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MAPPING HISTORICAL LAND-USE AND LAND-COVER CHANGE IN CENTRAL OKLAHOMA: INTEGRATING HISTORICAL GEOSPATIAL DATA AND MODERN AERIAL IMAGERY, 1871-2023

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MAPPING HISTORICAL LAND-USE AND LAND-COVER CHANGE IN CENTRAL OKLAHOMA: INTEGRATING HISTORICAL GEOSPATIAL DATA AND MODERN AERIAL IMAGERY, 1871-2023

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ABSTRACT

Reconstructing long-term land-cover change in heterogeneous landscapes is constrained by the fact that no single archive captures more than a century of fine-grained change, and that historical geospatial data are often inaccessible to the researchers who could use them. This thesis integrates nineteenth-century Public Land Survey System records, twentieth-century historical aerial photography, and modern orthophotography into a continuous, patch-scale reconstruction of land-cover change in the Upper Finn Creek Watershed (~1,300 ha), McClain County, Central Oklahoma, spanning 1871 to 2023, and applies that reconstruction at the site scale within University of Oklahoma's Kessler Atmospheric and Ecological Field Station (KAEFS). Eleven land-cover maps were produced using a consistent six-class legend, manual photointerpretation of historical sources, and object-based classification of recent imagery, with overall accuracy ranging from 80.7% to 91.8%. The reconstruction reveals three phases of change: rapid post-settlement cultivation expansion to a maximum of 57.6% of the watershed by 1937, subsequent cultivation decline and grassland-pasture increase, and pronounced woody expansion after 1981, when forest rose from a low of 189.7 ha (14.6% of the watershed) to 459.0 ha (35.3%) by 2023. These transitions shifted from broad, contiguous cultivation blocks to diffuse grassland-to-forest infilling consistent with eastern redcedar (*Juniperus virginiana*) encroachment. To make these products usable, the reconstruction was organized into an interactive web platform (K-Viz) and applied at KAEFS, where roughly 78% of the station changed land cover class more than once since 1871. Historical imagery independently placed 15 sampled eastern redcedar trees at a mean detection-based age of 14.0 years, substantially younger than their mean allometric age of 28.1 years, indicating that field-based ages may overstate the duration of encroachment influence. This work demonstrates that integrating survey records, archival photography, and modern imagery yields a historically grounded, spatially explicit, and accessible basis for interpreting present-day landscapes shaped more by their past than their current appearance suggests.

Keywords: historical aerial photography; Public Land Survey; woody plant encroachment; web GIS; land-use legacy; Southern Great Plains.

1. INTRODUCTION

1.1 Background and Motivation

A central challenge in research quantifying long-term historical land change with remote sensing is that no single sensor archive fully captures the history of landscape change over the last 90 years; the time frame since high resolution, repeated aerial photography began (Pinto et al., 2019; Rango et al., 2011). Although declassified Corona and Keyhole imagery can extend satellite-based land records back to the early 1960s and 70s (Brecheisen et al., 2020; Shahbandeh et al., 2023), continuous multispectral satellite monitoring began with Landsat in 1972 (Cohen & Goward, 2004; Wulder et al., 2019). Watershed-scale land-cover changes in North America, however, began before the satellite era and occur at spatial grains too fine to be reliably captured by moderate-resolution imagery such as Landsat and Sentinel-2. In heterogeneous landscapes, important evidence of change may appear in elements that occupy only one or a few 30m pixels, including agricultural fields (<1.5 ha), narrow riparian corridors (30-100 m wide), and scattered tree establishment at the scale of individual tree crowns (Fischer Jr & Fischenich, 2000; Mayer et al., 2005; Nabil et al., 2020; Weinstein et al., 2021). Long-term reconstruction therefore involves more than mapping past conditions, it is a problem of integrating records that differ in date, scale, geometry, tone, and information content (Pinto et al., 2019).

If we are looking to investigate long term change in the United States, one must cobble together a myriad of historical and remotely sensed sources, from early surveyor descriptions and aerial photography to the full spectrum of evolving satellite products and more recently, Unmanned Aircraft Systems (UAS) or drone-based imagery. These sources differ not only in age, but also in spatial resolution, spectral information (wavelength bands), radiometric quality (brightness sensitivity), temporal coverage (revisit frequency), viewing geometry, positional accuracy, and the kinds of land-cover information they record or imply (Y. Wang et al., 2023; Zhu et al., 2022). Multi-source studies show that integrating historical maps, aerial photographs, and contemporary imagery can reveal long-term land-use and land-cover (LULC) change that would be difficult to reconstruct from any single archive alone, but they also emphasize the need to reconcile differences in geometry, legend structure, and data quality across sources (Anderson, 1976; Liu et al., 2018; Osgouei et al., 2022).

Historical plats and survey records provide early spatial evidence of vegetation, land division, and settlement patterns, but they are selective representations rather than direct sensor measurements (Liu et al., 2018; Schulte & Mladenoff, 2001). Archival aerial photographs contribute much finer spatial detail and have long been especially valuable for land-cover change analysis in landscapes where important features occur at patch-level scales (sub-meter to a few meters spatial resolution), including woody encroachment; however, they also require scanning, orthorectification, georeferencing, mosaicking, and careful interpretation before image comparison is reliable (Evans, 2010; Hudak & Wessman, 1998; Kostrzewa, 2024; Persia et al., 2020). The now-declassified CORONA reconnaissance satellite program, developed for U.S. intelligence purposes by the CIA and U.S. Air Force, provides an important bridge between historical aerial photographs and later digital satellite archives by extending high-resolution observation into the 1960s (Central Intelligence Agency, n.d.). However, its use is complicated by geometric distortion, panchromatic (greyscale) imagery, and processing difficulties that can limit broader application (Brecheisen et al., 2020; Shahbandeh et al., 2023).

Satellite imagery provides repeatable coverage and consistent digital data across large areas, yet moderate-resolution satellites such as Landsat can still miss or blur fine-grained landscape elements and early-stage change, especially when compared with aerial photographs or UAS imagery (Filippelli et al., 2020; Y. Wang et al., 2023; Zhu et al., 2022). UAS imagery, by contrast, provides very high spatial detail for contemporary conditions but only over a short temporal window (Sun et al., 2021). The main challenge, therefore, is to stitch together records produced at different scales and for different purposes in order to reconstruct LULC change across more than a century while retaining sensitivity to small spatial features (Kostrzewa, 2024; Osgouei et al., 2022; Shahbandeh et al., 2023). In Oklahoma, that effort is especially promising because aerial photograph archives extend back to the 1930s (Pinto et al., 2019), while General Land Office (GLO) survey plats and field notes from the Public Land Survey (PLS) System reach into the 1870s (Everett, n.d.). This thesis takes that integrative view by treating historical imagery as primary evidence for LULC change reconstruction rather than as incidental background context and explores changes in the Upper Finn Creek Watershed, McClain County Oklahoma over the last 152 years, and applies that reconstruction to site-level questions about land cover history, research site suitability, and eastern redcedar establishment at a smaller field station within the watershed.

1.2 Remote Sensing and Historical Imagery for Long-Term Reconstruction

Archives of remotely-sensed spatial information (both satellite and aerial imagery) are foundational to historical land change research because they provide repeated observations that support regional monitoring, disturbance mapping, and long time-series analysis across broad extents (M. C. Hansen & Loveland, 2012; Wulder et al., 2008; Zhu et al., 2020). Specifically, aerial imagery refers to image data acquired from aircraft-based platforms, including conventional vertical photographs and more recent orthorectified (location corrected) airborne products, whereas satellite imagery refers to data collected by sensors/cameras mounted on orbiting platforms (NASA Earthdata, n.d.; U.S. Geological Survey, 1997). Aircraft-based imagery has often provided finer spatial detail than satellite data, making it useful for identifying landscape features that may be visible in ~1m aerial imagery but poorly captured in coarser satellite products such as Sentinel-2 (10-20m) and Landsat (30m) (European Space Agency, n.d.; Morgan et al., 2010; U.S. Geological Survey, 1997). For example, in a mixed agricultural and grassland landscape, aerial imagery can make small changes in cultivation, woody cover, and developed surfaces easier to separate than imagery in which multiple cover types are averaged into a single coarser pixel. Aerial photographs have long supported detailed land-cover interpretation, and recent work has renewed interest in archival aerial photography because advances in scanning, georeferencing, photogrammetric correction, and digital processing have made historical image collections a practical option for quantitative change analysis going back to the early 20th century and seamlessly linking that analysis to early satellite-based sensing (Bolles & Forman, 2018; Kostrzewa, 2024; Morgan et al., 2010; Pinto et al., 2019).

Historical maps and survey records are also important geospatial sources because they can extend land-cover reconstruction before the period covered by aerial photography and satellite imagery (Schulte & Mladenoff, 2001). In the United States, one of the most important early sources is the PLS System, a federal rectangular survey system established through the Land Ordinance of 1785 to divide public lands for ownership, sale, settlement, and administration (White, 1983). In this thesis, “survey records” refers specifically to GLO plats and field notes produced through the PLS System, not to modern field surveys or remotely sensed imagery. The GLO, created in 1812, oversaw the survey, platting, and disposal of public lands, and Congress authorized the survey of Indian Territory using this system in 1864 (Everett, n.d.; National Archives, 1995). In Oklahoma, the Indian meridian and baseline were established from an initial point in 1870, creating the framework through which much of Indian Territory and Oklahoma Territory was surveyed into townships and sections (Everett, n.d.).

Unlike aerial photographs or satellite images, PLS records do not provide continuous image coverage. Their spatial structure was based on a rectangular grid. Survey townships were intended to be six miles by six miles and divided into 36 one-square-mile sections. Distances were commonly measured with a survey chain, where one chain equaled 66 feet and 80 chains equaled one mile (White, 1983). The resulting plats and field notes recorded legal boundaries as well as selected landscape features encountered along survey lines, including streams, roads, vegetation, settlement features, and other markers (Schulte & Mladenoff, 2001; White, 1983). In this sense, PLS records provide line-based historical observations rather than pixel-based land-cover data.

For land cover reconstruction, these records are valuable because they provide spatial evidence from before the aerial photography record, but they must be interpreted carefully. Although PLS plats and field notes were created and intended for land subdivision rather than ecological mapping, they have been widely used to reconstruct historical vegetation and land-cover patterns across the United States (Bourdo, 1956; Eddy, 2024; Hanberry et al., 2025; Manies & Mladenoff, 2000). Reviews of PLS records show that witness-tree (or bearing tree) records, line descriptions, and surveyor observations provide one of the few spatially extensive sources of pre- or early-settlement vegetation information, although their use requires attention to surveyor bias, uneven observation, and scale (Schulte & Mladenoff, 2001; Tulowiecki, 2014; Y.-C. Wang, 2005). Oklahoma applications follow this wider use of PLS records, including reconstructions of Cross Timbers vegetation, Wichita Mountains vegetation, and historical woody-taxa distributions (Fagin & Hoagland, 2014; Hoagland et al., 2013; Shutler, 2004).

For multi-source reconstruction, the value of PLS records is that they provide a nineteenth-century spatial baseline that predates the aerial photography record. Their limitation is that they must be translated from survey documents into comparable geospatial data. This requires georeferencing, digitization, interpretation, and standardization before they can be compared with historical and recent aerial photographs, as well as satellite-based land-cover data. Recent work has shown that this conversion process can be painstaking and often still depends on manual interpretation, even as newer AI-assisted methods begin to accelerate feature extraction from historical maps (Goldman et al., 2025; Liu et al., 2018; Saxton et al., 2024; Schlegel, 2023).

Historical aerial photographs, especially 'black-and-white' imagery, are frequently used to quantify long-term change in forests, rangelands, and other heterogeneous landscapes (Hudak & Wessman, 1998; Morford et al., 2024; Morgan et al., 2010). However, archival variability—i.e. differences among photographs in image quality, scale, tone, season of acquisition, and geometric distortion— can make comparison across time difficult (Redecker, 2008). These differences can complicate georectification, mosaicking, and land-cover interpretation because the same landscape may appear differently from one image date to another (Kostrzewa, 2024; Morgan et al., 2010). Historical image collections were also produced using different camera systems, film types, flight heights, and viewing angles, and older collections often lack the metadata needed to fully correct these differences, such as camera calibration reports, flight information, or time of capture (Morgan et al., 2010; Redecker, 2008). As a result, corrections that are routine for modern digital imagery, such as orthorectified aerial or satellite datasets with consistent metadata and calibration information, may be incomplete or uncertain for historical photographs. For example, relief displacement can shift features away from their true ground position, especially in uneven terrain, and distortion near image edges can stretch or skew features during alignment. Shadows, seasonal vegetation differences, and variation in film or print quality can also change image tone across dates, making the same land cover appear different from one photograph to another (Morgan et al., 2010; Redecker, 2008; Verhoeven et al., 2013). Preservation issues add further uncertainty because some collections no longer include the original photographic negatives, or the original film images from which prints were made, leaving worn, faded, or copied paper prints as the best available source for scanning and analysis (Luman et al., 1997).

These limitations are important because historical aerial photographs are often used to study one dominant process rather than to reconstruct an entire landscape. Many studies focus on changes such as woody expansion (Rhodes et al., 2021), tree cover (Morford et al., 2024), canopy change (Fujita et al., 2003; Roman et al., 2017), or drought impacts (Bolles & Forman, 2018). In contrast, a multi-class reconstruction attempts to map several land-cover categories across the same study area and time period, including grassland, cultivation, forest, water, and built land. This distinction is important because a simplified classification can clearly show one major process, but it may obscure broader exchanges among land-cover types. For long-term watershed analysis, the challenge is therefore not only detecting whether one feature increased or decreased, but also building a consistent classification that can support comparison across multiple dates and multiple land-cover classes (Anderson, 1976).

Contemporary digital aerial programs such as the National Agriculture Imagery Program (NAIP) provide orthorectified, repeatedly collected imagery with more standardized acquisition and more consistent geometric correction than many historical aerial campaigns (U.S. Geological Survey, 2018). NAIP is a USDA aerial imagery program developed to acquire “leaf-on” imagery during the agricultural growing season, originally to support USDA/Farm Service Agency (FSA) county office GIS work, farm program administration, and maintenance of Common Land Unit boundaries (basic digital mapping unit for farmland), while also making digital orthophotography available to government agencies and the public (U.S. Department of Agriculture, Farm Service Agency, 2013). For this thesis, NAIP is considered a modern aerial source because it provides digital, georeferenced, and visible color imagery with consistent statewide coverage, repeated acquisition, and map-like positional properties, unlike many scanned historical aerial photographs that require separate georeferencing and correction before comparison. These characteristics make NAIP useful for patch-scale mapping, defined here as the delineation and comparison of individual land-cover patches and boundaries across years. For example, in Oklahoma, NAIP has provided 1m imagery since 2003 on a consistent acquisition schedule (2003, 2005, 2008, 2010, 2015, 2017, 2019, 2021, 2023, 2025), with finer-resolution imagery available more recently, including 0.6m data in 2019 and 0.3m data in 2023 (Oklahoma Office of Geographic Information, 2026). More broadly, long-term land-cover mapping depends on image classification, that is, the assignment of remotely sensed imagery to thematic classes using a defined legend, classification rules or algorithms, and reference data for validation and accuracy assessment (Congalton, 1991; Foody, 2002; Hermosilla et al., 2022). For instance, Baig et al. (2022) demonstrate this basic sequence by classifying Landsat images from 1991, 2001, 2011, and 2021 into six LULC classes, then evaluating map accuracy with reference points and a confusion matrix, with overall accuracies ranging from 94.0% to 96.7%. Similar workflows are commonly adapted to project-specific needs, including estuarine habitat mapping with aerial photography (Zharikov et al., 2005), urban land-cover classification with Sentinel-2 and Landsat (Topaloğlu et al., 2016), fine-resolution regional mapping with NAIP imagery (Peter et al., 2018), and agricultural watershed classification with Landsat and ancillary data (Dash et al., 2023).

