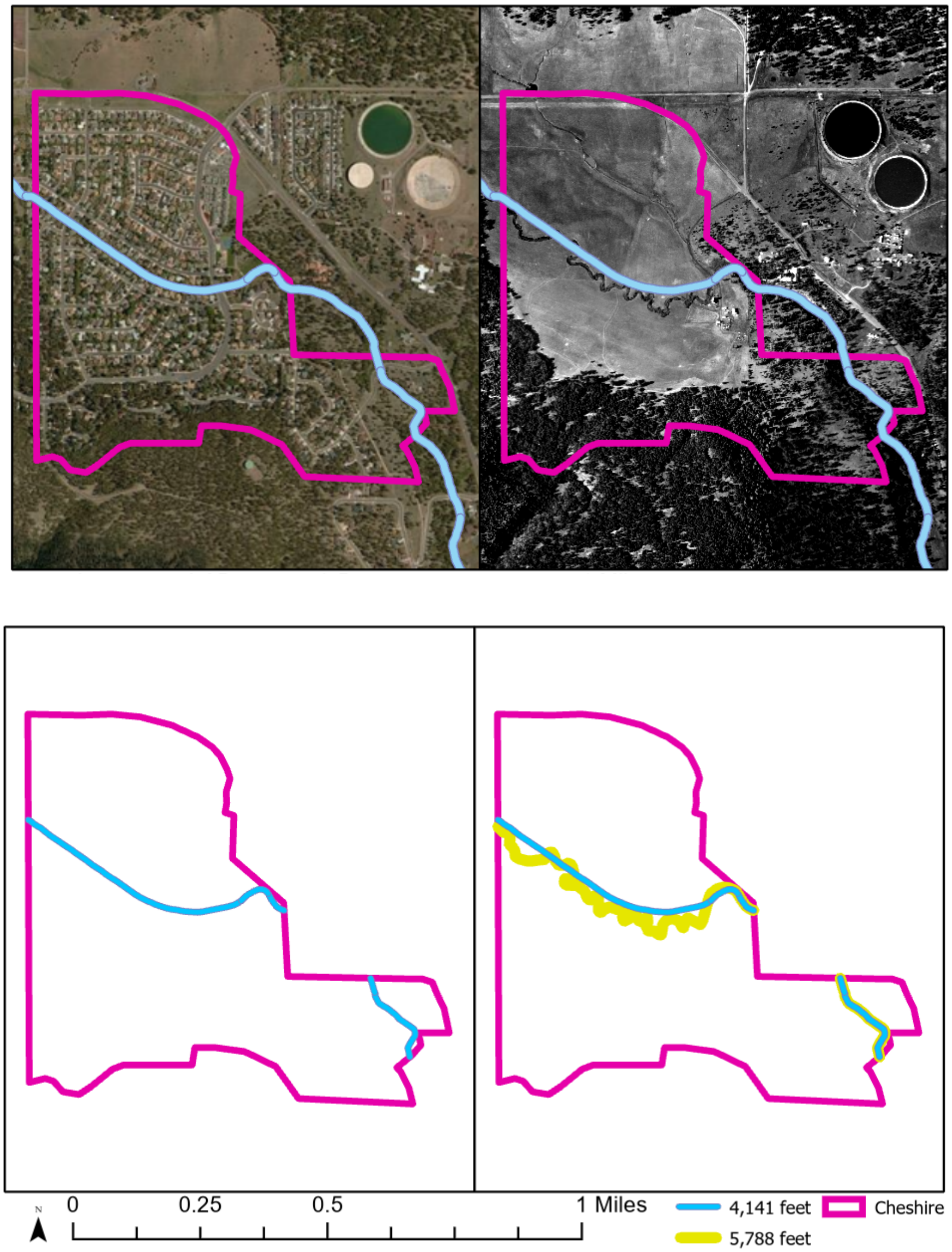

Figure 19: Length and sinuosity of the old and the current Rio de Flag flow path through Cheshire. The image on the right shows the current Rio de Flag overlaid on the 1959 image.