In historical land-cover reconstruction, this workflow becomes more complicated because mapped classes often have to be interpreted across multiple kinds of sources rather than from a single sensor or image product. In this study, multi-source reconstruction refers to the integration of historical aerial photographs, NAIP aerial imagery, historical maps and PLS records to build a temporally comparable land-cover dataset. Comparability across time therefore depends not only on the imagery itself but also on whether classes are defined consistently enough to support temporal interpretation (Anderson, 1976). This makes the choice of classification framework important, because the legend must be broad enough to apply across different source types while still detailed enough to capture meaningful local change. For this reason, the Anderson LULC classification system is useful in this context (1976). Developed by the U.S. Geological Survey, the Anderson system organizes LULC into broad categories that can be applied consistently across different kinds of remotely sensed imagery, including aerial photographs and satellite images. Its broad classes, such as urban or built-up land, agricultural land, rangeland, forest land, water, and wetlands, can also be divided into more detailed categories when needed for local studies. Other classification systems exist, including the FAO Land Cover Classification System, which was designed for global land-cover description (Jansen & Di Gregorio, 2000), and CORINE Land Cover, which uses a standardized set of classes for European mapping (Copernicus Land Monitoring Service, n.d.). However, Anderson remains useful for U.S.-based historical reconstruction because its broad categories have been modified and reused in major land-cover programs and project-specific studies, including the National Land Cover Database, or NLCD (Homer et al., 2007; Vogelmann et al., 2001), NOAA's Coastal Change Analysis

Program (Dobson, 1995), the USGS Land Cover Trends project (Soulard et al., 2014), and a regional land-cover change study in the SGP that reclassified NLCD data to a modified Anderson Level I scheme (Fagin et al., 2016).

After selecting a land-cover classification framework, another important methodological decision is how imagery is converted into mapped classes. In the land-cover classification literature, approaches are often distinguished by their basic unit of analysis. Traditional pixel-based methods classify individual pixels based mainly on their spectral properties, meaning differences in recorded brightness or reflectance across different wavelength bands. In contrast, object-based image analysis groups neighboring pixels into larger image objects and classifies them using not only spectral information but also texture, shape, size, and surrounding landscape context (Blaschke, 2010; Kucharczyk et al., 2020; Ma et al., 2017). This distinction is especially important for high-resolution imagery, where pixel-based approaches can produce noisy classifications because neighboring pixels within the same land-cover type may vary in brightness or tone. Object-based methods can reduce this issue by mapping more spatially coherent units that better approximate real-world landscape patches and boundaries (Blaschke, 2010; Kucharczyk et al., 2020). Recent work therefore shows a general shift toward object-based and hybrid classification workflows in high-resolution land-cover mapping especially when the objective is to combine image information with landscape context and produce spatially coherent map units (Blaschke, 2010; Ma et al., 2017; Qin & Liu, 2022).

A remaining challenge is deciding when an observed difference between dates should be interpreted as real land-cover change or differences in the source images (Morgan et al., 2010). This issue is especially important in historical reconstructions that combine black-and-white aerial photographs, NAIP imagery, satellite data, and historical records. For example, distinguishing grassland, cultivation, and early woody cover may be straightforward in some years when field boundaries, crop rows, canopy texture, or woody patches are visible, but much less certain in years when image tone, season, or resolution obscure those cues. A former cultivated field may appear similar to grassland or bare ground depending on the date of acquisition, while small or scattered woody plants may be visible in recent high-resolution imagery but ambiguous or undetectable in older photographs (Morford et al., 2024; Morgan et al., 2010).

This means that the main methodological challenge is not simply producing a classified map for each date but maintaining consistent interpretation across dates that differ in quality and information content. In this thesis, that challenge requires using broad land-cover classes, applying consistent decision rules, comparing each date with surrounding image years when possible, and treating uncertain boundaries or ambiguous patches cautiously. These decisions are especially important for watershed-scale reconstruction because the final analysis depends on whether mapped transitions, such as cultivation-to-grassland or grassland-to-forest, represent actual landscape change rather than differences in image source or interpretation (Olofsson et al., 2014).

1.3 Methodological Considerations for Multi-Source Reconstruction

Integrating archival imagery with contemporary orthorectified aerial datasets is a useful approach for studying land-cover change over the last century, but the reliability of the resulting maps depends on how differences among sources are managed (Morgan et al., 2010; Pinto et al., 2019). Recent methodological reviews identify georeferencing, orthorectification, camera information, and archive quality as some of the main constraints on extracting geographically accurate measurements from analogue photographs (Kostrzewa, 2024; Persia et al., 2020). For this thesis, the main concern is not only positional accuracy, but temporal comparability: mapped patches and boundaries must be interpreted consistently across dates even when the source imagery differs in quality, resolution, tone, and available documentation.

Positional errors can be especially important for fine-scale land-cover features and boundaries (~1~30m), because a slight offset may change whether a boundary is interpreted as stable, expanding, shrinking, or converting to another land-cover class (Morgan et al., 2010; Olofsson et al., 2014). This is especially relevant for transitions such as cultivation-to-grassland or grassland-to-forest, where the interpretation depends on both the location of the boundary and the visual evidence used to assign the class. For that reason, multi-source reconstruction requires more than classifying each date separately; it requires consistent class definitions, decision rules, and uncertainty treatment across the full image sequence (Anderson, 1976; Olofsson et al., 2014).

Several interpretation strategies are available for converting imagery into land-cover classes, ranging from manual photointerpretation to digital image classification (Table 1). Manual photointerpretation relies on the analyst's visual interpretation of tone, size, shape, texture, pattern, shadow, local characteristics, landscape context and position, which is especially relevant for historical aerial photographs where spectral information may be limited or inconsistent across dates (Morgan et al., 2010). For digital classification methods, Lu and Weng (2007) organize approaches by training requirements, classification output, unit of analysis, and use of spatial or contextual information. In practical terms, these approaches include pixel-based classification, object-based image analysis, and machine-learning or deep-learning classification. Pixel-based classification assigns individual pixels to classes based mainly on their spectral values, while object-based image analysis first groups neighboring pixels into larger image objects and then classifies those objects using spectral, textural, shape, and contextual information (Blaschke, 2010; Ma et al., 2017). Machine learning and deep-learning methods have expanded classification options, but their usefulness depends on the research question, available imagery, training data, accuracy needs, computing resources, and user expertise (Southworth et al., 2024).

Studies comparing manual and automated approaches show that no single interpretation method is consistently best across all imagery types or research goals, because performance depends on the imagery, available training data, mapping objective, and the level of ambiguity in the landscape (Husson et al., 2016; Liu et al., 2018; Southworth et al., 2024). Automated approaches can improve efficiency and consistency when training data and image quality are sufficient, but they may still require manual interpretation for training, validation, or resolving ambiguous areas. For example, Husson et al. (2016) showed that automated object-based image analysis can improve efficiency but still requires manual correction and validation, while Liu et al. (2018) used visual interpretation alongside pixel-based and object-based classification to handle the inconsistencies of multi-source historical data. Southworth et al. (2024) make a similar point for machine-learning and deep-learning approaches, emphasizing that method choice depends on the research question, image data, training data, accuracy needs, computing resources, and user expertise.

For this thesis, manual interpretation remains important because much of the archival imagery is heterogeneous, meaning that image quality, tone, resolution, and visible land-cover cues vary across dates. In these cases, interpretation cannot rely only on spectral values. It also requires texture, shadow, pattern, surrounding land cover, and comparison with adjacent image years (Morgan et al., 2010). Accordingly, this thesis relies primarily on manual interpretation, with automated classification used only for recent NAIP imagery where the data was consistent enough to support it. Across all years, the same generalized land cover categories, such as grassland, cultivation, forest, water, barren, and built land, were used to maintain comparability. The criteria used to assign those classes, including tone, texture, structure, pattern, and context, were also applied consistently across the image sequence. This consistency is important because change analysis depends not only on classifying each year, but on comparing mapped conditions across years (Olofsson et al., 2014). Inconsistent class definitions, mapping units, or uncertainty treatment can create apparent transitions that reflect mapping differences rather than landscape change (Anderson, 1976; Olofsson et al., 2014; Saura, 2002).

1.4 Regional and Applied Context

These methodological concerns are especially relevant in Central Oklahoma and the Southern Great Plains because many major land-cover changes in this region, including cultivation, agricultural contraction, urban expansion, and woody encroachment, overlap with the period covered by historical aerial photography (Coppedge et al., 2001; J. Wang et al., 2017). This creates an opportunity to examine 20th-century land-cover transitions in relatively fine spatial detail, rather than relying only on coarser satellite data (≥30m) or much older historical sources. In contrast, much of the eastern United States experienced major Euro-American land clearing, agricultural expansion, abandonment, and forest recovery over a longer historical period that began well before aerial photograph archives were available (Steyaert & Knox, 2008; Thompson et al., 2013). In the SGP, studies using historical aerial photography have documented recent landscape changes such as agricultural fragmentation, grassland conversion associated with the Conservation Reserve Program (a voluntary program that pays landowners to restore environmentally sensitive cropland to permanent vegetation), and juniper or woody vegetation expansion (Coppedge et al., 2001, 2007; Hellerstein, 2017).

These changes reflect a longer regional history of settlement, cultivation, erosion control, and land-use adjustment. Settlement, cultivation, and urbanization beginning in the late nineteenth and early twentieth centuries reorganized large areas of native vegetation across the Great Plains, while later agricultural contraction, abandonment, energy development, and other land-use shifts created enduring post-agricultural legacies (Spangler et al., 2020; Taylor et al., 2015; Xie et al., 2024). In the 1930s, severe drought and intensive land management contributed to widespread wind erosion and topsoil loss during the Dust Bowl (Hornbeck, 2012; USDA NRCS, n.d.). In response, government conservation programs promoted practices such as terracing, grassed waterways, and tree windbreaks to reduce erosion and stabilize agricultural landscapes (Mundende, n.d.; USDA NRCS, n.d.). Many of these features are visible in aerial photographs, making them important evidence for interpreting later land-cover patterns. For example, New Deal and post-Dust Bowl conservation programs promoted erosion-control practices, while the Great Plains Shelterbelt Project planted more than 100 million trees across the region to reduce wind erosion (Hoagland, 2010; Hornbeck, 2012; Howlader, 2023).

One more recent legacy of land management and erosion-control plantings is that shelterbelts created seed sources for eastern redcedar (*Juniperus virginiana*) (Lawson, 1990), contributing to the expansion of redcedar and other woody species across formerly open grassland systems (Van Haverbeke & Read, 1976). In Oklahoma, eastern redcedar (ERC) and related junipers were estimated to occupy approximately 1.5 million acres in 1950, 3.5 million acres by 1985, and about 8 million acres by the early 2000s, with some estimates suggesting expansion rates approaching 300,000 acres per year (Bidwell et al., 2009). This expansion has implications for forage production, water availability, and wildfire risk (Archer et al., 2017; J. Wang et al., 2017; Yang et al., 2023). Across the Great Plains, woody encroachment was estimated to reduce rangeland production by 22.4 million tons in 2019, including about 4.5 million tons in Oklahoma alone (Fogarty et al., 2023). ERC can also alter hydrologic processes by increasing year-round transpiration and reducing potential streamflow or groundwater recharge, while dense stands increase fuel loading and wildfire risk (Caterina et al., 2014; Hoff et al., 2018; Zou et al., 2018). Accurately mapping these changes and relating them to past land use, erosion-control practices, and disturbance history can therefore help identify where woody expansion has occurred and predict where similar transitions may occur in the future.

These regional patterns provide the context for interpreting land-cover change within the Upper Finn Creek Watershed (~1,300 ha; HUC12: 111303030301; McClain County, Oklahoma), where local reconstruction requires a time series that can capture both land-cover composition and patch history. A fine-scale reconstruction moves beyond net change by locating where forest increase, cultivation decline, and other transitions occurred across the watershed. Mapping these transition histories can clarify how past land use and repeated change continue to shape areas of future landscape vulnerability.

1.5 Research Gap, Purpose, and Objectives

Although historical geospatial sources are available in Oklahoma, few studies have combined nineteenth-century surveys (such as GLO plats), repeated historical aerial photography, and recent orthophotography into a single, continuous, patch-scale land-cover reconstruction. Existing historical image studies more often emphasize broader regional patterns or a narrower set of cover changes, such as woody expansion or tree cover, than a consistent multi-class reconstruction of watershed-wide composition and transitions (Bolles & Forman, 2018; Coppedge et al., 2001; Morford et al., 2024). Historical imagery has also less often been used to support site-level research applications, such as identifying areas with different disturbance histories, evaluating woody establishment timing, or communicating long-term landscape history through digital data products. This thesis addresses that gap in the Upper Finn Creek Watershed (UFCW) in Central Oklahoma.

In response, this thesis has three main objectives. First, it reconstructs long-term land-cover change in the UFCW using Public Land Survey records, historical aerial photography, and modern aerial imagery to produce a multi-temporal record spanning 1871 to 2023. Second, it evaluates how the watershed's composition, configuration, and dominant transition pathways changed through time, with particular attention to cultivation turnover, grassland persistence, and woody expansion. Third, it applies the historical reconstruction to a smaller study area to examine local forest-grassland change, assess how land-cover history can inform research-site suitability, communicate the resulting data products through a digital historical visualization platform, and provide image-based context for evaluating allometric age estimates of ERC (Frentz, 2025; Giddens & McCarthy, unpublished). The UFCW was selected as it affords the opportunity for a nested approach, i.e. examining land cover change at a broader watershed scale (~3200 acres) and then applied at finer spatial resolution at OU's 360-acre Kessler Atmospheric and Ecological Field Station (KAEFS) within the watershed.

1.6 Significance of the Study

This thesis contributes to biogeographic research by integrating survey-era records, archival aerial photography, and modern orthophotography to produce a long-term, fine-scale record of land-cover change in Central Oklahoma. It also converts that record into a quantitative change-index map that can be used to evaluate the spatial extent and recurrence of land-surface disturbance. These outputs can support future work on watershed change, habitat patterns, land-use legacies, woody encroachment. At KAEFS, the change-index map can be used to understand how a site may have inherited functional and structural characteristics based on the degree of change, which may influence its suitability for a particular ecological or geochemical study.

The study is also methodologically significant because it shows how sources that differ in age, format, geometry, and level of detail can still be brought together in a single land-cover reconstruction. It also demonstrates why long-term reconstruction depends on decisions about thematic standardization, source-specific interpretation strategies, and comparability between years rather than on any one image source alone. In that sense, it adds to a growing body of work that treats archival imagery as a usable source of spatial evidence rather than only as historical illustration (Morgan et al., 2010; Pinto et al., 2019).

1.7 Overview of Thesis Organization

This thesis is organized into four chapters. Chapter 1 introduces the broader research problem and reviews the remote sensing, historical imagery, and methodological context that motivates the study design. Chapter 2 presents the main analytical chapter, which reconstructs land-cover change in the UFCW from 1871 to 2023 using Public Land Survey records, historical aerial photography, and modern aerial imagery. This chapter also outlines in detail the methodology used in the study. Chapter 3 builds directly on that reconstruction by applying it at the site scale at KAEFS, where the historical record is organized into a visualization platform (K-Viz) and used to interpret land-use legacies, evaluate ERC establishment against allometric ages (Frentz, 2025; Giddens & McCarthy, unpublished), and support teaching and site planning. Chapter 4 concludes the thesis by synthesizing the main findings, discussing their broader implications, and identifying directions for future research and application.

Chapter 1 Figures and Tables

Classification method	Description	Use in reconstruction
Supervised	Land-cover classes are defined before classification, and reference data are used to train the classifier	Useful when reliable training data and consistent image characteristics are available
Unsupervised	The image is grouped into spectral clusters first, and the analyst later labels those clusters as land-cover classes	Useful for exploratory analysis, but less suited when predefined classes and temporal consistency are required
Per-pixel	Each pixel is classified individually, usually based on its spectral values	Can be useful for automated classification but may produce noisy results where land cover varies at fine spatial scales
Object-oriented	Neighboring pixels are grouped into objects, and classification is based on those objects rather than individual pixels	Useful for high-resolution imagery where land-cover features are better represented as patches, boundaries, and shapes
Fuzzy	Locations can have partial membership in more than one class instead of being assigned to only one class.	Useful for mixed or gradual transitions, especially where boundaries between land-cover types are uncertain
Spectral	Classification uses only spectral information from the image.	Limited when image tone, spectral information, or radiometric consistency varies among dates or source types
Contextual	Classification uses surrounding spatial information, not only the value of a single pixel.	Useful when class assignment depends on surrounding land cover, spatial pattern, or landscape position
Spectral-contextual	Spectral and spatial/contextual information are combined.	Useful for heterogeneous imagery because interpretation can include both image values and spatial context

Table 1. Common classification methods used in land-cover mapping and their relevance to multi-source reconstruction. These approaches vary in how they define classes, use spectral and contextual information, represent uncertainty, and support consistent interpretation across historical aerial photographs and modern imagery. Adapted from Lu and Weng (2007).

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2. FINE-SCALE RECONSTRUCTION OF LAND COVER CHANGE IN THE UPPER FINN CREEK WATERSHED, CENTRAL OKLAHOMA, 1871-2023

2.1. Introduction

Land-use and land-cover (LULC) change reorganizes landscapes in ways that can persist for decades to centuries, making it a major component of global environmental change (Foley et al., 2005; Foster et al., 2003; Lambin et al., 2003). Past cultivation, grazing, settlement, fire suppression, erosion-control practices, and vegetation conversion can alter soils, vegetation structure, hydrologic pathways, disturbance regimes, and the spatial arrangement of land-cover types (Foley et al., 2005; Foster et al., 2003; Rhemtulla et al., 2009; Vanwalleghem et al., 2017). These changes can reshape biodiversity and ecosystem function by converting habitat, fragmenting vegetation, and altering ecological communities with effects that may persist beyond the initial disturbance (Bowd et al., 2021; Foley et al., 2005; Haddad et al., 2015; Newbold et al., 2015). LULC change can also affect hydrologic and land-atmosphere processes through changes in runoff, recharge, albedo, and evapotranspiration (DeFries & Eshleman, 2004; Mahmood et al., 2014; Shuster et al., 2005). As a result, present-day landscape patterns are not only products of current climate or management but also reflect accumulated land-use legacies and prior landscape trajectories (Bürgi et al., 2017; Foster et al., 2003; Osburn et al., 2021). Historical reconstruction is therefore necessary for interpreting why contemporary landscapes respond differently to similar disturbances and for identifying where past land use continues to shape ecological and hydrologic conditions.

Remote sensing time series have become central to LULC monitoring because they provide repeated, spatially explicit observations of land-cover change. Satellite archives, specifically Landsat, have provided a continuous global record of the Earth's land surface since

1972 and remains foundational for regional-to-global change detection (Cohen & Goward, 2004; Kennedy et al., 2010, 2014; Wulder et al., 2019, 2022). However, many of the land-use transitions that shaped present-day landscapes occurred before the start of the satellite record, especially those associated with settlement, cultivation, and early twentieth-century agricultural change (Kumar et al., 2013; Li et al., 2023). In addition, common satellite products such as Landsat and Sentinel-2 provide broad, repeatable coverage, but their 10–30 m optical resolutions can limit reconstruction of fine-scale historical land-cover units in heterogeneous watersheds (Schug et al., 2024; United States Geological Survey, 2019). Sentinel-2, for example, includes 10 m visible and near-infrared bands, 20 m red-edge and shortwave-infrared bands (European Space Agency, n.d.), and 60 m atmospheric correction bands, while Landsat's commonly used optical bands are 30 m (U.S. Geological Survey, n.d.). Although both are widely used for long-term land monitoring, they provide only part of the record needed for this study because many relevant land-use changes occurred before satellite observation and because older land-use legacies may be expressed through local patterns of persistence, conversion, and spatial reorganization (Kumar et al., 2013; Li et al., 2023; Wulder et al., 2022).

Addressing this problem requires integrating historical geospatial sources, such as PLS records and black-and-white aerial photography, with modern geospatial sources, such as NAIP, satellite products, and UAS imagery, rather than relying on a single image archive. Previous work has shown that long-term LULC reconstruction is possible when a combination of these sources is standardized within a common classification framework (Liu et al., 2018; Osgouei et al., 2022; Pinto et al., 2019). For example, Osgouei et al. (2022) reconstructed land-cover change from 1858 to 2020 by linking nineteenth-century cadastral records, mid-twentieth-century aerial photographs, and recent satellite imagery through a shared classification scheme. Similarly, historical aerial image studies have shown that archival photographs can be converted into informative orthophotos for long-term socioecological research (Pinto et al., 2019; Redecker, 2008; Verhoeven et al., 2013), while methodological reviews emphasize both their scientific value and their processing challenges (Kostrzewa, 2024; Morgan et al., 2010).

The main methodological challenge is not simply placing these sources in chronological order, but making them comparable (Osgouei et al., 2022). Historical plats, black-and-white aerial photographs, and modern digital imagery differ in spatial accuracy, thematic detail, image tone, acquisition conditions, and interpretive reliability (Kostrzewa, 2024; Morgan et al., 2010; Pinto et al., 2019). Consequently, long-term reconstruction requires temporal consistency in classification, meaning that land-cover categories and interpretation rules are applied as consistently as possible across years (Osgouei et al., 2022). It also requires explicit attention to uncertainty, especially where image quality, positional accuracy, or visual evidence varies among dates. In this study, these issues are addressed through a generalized land-cover legend, consistent interpretation rules, and source-specific uncertainty categories.

This reconstruction is framed through landscape ecology, which links land-cover composition, spatial configuration, and disturbance processes through time (Risser, 1987; Turner, 1989; Turner et al., 2001). Here, composition refers to the amount of each land-cover class in the watershed, while configuration refers to the spatial arrangement and connectivity of those classes (McGarigal & Marks, 1995). Disturbance is treated as an event or process that disrupts ecosystem structure and changes resource availability or the physical environment (Pickett & White, 1985). This framework is useful because a watershed can show limited net change while still experiencing major spatial reorganization. For example, cultivated land may decline overall, but former fields may transition unevenly into grassland, forest, or developed land. At the same time, forest may expand from existing wooded areas or establish in formerly open areas, while grassland may persist in some locations but become fragmented in others. Mapping these transition pathways provides a more informative record of landscape history than net area change alone.

The SGP provides a strong setting for this type of reconstruction because regional land-cover change reflects overlapping histories of Euro-American settlement, cultivation, erosion control, agricultural adjustment, fire-regime change, and woody plant encroachment. USGS assessments document substantial late twentieth-century LULC change across the Great Plains between 1973 and 2000, including regional variation in both rates and causes of change (Taylor et al., 2015). Agricultural expansion and later land-use adjustment have been major drivers of this regional history, shaped by markets, policy incentives, conservation programs, and changing land-management priorities (Spangler et al., 2020; Taylor et al., 2015). In SGP grasslands, aerial photograph studies have documented landscape-pattern changes associated with agricultural fragmentation and juniper expansion, including Coppedge et al.'s (2001) use of imagery from 1965, 1981, and 1995. Later work by the same group modeled related transitions among grassland, cropland, shrubland, juniper, and Conservation Reserve Program land (Coppedge et al., 2007). These studies show the value of a longer spatial record that connects agricultural history, land management change, and vegetation transitions within the same framework. Fire is part of that history because frequent burning can limit woody plant recruitment, while reduced fire frequency or intensity can allow fire-sensitive species such as ERC to establish and persist (Archer et al., 2017; Briggs et al., 2002; Londe et al., 2022). However, woody plant encroachment is not driven by fire alone. It also reflects interactions among grazing, land management, soils, climate, and seed availability (Archer et al., 2017; Kaur et al., 2020; Londe et al., 2022; Yang et al., 2023). In the SGP, woody encroachment can shift grassland–woodland structure, reduce habitat continuity, and alter ecosystem function (Archer et al., 2017; Fuhlendorf et al., 2017; Londe et al., 2022). Remote sensing studies provide spatial evidence of this transition, including Wang et al.'s (2017) mapping of ERC encroachment in central Oklahoma from 1984 to 2010 using Landsat imagery and PALSAR, a phased array L-band synthetic aperture radar sensor sensitive to vegetation structure and woody biomass. Subsequent related studies have examined juniper and evergreen forest encroachment across broader portions of the Great Plains and SGP (J. Wang et al., 2018; Yang et al., 2021, 2023).

A historically grounded baseline is also important for interpreting post-settlement change, particularly where major land conversion occurred before aerial or satellite records. PLS records have been widely used to reconstruct pre- and early settlement vegetation and to provide baseline context before widespread Euro-American land conversion (Bourdo, 1956; Schulte & Mladenoff, 2001; Whitney & DeCant, 2001). In Oklahoma, prior applications demonstrate how PLS-era baselines can be compared with later records to interpret landscape transitions (Fagin & Hoagland, 2014; Hoagland et al., 2013; Shutler, 2004; Watkins, 2007). At the same time, PLS records have known limitations, including surveyor bias and uneven ecological detail, requiring careful interpretation and complementary data sources (Bourdo, 1956; Schulte & Mladenoff, 2001).

In this study, PLS data provide the earliest baseline, while historical aerial photographs and NAIP imagery extend the reconstruction through the twentieth and twenty-first centuries. This sequence of sources is well suited to the UFCW in Central Oklahoma, where historical land use, cultivation turnover, grassland persistence, and woody expansion intersect within a watershed of approximately 1,300 ha. Although historical geospatial sources are available in

Oklahoma, existing studies have more often used PLS records or historical aerial photography separately rather than integrating PLS records, twentieth-century aerial photography, and twenty-first-century orthophotography into a single reconstruction spanning more than 150 years (Coppedge et al., 2001, 2007; Fagin & Hoagland, 2014; Hoagland et al., 2013, 2019; Thomas & Hoagland, 2011). Existing work has also often focused on individual processes, such as woody expansion (J. Wang et al., 2017, 2018), tree/forest cover change (Yang et al., 2021; Yao et al., 2025), or grassland fragmentation (Coppedge et al., 2001), rather than reconstructing exchanges among multiple land-cover classes. A multi-class reconstruction is needed here because cultivation, grassland, forest, water, barren, and built land did not change independently. Instead, these classes shifted in relation to one another within the same watershed. Reconstructing these exchanges at the watershed scale makes it possible to identify where transitions were concentrated and which areas experienced repeated change or long-term persistence.

The primary objective of this study is to produce a continuous, multi-temporal reconstruction of land-cover change in the UFCW from 1871 to 2023 using an integrated LULC time series. To meet this objective, I develop an integrated LULC time series by combining PLS records from 1871 and 1898, historical aerial photography from 1937 to 1990, and NAIP imagery from 2003 to 2023. I address two research questions: (1) How have the spatial composition and configuration of the watershed changed since early Euro-American settlement baseline conditions? and (2) How have LULC patterns changed over time, and what land-use history and landscape context best explain the observed transitions? I expect cultivated land to increase during early Euro-American settlement and subsequently decline as land-use practices and policies shifted. I also expect grassland-to-forest conversions to accelerate in recent decades due to woody plant encroachment, particularly ERC expansion, and reduced fire activity (Archer et al., 2017; Briggs et al., 2002).

This research makes four main contributions. First, it compiles raw and analysis-ready geospatial datasets that provide historically anchored, spatially consistent inputs for future work on land-use suitability, ecological modeling, and long-term environmental change, including potential grassland loss and woody plant encroachment. These products can support comparative studies, restoration planning, and regional assessments that require both historical baselines and contemporary conditions. Second, it advances a methodological framework for time-series analysis that combines PLS records, historical aerial photography, and NAIP imagery into a unified analysis, using detailed manual digitization of historical imagery, object-based and machine-learning classification of recent imagery, and explicit treatment of positional and thematic uncertainty. Third, it provides a detailed, long-term reconstruction of LULC change in the UFCW from 1871 to 2023. Fourth, it provides a transferable workflow for reconstructing pre-satellite landscape dynamics in heterogeneous SGP landscapes where historical sources and modern imagery must be interpreted together.

2.2 Methods

2.2.1 Study Area

The Upper Finn Creek Watershed (UFCW) is part of the Washita River drainage in the Southern Great Plains, McClain County, Central Oklahoma. It extends from 34.96405° to 35.01384° at its headwaters and -97.54298° to -97.51232° at its outlet and covers about 1299 ha. There are two impoundments in the basin created by the USDA Small Watershed Program in the mid-20th century. Specifically, Finn Creek Site 21 Reservoir (Finn Lake) is located on the main creek, and the Site 22 Reservoir is located on an East tributary (Figure 1). The climate is humid subtropical (Cfa) type (Peel et al., 2007), with mean annual temperature of 16 °C, July maximum near 28 °C and a January minimum near 4 °C (Oklahoma Climatological Survey, 2025). Mean annual precipitation is 978 mm, and May is typically the wettest month. Physiographically, the study area lies within the Western Red-bed Plains, a landscape of gently rolling hills and broad, flat plains formed on Permian red shales and sandstones (Johnson & Luza, 2008). Within the UFCW, elevation ranges from 313 to 383 m, representing 70 m of local relief, and the median slope is 6.33% based on DEM-derived terrain metrics. Two upland soil map units predominate in the study area. First, the Nash-Lucien complex occurs on gently to moderately sloping uplands and is associated with shallow to moderately deep soils developed over reddish, weakly consolidated calcareous sandstone (Soil Survey Staff, n.d.). Second, Stephenville fine sandy loam is a common upland soil; the Stephenville series is well drained, occurs on hillslopes, and typically has a loamy fine sand to fine sandy loam surface over sandy clay loam subsoil, with paralithic contact at approximately 20–40 inches (Soil Survey Staff, n.d.).

The potential/historical vegetation type for the watershed is tallgrass prairie in the south, and Post Oak-Blackjack Oak Forest type (colloquially known as Cross Timbers) in the north (Duck & Fletcher, 1943; Tyrl et al., 2007). The upland forests and woodlands are dominated by post oak (*Quercus stellata*) and blackjack oak (*Quercus marilandica*) with common associates including black hickory (*Carya texana*), Shumard oak (*Q. shumardii*), chittamwood (*Sideroxylon lanuginosum*), sugarberry (*Celtis laevigata*), and hackberry (*Celtis occidentalis*). Toward the south, the tallgrass prairie formed a waist- to chest-high sward (1-3 meters) dominated by big bluestem (*Andropogon gerardi*), little bluestem (*Schizachyrium scoparium*), Indiangrass (*Sorghastrum nutans*), and switchgrass (*Panicum virgatum*), with numerous perennial forbs (Duck & Fletcher, 1943; Tyrl et al., 2007).

Since Euro-American settlement in the late nineteenth century, native prairie and woodlands were converted primarily to rangeland and croplands (Hoagland, 2000). Mid-twentieth century construction of flood control reservoirs altered local hydrology and created open-water features. Although the watershed lies near the transition between tallgrass prairie and Cross Timbers, the land-cover documented now, as is true for much of the SGP, primarily reflects human land use and management since Euro-American settlement rather than long-term ecotonal boundary shifts (Archer et al., 2017; Meneguzzo & Liknes, 2015; J. Wang et al., 2017). The current landscape is characterized by grassland-pasture with limited cropland in the north, and bottomland forests along Finn Creek and its tributaries. Similar to other areas across the Great Plains, fire suppression and grazing have facilitated woody plant encroachment, particularly the expansion of ERC into open grasslands (Archer et al., 2017; Kaur et al., 2020; J. Wang et al., 2017).