There are efforts in places to restore meandering rivers to reduce flood potential or return areas to better habitat. In Flagstaff, a local project is the Picture Canyon Restoration that is trying to change a stretch of the Rio de Flag back to wildlife habitat. The local group called Friends of the Rio de Flag is trying to un-straighten the Rio de Flag in areas for improved habitat as well.

3.4.2 Northern Arizona University

Another place of heavy change in Flagstaff has been the growth of Northern Arizona's campus. The college was founded in 1899 with twenty-three students and two faculty members. From 1958 through 1979, president Dr. J. Lawrence Walkup pushed for the expansion of the campus. In May 1966, the Arizona State College became Northern Arizona University (NAU).

NAU's Campus footprint has grown 84% since 1959. The campus footprint was digitized using the 1959 orthomosaic and a current georeferenced campus map using the perimeter of the campus buildings (Fig. 20). The area of NAU's campus with buildings on it was about 71 acres in 1959 and about 445 acres currently.

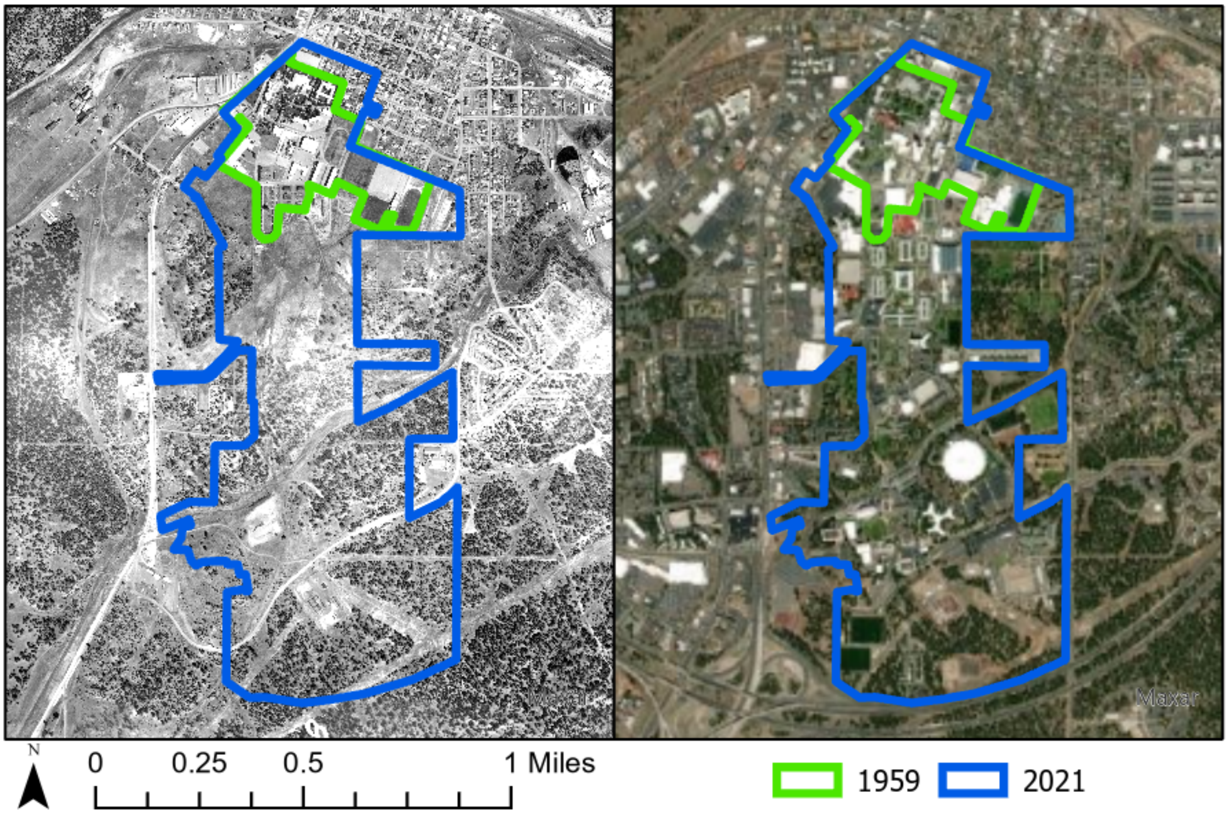

Figure 20: The change in NAU campus footprint from 1959 to 2021

The NAU campus was built in the Rio de Flag floodplain. When the NAU campus foodprint from 1959 and 2021 was aligned with the current flood maps, it is clear that most of the new buildings on North Campus were developed in the flood areas defined by FEMA (Fig. 21).