PLS records in Oklahoma provide baseline conditions of how the landscape looked like before widespread Euro-American settlement. Specifically, the 1870s survey and plat depicted predominantly two land cover classes, grassland (recorded as prairie), and forest/woodland (Figure 2). In the survey, it speaks of a single cattle trail that traverses the southern part of the watershed but apart from that, there is no mention of human population, cultivation, or other land use. By the 1890s survey, reports of wire fencing throughout the watershed and the clearing of former forests indicate that settlement and land-use change had occurred. Multiple trails were plotted on the map, and an agricultural field was shown in the southeastern portion of the watershed. In the township description, the surveyors also noted one settlement located just outside the watershed boundary. They estimated the township population at 96 individuals and reported that residents were engaged in stock raising. Tree taxa recorded within the watershed included post oak and blackjack oak. There was no mention of juniper species anywhere in the field notes for either survey, although this does not rule out their presence. Because PLS records were not designed as systematic vegetation surveys, surveyor bias and uneven ecological detail may have influenced which species were recorded and which were omitted.

2.2.2 Data Sources Utilized for LULC Change Analyses

Three data sources spanning the years 1871-2023 were used to quantify land cover change (Table 2): (i) Public Land Survey (PLS) plats (1871, 1898), (ii) historical aerial photography (1937, 1949, 1956, 1969, 1981, 1990), and (iii) NAIP aerial imagery (2003, 2013, 2023). The PLS plat for Township 6N Range 3W were downloaded from the Bureau of Land Management (https://glorecords.blm.gov/). These plats depict rivers, roads and railroads, fences, settlements, cultivated areas, and prairie/forest notations, and are accompanied by field notes including township summaries, line descriptions, and bearing tree records. Historical aerial photographs were obtained as digital scans of film acquired from associated agencies at map scales between 1:20,000-1:58,000 (Table 2). All frames are in greyscale except for the 1981 false color-infrared imagery. NAIP tiles were downloaded from USGS EarthExplorer (https://earthexplorer.usgs.gov/) at 1 meter spatial resolution for 2003 and 2013, and 0.3 meter for 2023. All NAIP years include visible color (red-green-blue) bands and near-infrared is available for 2013 and 2023.

2.2.3 Preprocessing and Georeferencing

The 1870s plat was manually digitized previously from paper documents into a working land-cover database for the 1870s Oklahoma Territory and Chickasaw Nation (Hoagland, unpublished). The 1890s plat was georeferenced herein to Township-Range-Section grids (Chickasaw baseline) available from the Oklahoma Office of Geographic Information (https://okmaps.org/ogi/). Control points targeted section corners identifiable on both the plat and the base reference.

Historical aerial photographs with existing spatial referencing from the Oklahoma Historical Aerial Digitization Project (OHADP) were re-georeferenced to ensure consistency across years. Stable features such as section corners, fence-line junctions, road intersections, and building corners served as ground control points, with 4–15 points per image and higher counts where obliquity or relief was evident. All imagery was transformed to NAD 1983 (2011) Contiguous USA Albers (EPSG:6350). First-order polynomial transformations were used when the photograph could be aligned through basic shifting, rotating, scaling, and skewing. Second-order transformations were used only when a photograph showed systematic curvature or tilt that could not be corrected with a simpler transformation. A target root mean square error (RMSE) of less than 8 m was applied to each image, and any frame exceeding that threshold was flagged and georeferenced again. One 1949 photograph required a third-order transformation because lower-order transformations did not meet the RMSE target or align consistently with stable reference features. This higher-order transformation was treated as an exception because it allows more local adjustment and can distort areas away from control points if used unnecessarily. NAIP tiles were used in their existing orthorectified form and reprojected to EPSG:6350 for analysis.

2.2.4 Image Classification and Interpretation

Features on the georeferenced images were manually digitized at mapping scales between 1:1,000 and 1:4,000 to maintain consistency across years. All years used a six-class legend – Forest, Grassland, Cultivation, Water, Built, and Barren – adopted from Anderson (1976). Pasture was merged into the grassland class due to the difficulty in discerning the two separately. The minimum mapping unit was 0.2 ha. Topology was enforced during digitizing to prevent gaps and overlaps, and snapping tolerance was set to 1 m. The PLS plat was interpreted and digitized directly from the georeferenced sheets. The PLS category 'Timber' was mapped as the Anderson class forest, 'Prairie' as grassland, and 'field' as cultivation. PLS field notes were consulted to confirm the extent of forest versus grassland but were not used to infer vegetation composition.

Historical aerial photographs (1937–1990) were interpreted through manual photo-delineation due to cross-year variability in illumination, film type, acquisition timing, and frame tilt (Kostrzewa, 2024; Morgan et al., 2010). A written key was used for interpreting based on the elements of image interpretation (Lillesand et al., 2015): tone, shape, size, texture, color, shadow, location, depth, and site/association. To limit shadow inflation of canopy extent, delineation referenced overlapping photos where available and used consistent edge cues (i.e. tone and texture of leaves, crown shapes, gaps between trees) across the frame set. Post-editing removed islands below the minimum mapping unit and removed any overlapping features.

NAIP imagery (2003, 2013, 2023) was classified using an object-based workflow. Segment Mean Shift in ArcGIS Pro was applied to RGB for all years. Segment features included active chromaticity color, mean digital number, standard deviation, count of pixels, compactness, and rectangularity. A Random Forest classifier with 200 trees was trained using stratified samples for each class. The resulting maps were reviewed to ensure consistency with PLS-derived and historical aerial photograph-derived land-cover layers. Context rules and the written interpretation key described above were then used to refine ambiguous classes. For example, linear and rectilinear patterns with high reflectance were favored for the built classification, and persistent open water connected to channels was favored for the water classification. Cross-year standardization prioritized legend consistency over within-year detail. Mixed pixels or objects at class boundaries were assigned using the dominant cover within the object and verified against adjacent years to reduce implausible one-off transitions.

2.2.5 Accuracy Assessment and Uncertainty

Positional accuracy was summarized by image-level RMSE from the georeferencing step. Photos with RMSE above 8m were corrected and re-evaluated. Thematic accuracy was assessed for each mapped year using a modified stratified random sampling approach. The total sample size was computed using Cochran's formula for stratified sampling (1946):

$$n = \left(\frac{\sum_{i=1}^{L} W_i S_i}{S(\hat{O})}\right)^2$$

where W_i is the mapped proportion of class i, $S_i = \sqrt{U_i(1 - U_i)}$ is the within-class standard deviation derived from expected user's accuracy U_i, and $S(\hat{O})$ is the desired standard error of overall accuracy set to 0.025. Samples were then allocated across classes using Neyman's optimal allocation (1992):

$$n_i = n \cdot \frac{W_i S_i}{\sum_{j=1}^{L} W_j S_j}$$

A minimum of 10 samples per class was imposed to ensure adequate representation of rare classes, and the remaining samples were distributed proportionally according to mapped area.

Each sample point was assigned two labels: the mapped class from the classified land-cover layer and a reference class interpreted from the source imagery for the target year. When needed, adjacent-year imagery was used only as supporting context to resolve ambiguous boundaries or temporary artifacts, but the final reference label was based on the target-year evidence. These mapped and reference labels were cross-tabulated in an error matrix for each year, with mapped classes represented as rows and reference classes represented as columns (Stehman, 1997). For each class, user's accuracy was calculated as the number of correctly classified samples in that mapped class divided by the total number of samples mapped as that class. This measures the reliability of the mapped class from the map user's perspective and is the complement of commission error. Producer's accuracy was calculated as the number of correctly classified samples in a reference class divided by the total number of reference samples for that class. This measures how well the classification captured the reference class and is the complement of omission error. Overall accuracy was calculated as the total number of correctly classified samples divided by the total number of samples. The Kappa coefficient was also calculated from the error matrix as an additional summary measure of agreement (Congalton & Green, 2019; Stehman, 1997).

PLS-based maps were treated as interpreted baselines. Because photo validation is not possible for 1871 and 1898, accuracy for those years could not be assessed systematically. Other consistency checks included agreement with PLS field notes, agreement with later imagery, and absence of improbable land-cover configurations.

2.2.6 Land Use Land Cover Change Frequency Assessment

To identify where land cover remained stable, changed once, or changed repeatedly through time, a change index map was created for the UFCW from 1871 to 2023. This index was used to distinguish areas of long-term persistence from areas of repeated land-cover turnover and to locate portions of the watershed where transitions relevant to management and woody expansion were concentrated. Change frequency was calculated between each consecutive map year and across two multi-decadal intervals: 1871-1937 and 1981-2023. A transition matrix was built from the final classified maps to summarize land-cover gains, losses, net change, and swap for each class. Targeted transitions focused on processes relevant to management and woody expansion, including forest-to-grassland, cultivation-to-grassland, grassland-to-cultivation, cultivation-to-forest, and forest-to-cultivation. All outputs included per-year class areas with confidence intervals, complete transition tables, and a change index map highlighting areas of persistence, single change, and repeated change. Chapter 3 uses these standardized products to evaluate ERC expansion in detail within a smaller study area.

2.3 Results

2.3.1 Classification Products

Across the eleven mapped years (1871-2023), land cover was consistently dominated by grassland, forest, and cultivation, whereas water, built, and barren remained minor components of the landscape in the 1299 ha of UFCW (Table 3; Figures 3-5). In 1871, the watershed consisted of 706.2 ha of grassland (54.4%) and 592.7 ha of forest (45.6%), with no mapped cultivated, built, barren, or water classes. By 1937, cultivated land had expanded to 747.6 ha (57.6%), representing the highest cultivated extent in the time series and coinciding with the lowest mapped grassland extent (260.4 ha; 20.0%). Grassland later increased to a maximum of

799.2 ha (61.5%) in 1990, whereas forest declined to a minimum of 189.7 ha (14.6%) in 1981 before increasing to 459.0 ha (35.3%) by 2023. Water, built, and barren features first appeared in 1937 and remained collectively limited in extent throughout the record, with water mostly appearing after the construction of mid-20th-century impoundments in the 1969 photos.

2.3.2 Composition Through Time

Using 1871 as the historical baseline, the watershed exhibited a long-term trajectory characterized by (i) an early expansion followed by decline in cultivation, and (ii) a late-period increase in forest cover (Table 3; Figures 3-5). Forest cover declined from 592.7 ha in 1871 to 189.7 ha in 1981, then increased to 459.0 ha by 2023. Grassland remained the dominant class in most years, increasing from 706.2 ha in 1871 to 799.2 ha in 1990, before declining to 660.8 ha in 2023. Cultivated land was absent in 1871, appeared by 1898 (23.3 ha), peaked in 1937 (747.6 ha), and then declined steadily to 74.6 ha by 2023.

Relative to 1871, forest cover showed a net loss of 133.7 ha by 2023, or 10.3% of the total watershed area, while grassland showed a net loss of 45.4 ha. Cultivated areas followed a rise-and-decline trajectory, increasing to 747.6 ha, 57.6% of the total area, above baseline in 1937 before declining to 74.6 ha, 5.7% of total area, by 2023. Minor classes remained limited in areal extent. Water cover increased from 0.5 ha in 1937 to 27.7 ha in 2023, built areas increased from 10.6 to 25.0 ha over the same period, and barren features increased from 1.4 ha in 1937 to a peak of 70.2 ha in 2013 before declining to 51.8 ha in 2023 (Table 3).

2.3.3 Accuracy Assessment and Uncertainty

Thematic accuracy for the mapped years with available imagery indicated consistent classification performance across the time series. Overall accuracy ranged from 80.7% to 91.8%, with a median of 86.0% (Table 4). User’s accuracy was highest for water and lowest for grassland, whereas producer's accuracy was highest for grassland and lowest for cultivated. The lower-performing years were associated with archival imagery conditions that increased interpretive difficulty, including variable illumination, shadowing, tonal similarity among classes, and geometric distortion. Confusion was greatest along boundaries between grassland and cultivated areas and in locations with scattered woody cover or mixed patch structure.

Accuracy assessment for 1871 and 1898 was not comparable to later years because those maps were derived from PLS plats and no imagery existed for either period. In contrast, later classifications were evaluated using their corresponding source images. These two years were therefore treated as interpreted historical baselines and were evaluated using ancillary consistency checks, including agreement with PLS field notes, internal consistency with plat labels, and plausibility relative to later aerial imagery. In contrast, later classifications were evaluated using their corresponding source images. Uncertainty in class-area estimates was represented using 95% confidence intervals which indicated generally similar precision across mapped years despite differences in source material.

2.3.4 Interval Transition Rates and Targeted Flows

Targeted transitions among forest, grassland, and cultivated classes varied substantially across consecutive intervals (Figure 7; Table 3). Expressing change as annualized rates (ha yr^{-1}) allowed comparison among intervals of unequal duration. The largest transition rates were associated with cultivation expansion in the early part of the time series and with grassland-to-forest conversion in the later part of the series. Transitions from cultivation to grassland were also prominent in several post-1937 intervals, indicating repeated reallocation of formerly cultivated land to non-cultivated cover probably for grazing. Overall, the transition rate results show a shift from early dominance of cultivation-related conversions to later dominance of grassland-forest exchange.

2.3.5 Net Outcomes by Time Interval

Net change rates by class and interval further illustrate the shift in dominant landscape processes through time (Figure 8). Forest showed net loss through 1981, followed by net gain in subsequent years. Grassland showed the opposite pattern, with earlier net gains and more recent net losses, mostly being conversion to forest. Cultivation showed net decline from 1969 onward, with the strongest decrease occurring during 1981-1990. Intervals with values near zero indicate periods of relatively limited net change despite ongoing gross exchanges among classes.

2.3.6 Spatial Patterns of Change

Spatial summaries showed that dominant transitions were not uniformly distributed across the watershed (Figure 9). During 1871–1937, grassland-to-cultivated conversion was concentrated primarily in the southern and eastern portions of the watershed, with more scattered forest-to-grassland transitions. During 1981-2023, grassland-to-forest conversion was widespread across the watershed, whereas cultivated-to-grassland transitions were concentrated mainly in the northern and southeastern areas.

The change-frequency map showed that some locations changed class repeatedly across the eleven mapped years, whereas others remained comparatively stable (Figure 10). Areas of highest change frequency were associated with zones of repeated exchange among grassland, cultivation, and forest classes, while lower-frequency areas corresponded to more persistent land-cover states across the record.

2.4 Discussion

2.4.1 Long-Term Trajectories of Cultivation, Grassland, and Forest

The long-term reconstruction of land cover in the Upper Finn Creek Watershed shows a sequence of change that is clearer when the mapped years are read as phases rather than as isolated snapshots. The first phase is marked by rapid expansion of cultivation after settlement, culminating in a mid-twentieth century landscape in which cultivation occupied more of the watershed than any other class. The second phase is characterized by declining cultivation and partial recovery of grassland. The third phase, most evident after 1981, is marked by renewed forest increase through widespread grassland-to-forest transitions. These phases indicate that the modern watershed is not simply the product of recent vegetation change, but the cumulative result of settlement-era conversion, twentieth-century land-use change, and more recent woody expansion.

The scale of early agricultural change was substantial. Forest declined sharply from its early-settlement extent, while cultivation expanded rapidly and became the dominant cover by 1937. Rather than reflecting gradual adjustment, this phase marks widespread conversion of grassland and forest to cultivation across the watershed. This rise-decline trajectory in cultivation is consistent with broader agricultural change documented elsewhere in the Great Plains, where widespread conversion of native grasslands was followed by later turnover in agricultural land use, including cropland contraction, abandonment, and reversion to pasture, rangeland, or other covers in some areas (Drummond et al., 2012; Lubowski et al., 2006; Xie et al., 2024). Elsewhere in North America, agricultural extent has likewise expanded and contracted over time in response to changing profitability, policy, technology, and environmental constraints (Lubowski et al., 2006; Waisanen & Bliss, 2002). In the UFCW, those broad processes are expressed in a more localized form: cultivation expanded rapidly, became structurally dominant by 1937, and then receded over subsequent decades rather than remaining fixed once established.

The decline in cultivation after the mid-twentieth century is especially important because formerly cultivated areas followed multiple post-agricultural trajectories, including abandonment, conversion to grazing or pasture, woody expansion, and other land-cover changes (Figures 4–6). In some parts of the watershed, formerly cultivated land was later mapped as grassland or pasture, contributing to the late century increase in grass cover. In other places, land previously under cultivation appears to have entered a longer transition toward woody cover. This distinction matters because it suggests that agricultural retreat did not simply restore the watershed to pre-settlement conditions. Instead, it produced a mosaic of land-use legacies in which past conversion continued to shape subsequent vegetation dynamics (Osburn et al., 2021).

That interpretation is especially important in the SGP because the decline of cultivation after the early 20th century occurred within a broader regional history of drought, soil erosion, and conservation intervention. During the 1930s, Oklahoma was part of the Dust Bowl region, where drought, exposed cultivated soils, and land-management practices contributed to severe wind erosion and topsoil loss. In Oklahoma, erosion was already a major concern by the 1930s, and state and federal conservation efforts promoted practices intended to stabilize agricultural landscapes, including contouring, terracing, strip cropping, fallow management, and shelterbelts (Z. K. Hansen & Libecap, 2004; Oklahoma Conservation Commission, n.d.; Hoagland, 2010). These practices mean that later increases in grassland or woody cover should not be interpreted as simple ecological return. They may instead reflect a combination of abandoned or retired cultivation, grazing use, erosion-control infrastructure, altered hydrology, and conservation plantings.

Shelterbelt and windbreak planting further complicate the interpretation of later woody expansion. The Prairie States Forestry Project began in mid-1930s in response to Dust Bowl drought and wind erosion, with the goal of planting shelterbelts across Great Plains states to protect crops, wildlife, and soils from wind, blowing snow, and sand (Hoagland, 2010). ERC and Rocky Mountain juniper were also extensively planted in Great Plains windbreaks and other conservation plantings, which increased planted tree cover and may have increased local seed sources for later spread (Cunningham & King, 2000). Therefore, woody cover that appears in later imagery should be interpreted as a land-use legacy as well as a vegetation transition. In the UFCW, the reconstruction cannot distinguish every planted windbreak from spontaneous woody expansion, but it does show that twentieth-century land management created conditions under which woody cover could persist and spread.

The increase in grassland after cultivation declined should therefore be interpreted as expansion of open herbaceous or pasture-like cover, not as grassland recovery. Some of this increase likely reflects post-cultivation land entering grazing, pasture, or conservation-oriented cover rather than a deliberate return to historical prairie structure. This interpretation is consistent with broader Great Plains land-change studies showing that agricultural land use expanded and contracted unevenly through time, with agriculture-to-grassland conversions becoming especially important during the Conservation Reserve Program period in the late twentieth century (Drummond et al., 2012; Taylor et al., 2015). Work in Oklahoma grassland landscapes has also documented increases in pasture associated with CRP activity and simultaneous increases in juniper woodland, mixed woodland, and other post-agricultural cover types (Coppedge et al., 2007). Thus, the mapped grassland increase in the UFCW is better understood as a post-cultivation land-cover pathway shaped by grazing, conservation programs, and prior soil disturbance, rather than as a return to pre-settlement prairie.

The recent increase in forest cover represents a different process from the earlier rise in cultivation and the later expansion of grassland-pasture. Forest extent increased from 189.7 ha in 1981 to 459.0 ha in 2023, yet it did not return to the 1871 baseline. Rather, the mapped transitions suggest widespread woody expansion into areas that had long functioned as cultivated land, grassland, pasture, or other managed open cover. This pattern is more consistent with encroachment and post-agricultural woody expansion than with restoration. It indicates that the late-period landscape was being reshaped by vegetation change operating within the legacy of earlier land conversion, soil disturbance, erosion-control practices, grazing, and altered fire regimes.

Studies done in Oklahoma support this interpretation. A Soil Conservation Service survey reported that ERC and ashe juniper had invaded almost 1.5 million acres in Oklahoma by 1950 and 3.5 million acres by 1985, showing that juniper expansion was already a major statewide land-cover issue during the twentieth century (Bidwell et al., 2009). More recent work in Oklahoma has linked ERC encroachment to fire exclusion, broad soil and climate tolerance, seed dispersal by birds, and site conditions such as soil texture and productivity (Kaur et al., 2020). Remote-sensing work in the SGP by J. Wang et al. (2017) and Yang et al. (2023) show continued evergreen forest encroachment across Oklahoma, Kansas, and Texas. In the UFCW, the timing of forest increase after 1981 and the prevalence of grassland-to-forest transitions suggest that woody expansion is part of this broader Oklahoma and SGP process, although its local expression was conditioned by prior cultivation, grazing, erosion-control features, and proximity to existing wooded areas.

Fire suppression remains a key mechanism, but it should not be treated as the only explanation. In fire-maintained systems, frequent burning historically limited establishment of fire-sensitive woody species and helped maintain open structure (Archer et al., 2017; Fuhlendorf et al., 2017). In Oklahoma and the broader SGP, fire exclusion beginning in the mid-twentieth century allowed ERC to establish beyond its former habitats, while grazing, soil conditions, climate, land management, and seed availability also influenced where encroachment occurred (Archer et al., 2017; Kaur et al., 2020; Londe et al., 2022; Yang et al., 2023). For the UFCW, this means the mapped forest increase should be interpreted as the outcome of interacting land-use and disturbance legacies rather than as a single-process vegetation shift.

2.4.2 Spatial Pattern, Patch Dynamics, and the Value of Fine-Scale Reconstruction

Area-based trends describe how land cover changed through time, whereas the spatial distribution of transitions shows how those changes were organized across the watershed. The early spread of cultivation did not occur as scattered, isolated conversions, but as relatively large and contiguous patches concentrated in particular parts of the watershed. That pattern is consistent with the spatial logic of agricultural field creation, which tends to produce more regular and rectilinear patch forms than those associated with native vegetation mosaics (Turner et al., 2001). In the UFCW, cultivation expanded broadly across the watershed in relatively coherent blocks, producing a pattern that differed from the more diffuse and patchy character of later woody increase. This shift changed not only the relative extent of land-cover classes, but also the spatial structure of the landscape.

The later increase in forest looks very different. Instead of appearing as a single large block of expansion, it is distributed across numerous smaller grassland-to-forest transitions. That pattern suggests spread, infilling, and coalescence of woody patches rather than a uniform front of regeneration. In practical terms, the difference matters. Large cultivation patches imply direct and concentrated landscape transformation, whereas smaller and more spatially diffuse woody transitions imply gradual encroachment operating through patch expansion, local establishment, and boundary movement. These are different mechanisms, and they leave different landscape signatures. This is where the patch-based reconstruction becomes especially valuable. Many satellite-derived land-cover products are built at 30m resolution or coarser, which can generalize small forest patches, small cultivated fields, and narrow linear features. Higher-resolution studies have shown that finer spatial data preserve patch shape, detect smaller patches, and better capture narrow features that are often simplified or lost in coarser imagery (Boyle et al., 2014; Lechner et al., 2009). In a watershed such as the UFCW, where change often occurs through small patch transitions and irregular edge movement, that difference is not trivial. It affects what kinds of trajectories can be seen at all.

By combining PLS records, historical aerial photography, and modern aerial imagery, this study captures patch-level dynamics across more than a century of change. That makes it possible to trace pathways such as grassland-to-cultivation-to-grassland and grassland-to-forest, rather than only comparing beginning and end states. Those pathways are important because they reveal that current land cover is not simply the product of present conditions, it is structured by the order and timing of past transitions. In other words, the method does not just improve spatial detail. It improves historical interpretation.

Landscape ecology has long emphasized that ecological processes depend not only on the amount of habitat present, but also on how it is arranged (Haddad et al., 2015; Turner et al., 2001). In that context, the patch structure documented here has implications beyond cartographic description. Changes in patch size, edge density, and connectivity can affect species movement, ecological interactions, and the way disturbances propagate across the landscape (Haddad et al., 2015; Turner et al., 2001). Although this study did not quantify landscape metrics directly, the mapped transitions indicate clear differences in how change was organized spatially through time. In the UFCW, the contrast between earlier broad cultivation expansion and later diffuse woody increase suggests that the watershed has experienced not only shifts in dominant cover, but repeated restructuring of the spatial pattern through which ecological processes operate.

The broader implication is that fine-scale historical reconstruction is not only useful for documenting what changed. It is also necessary for understanding how change was organized spatially and how those arrangements may continue to matter. Similar legacy studies have shown that historical land use can leave long-lasting effects on present-day vegetation, biodiversity, and ecosystem processes (Johnstone et al., 2016; Le Provost et al., 2020). The UFCW appears to fit that pattern. The present landscape reflects not just current management or current vegetation dynamics, but the accumulated imprint of earlier cultivation, later abandonment or turnover, and subsequent woody expansion.

2.4.3 Uncertainty and Interpretation of Historical Baselines

Although the reconstruction provides a detailed view of long-term change, the results should still be interpreted with appropriate caution. One source of uncertainty comes from the imagery itself. Historical aerial photographs vary in quality, acquisition conditions, illumination, and seasonality, all of which can influence interpretation and classification performance (Chalençon et al., 2025; Morgan et al., 2010). In this study, those issues are most likely to affect boundaries between grassland and cultivation, particularly where tonal contrast is weak, vegetation condition is transitional, or field edges are indistinct. The accuracy assessment indicates that overall classification performance is reliable, but the persistence of some confusion between these classes means that fine differences in area should be interpreted more cautiously than the broader multi-decadal trends.

A second source of uncertainty lies in the historical baseline itself. PLS plats were not created for ecological mapping and therefore contain known limitations, including surveyor bias, selective witness-tree recording, uneven taxonomic detail, and variation in survey practice (Bourdo, 1956; Manies et al., 2001; Schulte & Mladenoff, 2001). For that reason, the 1871 and 1898 maps are best treated as interpreted historical baselines rather than as classification products fully equivalent to later aerial-image-derived maps. Their value lies in establishing broad early-settlement structure and context, not in providing the same level of thematic precision available for later years.

At the same time, these limitations do not negate the larger findings. The consistency of the major trends across multiple independent sources—PLS records, historical aerial photographs, and modern aerial imagery—supports the interpretation that the watershed underwent substantial agricultural expansion followed by later decline in cultivation and a more recent increase in woody cover. The exact boundaries of individual patches may contain uncertainty, especially in the earliest years, but the overall direction and sequence of change are well supported. For that reason, the historical reconstruction is best understood as an uncertainty-aware interpretation of long-term landscape trajectory rather than as a claim of exact equivalence across all years and source types.

2.5 Conclusion

The results show that long-term landscape change in the Upper Finn Creek Watershed was shaped by the interaction of land use and disturbance over more than a century. Early agricultural expansion reorganized much of the watershed during the first half of the twentieth century, followed by later decline in cultivation and increasing woody cover in recent decades. These shifts indicate that present-day landscape structure reflects not a single transition, but the cumulative effects of settlement-era conversion, subsequent land-use turnover, and later vegetation change.

By reconstructing land-cover change at patch-level resolution across both the pre-satellite and satellite eras, this chapter provides a historically grounded interpretation of contemporary landscape conditions. The reconstruction shows that current patterns of grassland, forest, and cultivation cannot be fully understood without reference to earlier land-use history and its lasting spatial legacies. More broadly, this approach demonstrates the value of integrating PLS records, historical aerial photography, and modern imagery to examine long-term change in heterogeneous landscapes. Such reconstructions provide a critical historical basis for understanding present ecosystem dynamics and for informing management aimed at conserving grasslands and responding to ongoing woody encroachment.

Chapter 2 Figures and Tables

Image Year	File Name \ Flight Number	Date Taken	Image Source	Agency / Program	Scale	Image Cell Size (m)	Band Type
1871	OK170060N0030W00001	03/1871	GLO Records (T6N R3W IM) [Survey Plat]	BLM	Unknown	N/A	N/A
1898	OK170060N0030W00002	03/1898	GLO Records (T6N R3W IM) [Survey Plat]	BLM	Digitized at 1:5,000	4.1	N/A
1937	AE-043- 046, 048 AE-044- 010, 012	2/9/1937 2/10/1937	National Archives	SCS (Now NRCS)	1:20,000	~0.48	BW
1949	CQY-6F- 18, 20, 63, 65	6/22/1949	OCC	FSA	1:20,000	~1.70	BW
1956	CQY-5R- 771, 791, 811 & CQY-6R- 441, 461	6/25/1956	OCC	FSA	1:20,000	~1.77	BW
1969	CQY-3LL- 171, 173, 175 & CQY-3LL- 231, 233, 235	12/12/1969	OCC	FSA	1:20,000	~1.84	BW
1981	HAP81_153_24	9/19/1981	USDA APFO	USGS (NHAP Program)	1:58,000	0.79	CIR
1990	6940_217	12/11/1990	USDA APFO	FSA	1:40,000	0.50	BW
2003	n_3409704_ne_14_1_20030628 n_3509760_se_14_1_20030628	6/28/2003	USGS Earth Explorer	NAIP	N/A	1	NC
2013	m_3409704_ne_14_1_20130610 m_3509760_se_14_1_20130610	6/10/2013	USGS Earth Explorer	NAIP	N/A	1	M4B
2023	m_3409704_ne_14_030_20230619 m_3509760_se_14_030_20230619	6/19/2023	USGS Earth Explorer	NAIP	N/A	0.3	M4B

Note. GLO = General Land Office; BLM = Bureau of Land Management; SCS = Soil Conservation Service (now NRCS = Natural Resources Conservation Service); OCC = Oklahoma Conservation Commission; FSA = Farm Service Agency; USDA APFO = U.S. Department of Agriculture Aerial Photography Field Office; USGS = U.S. Geological Survey; NHAP = National High Altitude Photography; NAIP = National Agriculture Imagery Program; BW = black-and-white (panchromatic); CIR = color-infrared; NC = natural color; M4B = four-band imagery (red, green, blue, and near-infrared).

Table 2. Data sources used to quantify land-cover change in the Upper Finn Creek Watershed, 1871–2023.

Land Cover Class	Area (hectares) by Year										
	1871	1898	1937	1949	1956	1969	1981	1990	2003	2013	2023
Grassland	706.2	730.7	260.4	533.0	541.1	545.4	644.0	799.2	726.8	683.0	660.8
Forest	592.7	544.9	278.4	308.1	288.9	213.0	189.7	273.0	353.2	359.9	459.0
Cultivated	0.0	23.3	747.6	414.4	447.7	467.5	409.9	170.6	125.4	118.0	74.6
Built	0.0	0.0	10.6	18.4	11.7	29.4	24.9	23.8	28.4	38.5	25.0
Barren	0.0	0.0	1.4	23.1	8.3	15.1	4.4	8.0	40.2	70.2	51.8
Water	0.0	0.0	0.5	1.9	1.2	28.6	26.1	24.4	25.0	29.3	27.7

Table 3. Land-cover class areas (ha) by mapped year in the Upper Finn Creek Watershed, 1871–2023.