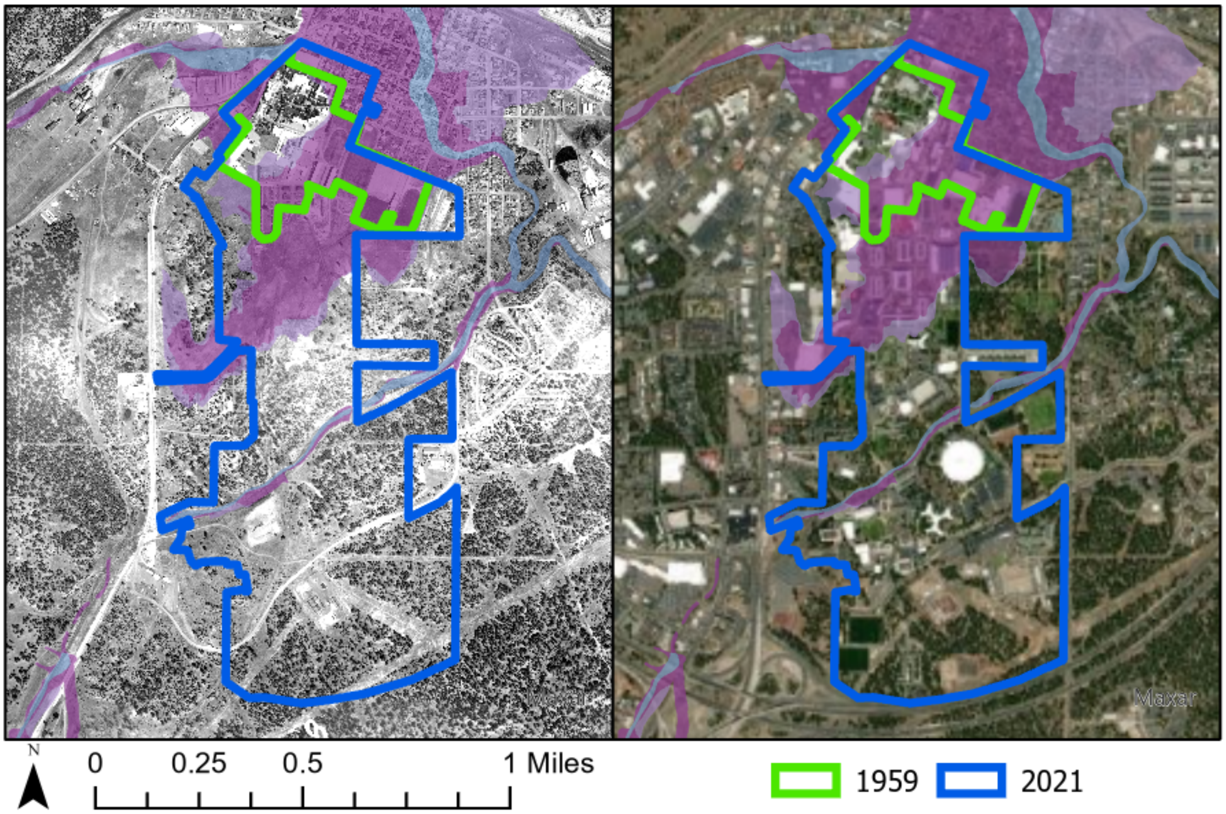

Figure 21: NAU original buildings are not in the Rio the Flag floodplain while many buildings in the modern campus are in the flood-prone area.

3.4.3 Information sharing with ArcGIS Online

ArcGIS Online (AGOL) was used to produce a comparison application. Users can scroll the 1959 imagery simultaneously with current imagery to compare landscape change. Linear and area calculation tools were added as well as a search bar for finding places of interest and addresses. The current imagery map can also toggle to another base map with labels of roads, parks, and other features. Finally, there is a share button to easily share an abbreviated web address with others who may be interested.

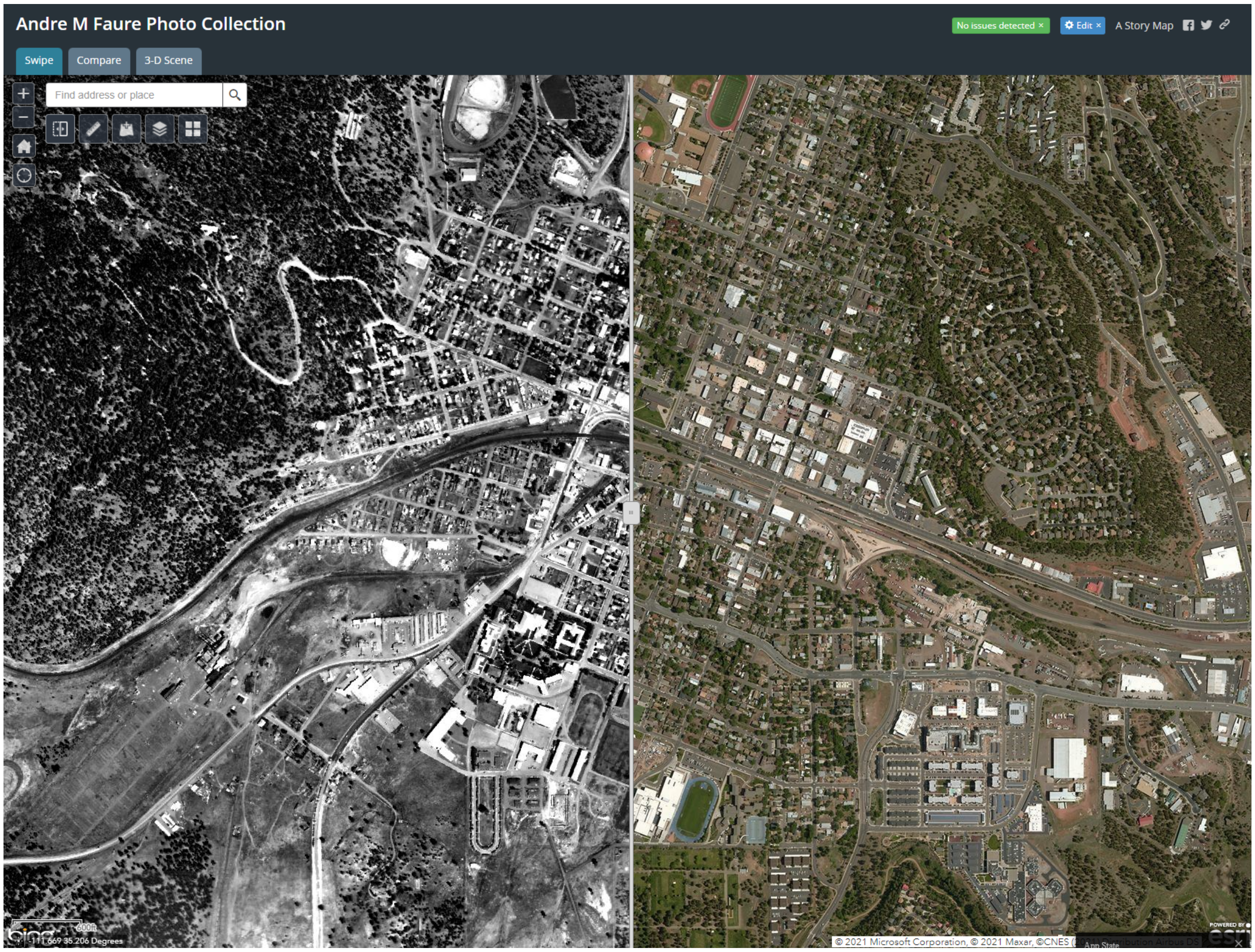

Figure 22: This is a screenshot of the compare application in ArcGIS Online.