Year	Forest		Grassland		Cultivation		Water		Built		Barren		Overall Accuracy	Kappa Coefficient
	PA	UA	PA	UA	PA	UA	PA	UA	PA	UA	PA	UA		
1871	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1898	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1937	95%	100%	97.4%	52.1%	66.7%	92.5%	100%	100%	58%	100%	91%	100%	80.7%	0.74
1949	84.4%	97.4%	92.9%	80.2%	91%	100%	91%	100%	77%	100%	84.6%	64.7%	88.9%	0.85
1956	93.0%	95.2%	94.3%	75.0%	66.7%	97.6%	100%	100%	92%	100%	100%	79%	86.5%	0.82
1969	76.5%	92.9%	91.5%	77.4%	74.2%	90.2%	93%	100%	92.9%	76.5%	91.7%	78.6%	84.1%	0.79
1981	87.5%	93.3%	95.1%	78.0%	59%	100%	100%	100%	92.3%	92.3%	81.8%	60.0%	81.6%	0.75
1990	78.0%	94.1%	98.0%	82.9%	62%	100%	100%	100%	100%	100%	90.9%	90.9%	88.8%	0.83
2003	90.0%	84.9%	92.3%	82.4%	50.0%	92.3%	76.9%	90.9%	78.6%	73.3%	73.3%	84.6%	83.6%	0.77
2013	93.9%	90.2%	96.5%	84.7%	37.5%	100%	100%	100%	93.3%	93.3%	66.7%	63.2%	86.0%	0.81
2023	96.7%	93.7%	96.4%	91.0%	73.7%	93.3%	85.7%	92.3%	92.3%	85.7%	75.0%	92.3%	91.8%	0.89
Mean	**88%**	**94%**	**95%**	**78%**	**65%**	**96%**	**94%**	**98%**	**86%**	**91%**	**84%**	**79%**	85.8%	0.81
Median	**90%**	**94%**	**95%**	**80%**	**67%**	**98%**	**100%**	**100%**	**92%**	**93%**	**85%**	**79%**	86.0%	0.81

Note. N/A = not applicable**.** PA = producer's accuracy, the percentage of a class's actual (reference) area correctly classified, reflecting omission error. UA = user's accuracy, the percentage of a class's mapped area that matches the reference data, reflecting commission error. Overall Accuracy = the percentage of all sampled points correctly classified across all classes. Kappa Coefficient = a chance-corrected agreement statistic ranging from 0 (agreement no better than random) to 1 (perfect agreement), calculated from the full confusion matrix.

Table 4. Thematic accuracy assessment by classification year for six land-cover classes (Forest, Grassland, Cultivation, Water, Built, and Barren). Mean and median values summarize accuracy across all mapped years for each metric. Accuracy for 1871 and 1898 was assessed using ancillary consistency checks against PLS plats and field notes rather than source imagery, as no imagery exists for those periods; all other years were assessed against their corresponding source imagery.

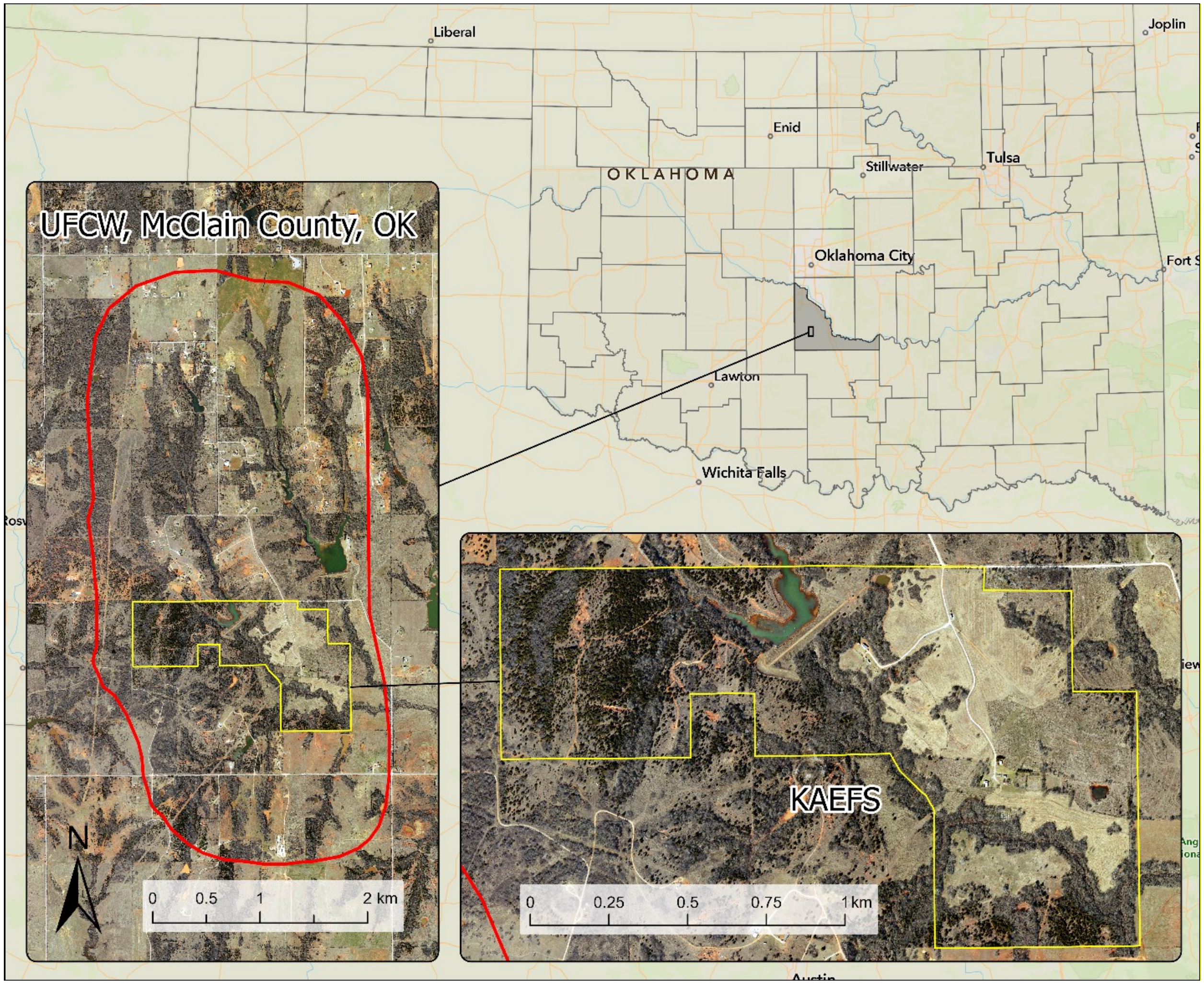
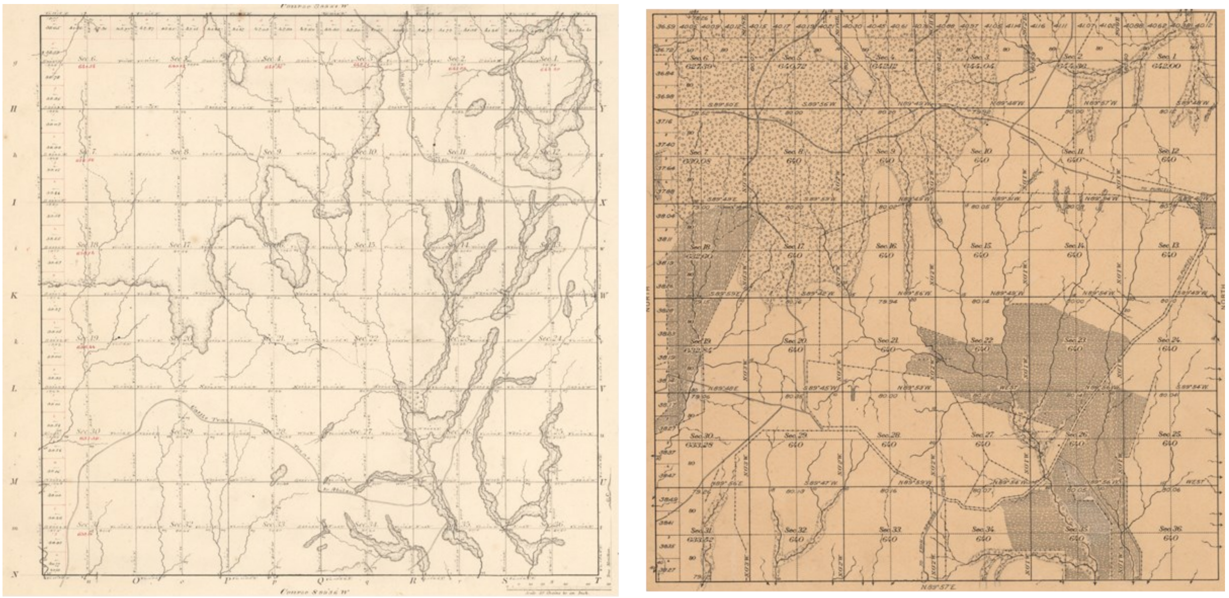


Figure 1. Location of the Upper Finn Creek Watershed (UFCW) in McClain County, Oklahoma. Nested within this watershed is the University of Oklahoma's Kessler Atmospheric and Ecological Field Station (KAEFS).



1871 1898

Figure 2. Public Land Survey System (PLSS) plats from surveys conducted in Oklahoma, showing Township 6 North, Range 3 West, Indian Meridian (T6N, R3W, I.M.).

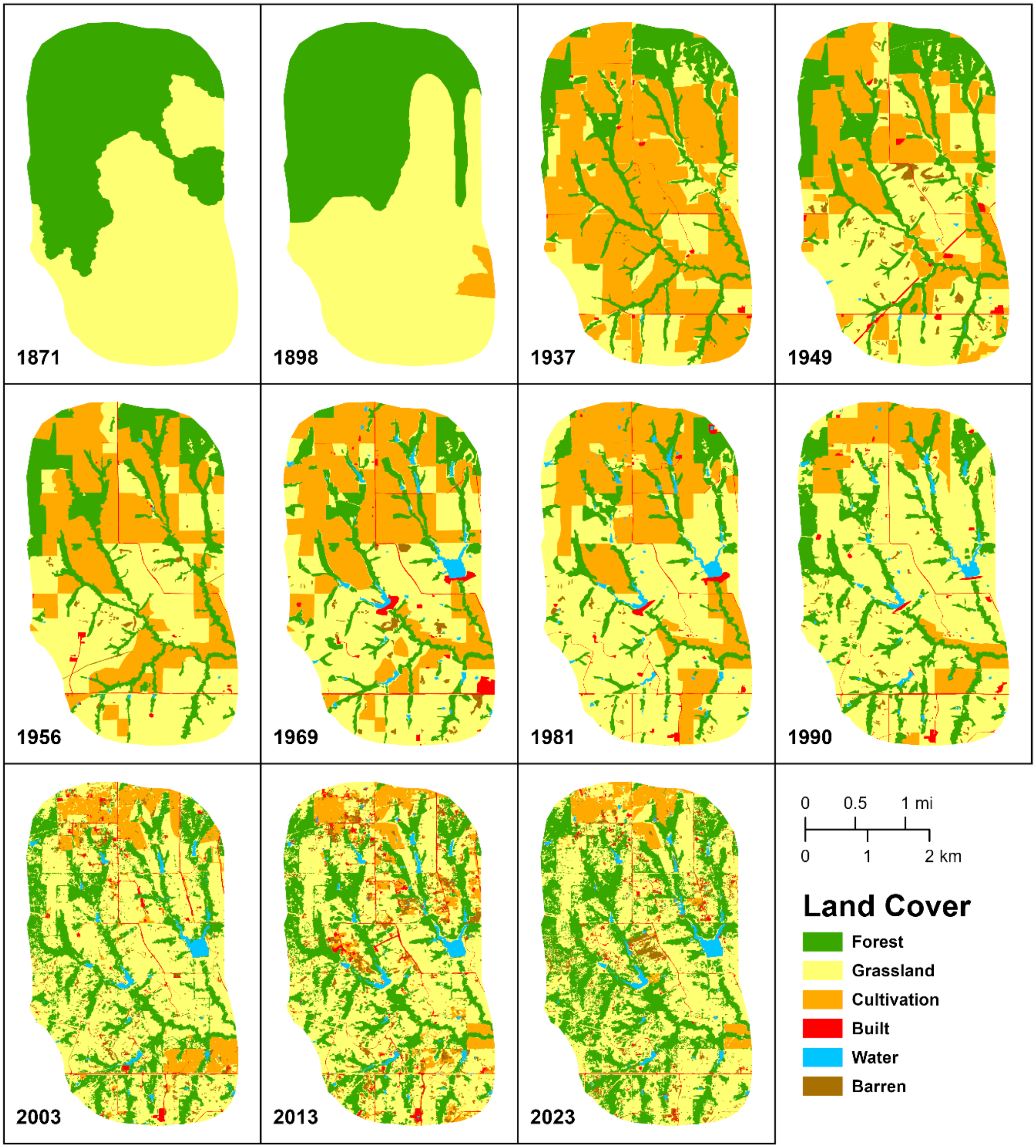


Figure 3. Land cover classification maps for the Upper Finn Creek Watershed for the time frame of 1871-2023. Data for the first two years (1871 and 1898) are derived from Public Land Survey Plats, the years 1937-1990 are derived from georeferenced aerial photographs, and the subsequent years from NAIP imagery.

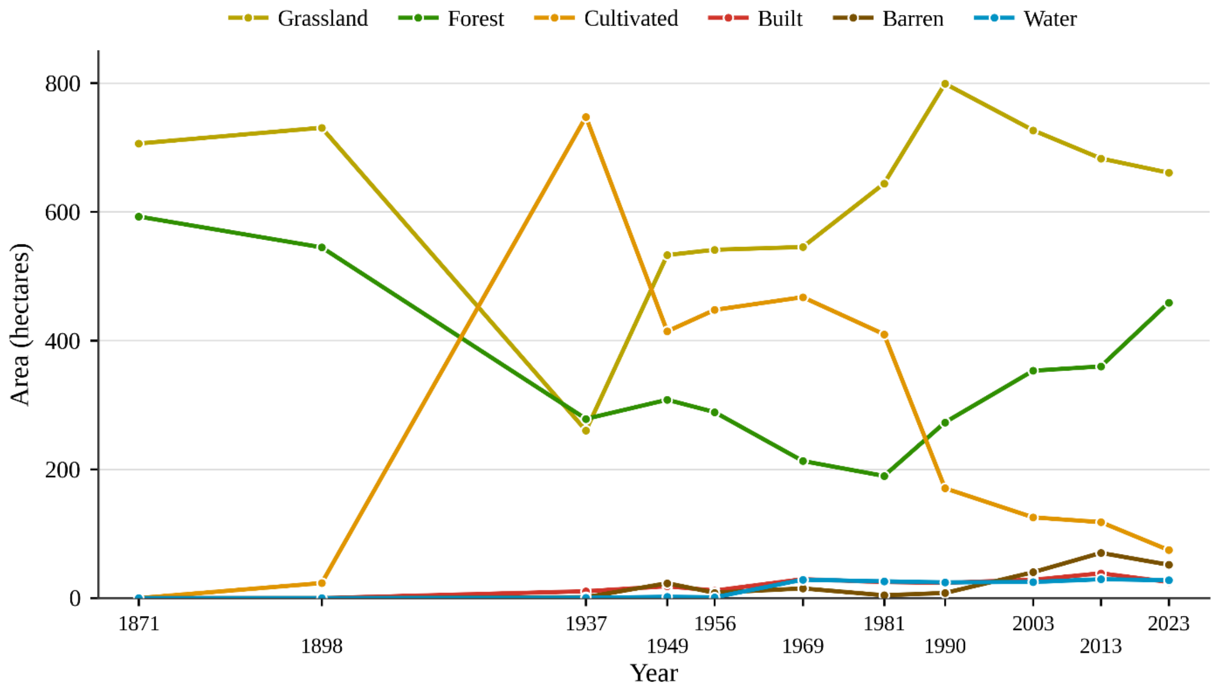


Figure 4. Land cover change through time for the years 1871 through 2023 in the Upper Finn Creek Watershed in hectares. This figure shows absolute expansion and contraction rather than percent composition.