The application can be found here: https://arcg.is/W1Gm1

4. Discussion

The orthomosaic allows for a comparison between historical imagery and current imagery. With a similar resolution and geometry, it is possible to make calculations of land-use change. In this project, significant changes to the Cheshire neighborhood and the campus of

Northern Arizona were measured. However, the great potential for the orthomosaic is its ability to be shared with others that can find changes they are interested in.

One of the best ways to share this imagery is through web-based applications. ESRI has the ArcGIS Online (AGOL) platform that enables sharing of GIS products. Using AGOL to build an application for comparison of the imagery visually and geometrically gives users a way to look at changes themselves. This empowers individuals to explore data they did not have and look for changes they think are important. This can add to discussions regarding past and future planning in the city.

These images are especially interesting as they capture the first decade of substantial growth for the city. Paired with other imagery from different times, this can be part of a collection tracking change over time. There are existing images going back to the 1980s easily found online but the gap from the 1960s and 70s provides a more complete timeline.

The photos are limited to the area in and around the city of Flagstaff. As such they are best used for urban land-use change. There is likely non-urban landscape change past the extent of the photos. One example is the Radio fire in 1977 on Mt. Elden north of town. The extent of the photos goes right up to the base of the slope and just misses the high severity portions of the fire. It seems like a just missed opportunity to have good imagery of what Mt. Elden was like almost 20 years before the fire. With the Coconino National Forest surrounding Flagstaff, there are likely other fire, logging, and grazing disturbances just missed off the edges of the photographs.

5. Recommendations for future work

This workflow for using structure from motion has enormous potential for future work. The ease at which so many photos can be aligned, orthorectified, and mosaiced is a great asset. The software needed to do this is not very expensive and can run on most computers.

One aspect of this workflow that was not explored was creating a digital elevation model (DEM). Production of a digital elevation model could be useful to track further land changes. There are applications of this for slope erosion, and sediment flows in streams. With the Rio de Flag being a primary flow path for water, further analysis could look at how that watershed has changed over time. It could help shed light as to whether any problems of flooding have been self-induced.

To create a DEM, ground control points are needed. This is difficult with historical aerial imagery, especially with no camera information. If images have focal length, altitude, and ground control points, it is possible to create a historical DEM. Otherwise, there are workflows where you can physically go and locate ground control points and tie them to the old images. Care must be taken to use points that were likely to exist at the same point and elevation over time.

A product that can be produced from a DEM is historical flood potential. In this project that would have been interesting to see if the current FEMA flood plain would have changed. Especially with the changes in the Rio de Flag's flow.

Another analysis that could be interesting would be to classify the historical images for building footprints. This could be compared to a more modern building footprint layer like the one produced by Microsoft. Analyzing how much has been built or how much the density of buildings has increased would be useful for urban planners.

I think the use of historical imagery can be very valuable and almost limitless in applications. Images like those found in the Faure collection are especially useful because they are of such high resolution. The resolution makes it easier to georeference and digitize features. Once brought into a GIS, these images can be used to identify most changes in a landscape.

6. Conclusions

The orthomosaic generated in the software Agisoft Metashape using structure from motion is the product of this practicum. It serves its purpose as being helpful in comparing past imagery with current imagery and being able to be shared on online applications. The accuracy of the orthomosaic also allows for geometric calculations to be made and compared with current imagery. The workflow used is repeatable and efficient for other sets of historical photographs.

Ultimately it was very interesting to see the large expansion of Flagstaff. The Cheshire neighborhood and the Campus of Northern Arizona University were built and significantly expanded. Using the AGOL application allows further visualization of the past imagery compared with current imagery. There are other neighborhoods built, streets widened, and other infrastructure changed as the population increased. The Faure photo collection is now preserved as a GIS layer that can aid others in seeing the past and planning for the future.

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