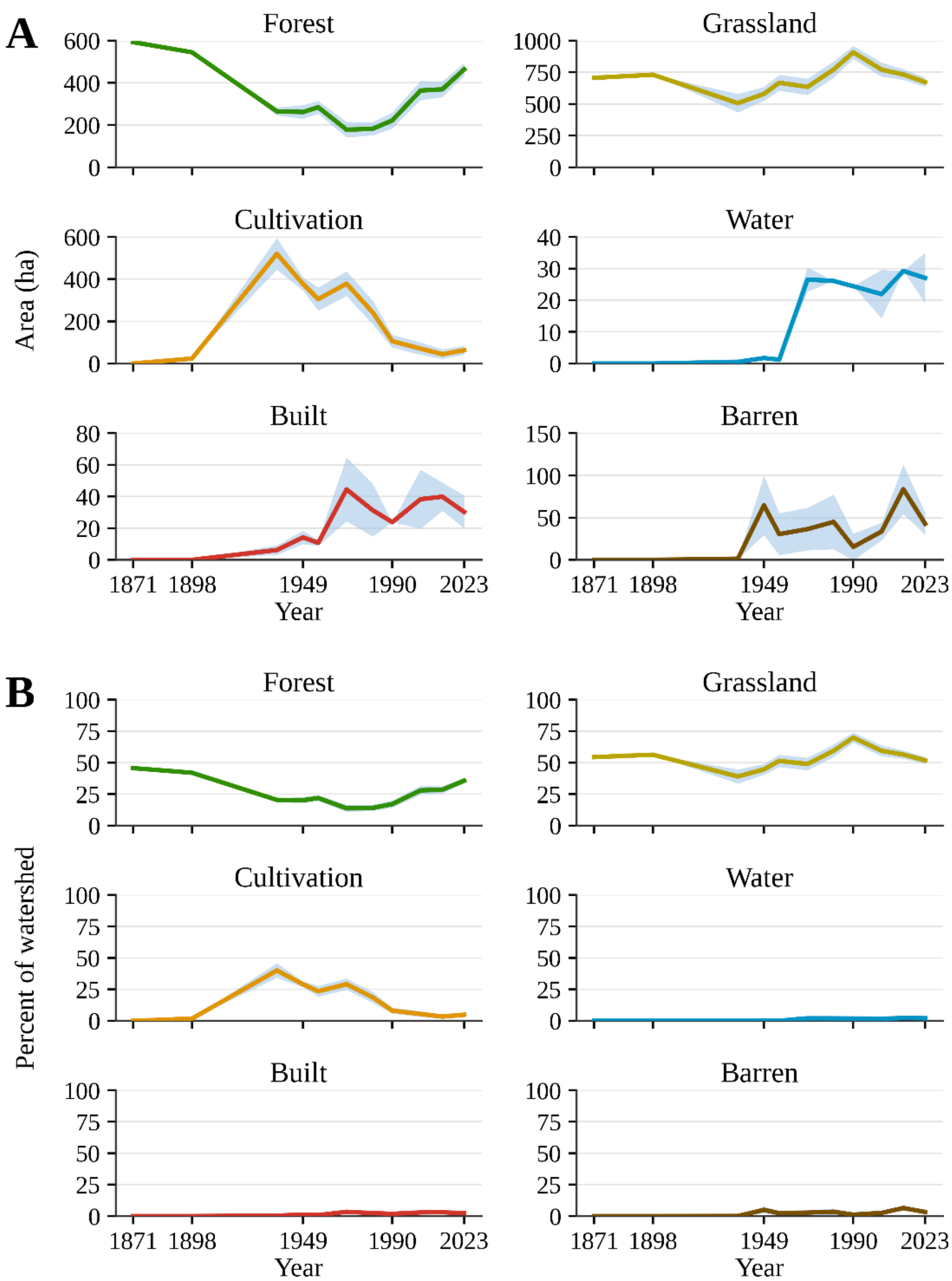


Figure 5. Temporal trends in land-cover classes within the Upper Fin Creek Watershed. (A) Estimated area (ha) of each land-cover class from 1871 to 2023. (B) Estimated proportion (%) of the watershed occupied by each land-cover class over the same period. Each facet represents a single land-cover class. Solid lines indicate point estimates, and shaded ribbons represent 95% confidence intervals derived from the stratified accuracy assessment and area-estimation process.

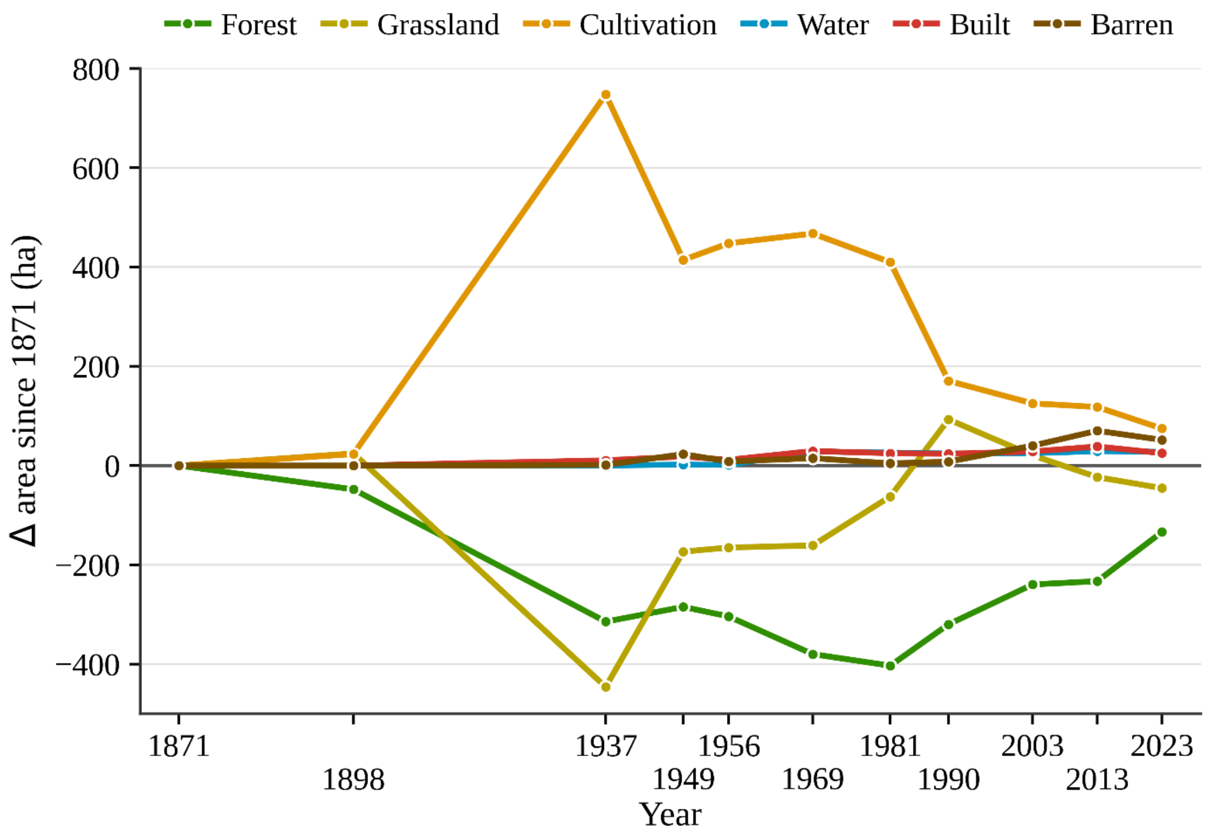


Figure 6. Cumulative net change in land-cover area relative to the 1871 baseline for each land-cover class in the Upper Fin Creek Watershed. Positive values indicate a net increase in area since 1871, whereas negative values indicate a net decrease. Values are expressed as the difference in area (ha) from the 1871 estimate.

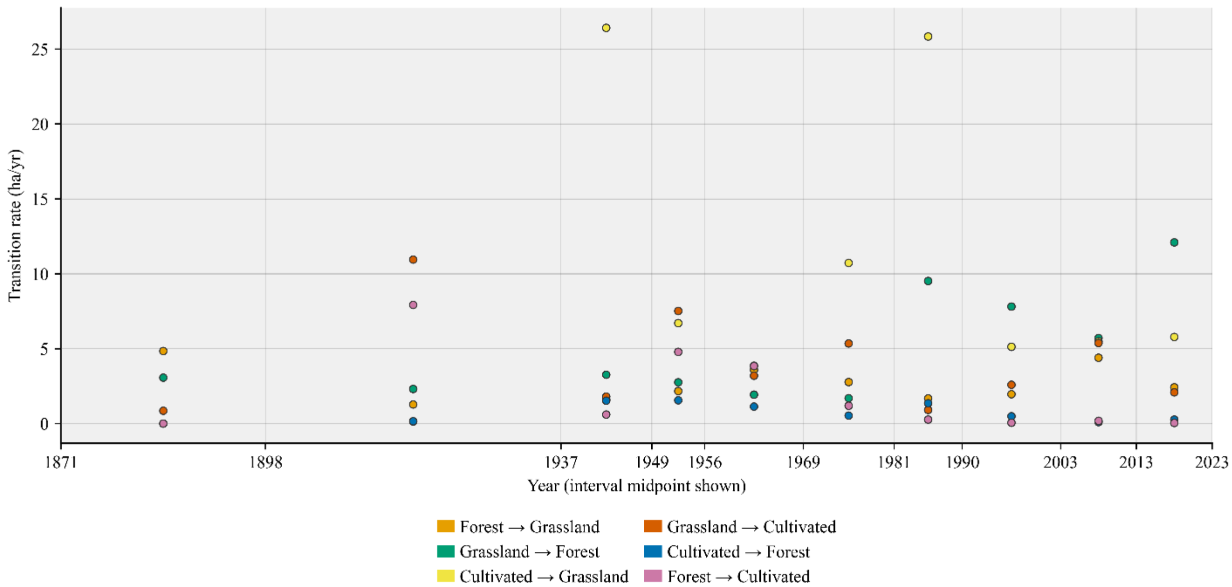


Figure 7. Annual transition rates (ha yr^{-1}) among forest, grassland, and cultivated land for consecutive mapping intervals in the Upper Fin Creek Watershed. Each point represents the average annual area converted from one land-cover class to another during the interval, plotted at the midpoint year of that interval.

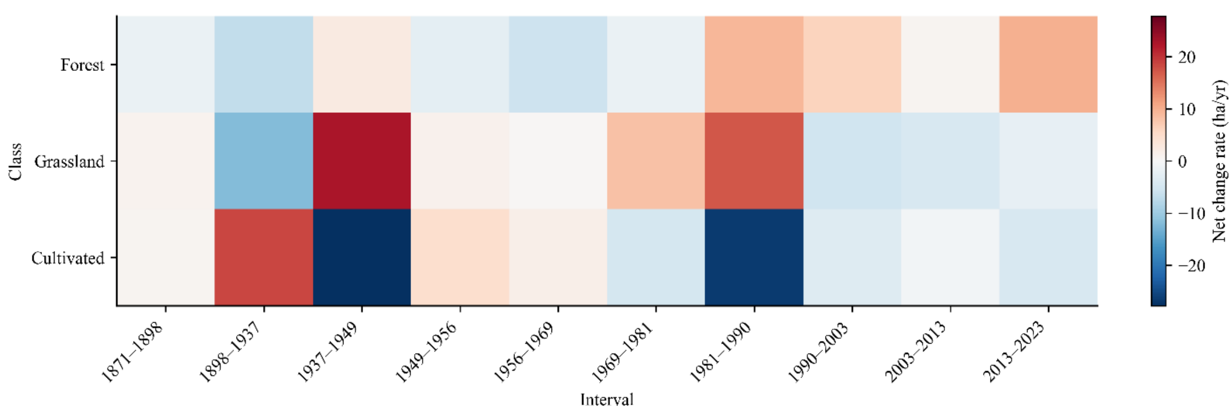


Figure 8. Net change rate (ha/yr) by land-cover class and time interval, 1871–2023.Warm colors indicate net area gain and cool colors indicate net area loss.

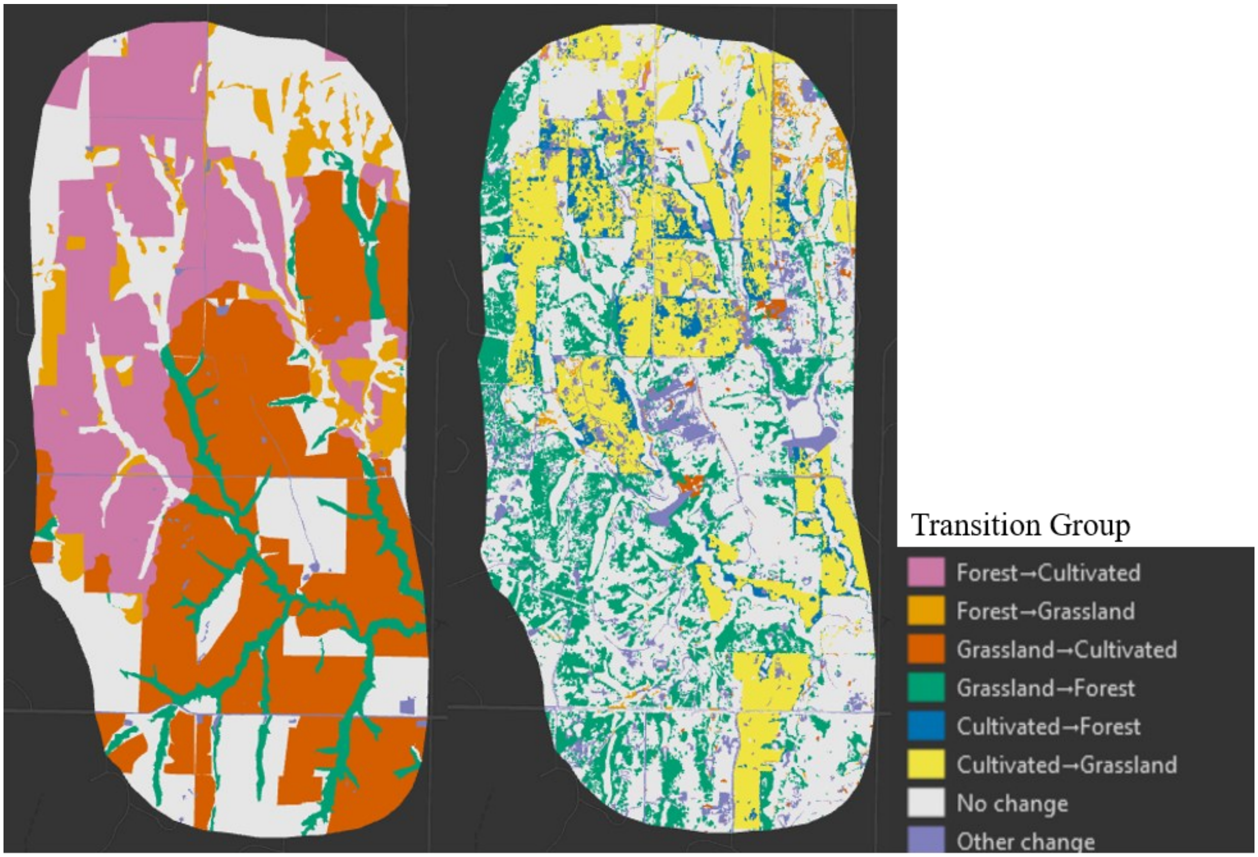


Figure 9. Land-cover transitions between 1871–1937 and 1981–2023, showing the six dominant class-to-class transitions plus areas of no change and other change. Transitions during 1981–2023 are more spatially fragmented than the larger, contiguous transition blocks seen during 1871–1937.

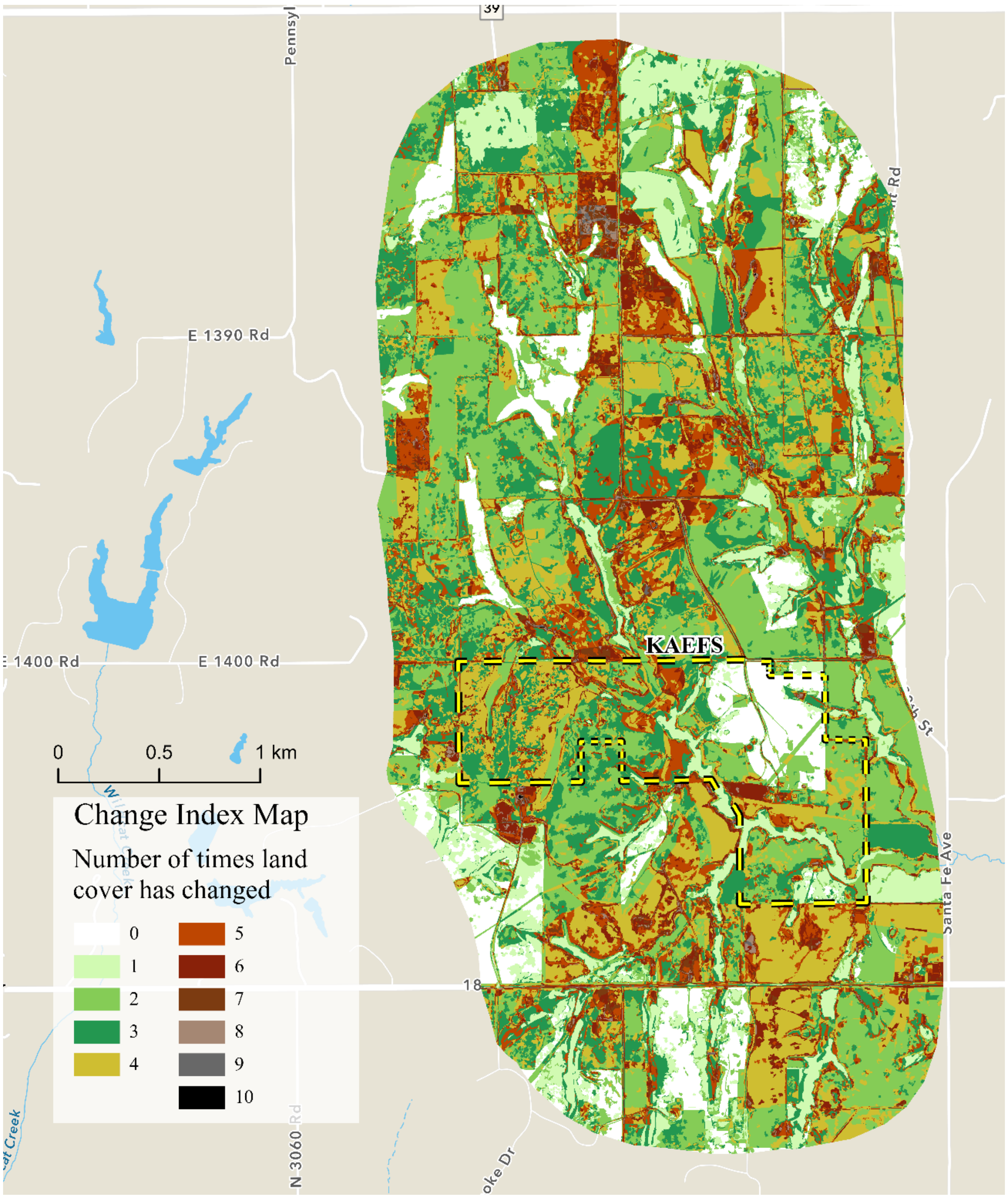


Figure 10. Change-index map of the Upper Finn Creek Watershed (1871–2023), showing the number of times mapped land cover changed class at each pixel across the eleven reconstructed years. Higher values indicate more frequent land-cover transitions; because the source image dates are unevenly spaced, values represent a count of changes rather than an annual rate. The dashed yellow line marks the boundary of the Kessler Atmospheric and Ecological Field Station (KAEFS).

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3. A DIGITAL LAND-USE AND LAND-COVER HISTORY OF KAEFS: K-VIZ

3.1 Platform Design

3.1.1 Introduction

Ecological and environmental processes at research field stations are often interpreted through the lens of present-day conditions (Swetnam et al., 1999; Foster et al., 2003; Tydecks et al., 2016). Researchers often select sampling locations based on current vegetation, soil characteristics, accessibility, infrastructure, or management boundaries (Dyson et al., 2023). Although these conditions are essential for field design, they fail to consider site history which may include significant disturbances that influence current processes. What appear today to be intact forest-woodland, grassland, or riparian and wetland communities may be the product of earlier cycles of land abandonment following grazing and/or cultivation, woody encroachment, infrastructure development, soil conservation actions, or other management practices. Historical studies using aerial photographs, historical maps, repeat photography, and long-term field records show that present-day vegetation patterns can carry the legacy of earlier land use and management (McClaran, 2003; Thomson et al., 2007; Gerard et al., 2010; Munteanu et al., 2015; Plieninger, 2011; Diez et al., 2026). As a result, two locations with superficially similar biotic communities may have very different histories that produce differences in vegetation structure, species composition, soil properties, biogeochemical processes, or hydrology (Foster et al., 2003; Diez et al., 2026). Documenting land-use history is therefore necessary for interpreting present-day field conditions accurately.

Ecological field stations have been described as important research and education facilities that support long-term environmental observation, interdisciplinary study, and public engagement (Tydecks et al., 2016). However, the value of a field station also depends on whether researchers can access contextual information that explains how the site developed over time (National Research Council, 2014). This issue is especially relevant for university-operated field stations, which are often designed to serve as long-term research, teaching, monitoring, and outreach infrastructure and quite often have good historical records. If researchers are unable to examine prior land cover, management history, repeated disturbance, or hidden infrastructure, then current field observations may be interpreted without important historical context (Swetnam et al., 1999).

The Kessler Atmospheric and Ecological Field Station (KAEFS), a research facility of the University of Oklahoma (OU), provides an opportunity to examine the impact and residual influences of land-use history on the modern ecological communities and ecosystem functions in the SGP (University of Oklahoma, 2019). KAEFS is located ~28 km southwest of the OU campus in Norman and occupies 145.8 hectares (360 acres) in the Upper Finn Creek Watershed (UFCW) in McClain County, Oklahoma. The facility supports long-term meteorological and biological experiments in a rural SGP landscape.

The landscape, geomorphology, and history of KAEFS are not uniform. Located within the Western Red-bed Plains geomorphic province, the KAEFS landscape consists of gently rolling hills with a surface geology of Permian red sandstone and shale (Curtis et al., 2008; Johnson, 2008; Buthod and Hoagland, 2016). The potential natural vegetation of the site is tallgrass prairie, as mapped by Duck and Fletcher (1943), but modern-day vegetation is a mosaic of forest, grassland, and pastures (University of Oklahoma, 2019; Buthod and Hoagland, 2016). Forest vegetation occurs both in the uplands and as riparian woodlands bordering Finn Creek and an unnamed tributary. Native grassland is predominantly little bluestem, Indiangrass and mixed forbs. The pastures consist of two types: upland areas consisting primarily of native species, and the floodplain of Finn Creek, which was converted to bermudagrass.

The 2023 land-cover classification from Chapter 2 shows that KAEFS is dominated by grassland and forest, with grassland covering 73.69 ha (50.54%) and forest covering 62.97 ha (43.18%) of the site. The remaining classes each accounted for less than 2.5% of the site and included water, barren ground, cultivation, and built land. At the site level, however, forest and grassland include distinct vegetation types and management histories (Buthod and Hoagland, 2016). Grassland areas on the eastern portion of the site near the main access road are maintained by mowing, while grasslands elsewhere receive little or no active management and show woody expansion and ERC encroachment (Figure 11). Because ERC encroachment is a prominent driver of grassland change across the SGP (Briggs et al., 2005; Yang et al., 2023), distinguishing woody cover that reflects deliberate planting or management from cover that reflects unassisted encroachment is central to interpreting present-day conditions at KAEFS. Fire is not currently used as a management tool at KAEFS, so current vegetation patterns must also be interpreted within a management regime in which prescribed burning is absent. Forested areas also vary across the site and include both upland forest and riparian woodland along Finn Creek. Although both forest types are associated with woody plant expansion, they differ in topographic position, species composition, and ecological function (Naiman and Décamps, 1997; Buthod and Hoagland, 2016). These differences in land cover, vegetation type, and management raise the question as to the legacy land-use drivers of change at KAEFS. Present-day ecological and biogeochemical research at the site therefore requires a way to connect current research locations and field conditions to the longer land-cover history of the landscape.

Chapter 2 clearly illustrates the changing landcover in the UFCW, where the KAEFS resides. Public Land Survey records from 1871, together with historical and modern aerial imagery, were used to produce a set of classified land-cover maps to analyze transitions in land cover, and create a change-index map. At the watershed scale, the analysis detected extensive spatial reorganization and repeated transitions in land cover that have left a varied legacy on ecological systems across the landscape.

The purpose of this chapter is to provide an accessible historical framework for interpreting research locations at KAEFS that can inform present ecological function and processes of the site. To address this need, this chapter develops a KAEFS digital history visualization and data access platform that brings these geospatial materials together with relevant site features in an accessible web-based format. This chapter is organized into two parts: a) articulation of the need for a historical perspective at KAEFS and the methodology used to develop the platform, and b) case-study applications of the platform.

Specifically, the objectives of this chapter are:

1. Platform design: Develop a digital KAEFS land-use history platform (K-Viz) that organizes data products, historical imagery, remote sensing layers, and relevant site features into accessible research infrastructure for users.
2. Site characterization: Use the platform products to characterize the site-scale land-cover history of KAEFS, including the balance of persistence and repeated change, forest expansion, management-maintained grassland, and historical infrastructure.
3. Platform applications: Demonstrate applied uses of K-Viz through research-support examples, including change-index interpretation, ERC imagery/allometry comparison, teaching uses, and future site planning or monitoring applications.

3.2 Conceptual Background: Historical Context and Field-Station Interpretation

3.2.1 Land-Cover History as Site Context

The focal scale of this chapter is the 145.8 ha occupied by KAEFS itself, treated here as a nested study area within the larger UFCW reconstruction developed in the previous chapter. This smaller scale is important because field-station users make decisions at the level of plots, trails, monitoring locations, forest edges, grassland units, and infrastructure features rather than at the full watershed scale. The watershed analysis in Chapter 2 provides important context for understanding factors outside KAEFS that could influence ecological processes, but ongoing experiments and observations at the station are fine grain (10 m^2 – 100 m^2) and require a localized understanding of land-use history to interpret legacy effects at experimental sites. The platform allows researchers to determine whether a modern cover type has persisted since the 19th century or has been subject to transitions in land cover, and thereby to confirm that a site's history is compatible with the research questions being asked.

Historical land-cover data does not directly measure soil, vegetation, carbon storage, hydrologic response, or atmospheric processes, but it can help explain why those measurements differ across locations. For example, two monitoring plots that are presently grassland in composition could have followed very different trajectories: one may have been continuously mapped as grassland since 1871, whereas the other may have been in cultivation until the mid-twentieth century—producing differences in species composition that present-day cover alone would not reveal. This is not merely hypothetical at KAEFS, where formerly cultivated fields were converted to planted native grasses in the 1970s and 1980s (see Section 3.2.2). Beyond these differences in vegetation history, plots may also carry distinct legacies of physical disturbance. Former roads, cleared areas, pipeline rights-of-way, well pads, and other oil-and-gas infrastructure can create localized disturbance histories that differ from the surrounding landscape and may leave ecological legacies that are not fully apparent from current vegetation alone (Foster et al., 2003; Naeth et al., 2020; McClung & Moran, 2018). Together, these vegetation and disturbance legacies mean that plots which appear identical today may require very different interpretation, particularly where research locations fall near former disturbance areas or where present-day cover does not reveal prior land use.

3.2.2 Historical Imagery as Evidence, Not Explanation

Analysis of historical imagery examines KAEFS as a chronosequence, identifying areas that have experienced change or alteration, and those that have not. The role of imagery thus allows for site interpretation as opposed to broad reconstruction. The platform allows researchers to add historical criteria to the process of site selection. However, imagery should be treated as evidence, not as explanation. It can show whether a location was open, wooded, cultivated, cleared, ponded, crossed by infrastructure, or visibly disturbed at a particular date, but it does not necessarily explain the process that produced that condition. For example, an open area could reflect mowing, grazing, cultivation, drought, fire, clearing, or some combination of these factors, while a visible disturbance feature may indicate infrastructure, erosion, or management activity without revealing its purpose, duration, or intensity. The same limitation applies to ERC interpretation: a tree crown that first appears in an image marks the first point at which it became visible in the available imagery, not the tree's germination date. For this reason, the platform uses imagery as one line of evidence alongside mapped land-cover layers, change-index information, site features, and field knowledge. At KAEFS, this allows users to evaluate whether a research plot, sensor location, infrastructure zone, or management area has a history of persistence, transition, or disturbance before interpreting present-day soil, vegetation, carbon, microclimate, hydrologic, or methane patterns.

Historical map and image data achieve their greatest utility when narrative resources that describe land use on the ground are available. Fortunately, Edwin Kessler, KAEFS namesake and former director of the National Severe Storms Laboratory, compiled documents that describe land ownership and land management in the mid-20th century. Two of these documents are especially useful at the site scale: A Brief History of this Homestead (Kessler, 1980; Appendix I) and Great Plains Apiaries: An Activities Report (Kessler, 1989; Appendix II). Together they provide a narrative record of ownership and on-the-ground management for the homestead parcels that form the core of present-day KAEFS, from the 1904 allotment-era homestead through the University of Oklahoma's acquisition of the farm in 1988. Because these accounts describe management activity and intent rather than surface appearance, they supply the kind of process information that aerial imagery cannot resolve on its own. They are informal recollections with minor internal inconsistencies and they describe the historical farm parcels rather than the full modern station boundary, so they are best treated as one corroborating line of evidence alongside the mapped products.

Land use at the site was strongly organized by landscape position. According to Kessler (1980), the Finn Creek bottomland was cultivated in row crops for much of the twentieth century—cotton, broomcorn, and sorghums under the Plaster family, and later cotton, grain, broomcorn, peanuts, and watermelons under the Stephens family—while a dairy operation was maintained on the property more or less continuously between 1925 and 1972. This history is directly relevant to interpreting the present-day floodplain pasture, now in bermudagrass, and helps explain why areas that today appear as managed grassland may carry a legacy of cultivation and grazing rather than persistent prairie. A deliberate shift away from cultivation began after the Kesslers acquired the farm in 1973. Formerly tilled land was converted in stages to planted native grasses—about 25 acres by 1980 and roughly 40 acres by the late 1980s—while erosion-control projects were undertaken with the U.S. Soil Conservation Service (now the NRCS), the property was cross-fenced, and grazing pressure was reduced (Kessler, 1980, 1989). Several farm ponds, including a large reservoir whose dam meets the northwestern corner of the property, were constructed by the Soil Conservation Service in the late 1960s.

The documents also record actions that bear directly on the woody plant expansion visible in the modern land-cover classification. Kessler (1989) described a range of trees deliberately planted along Finn Creek and in adjacent lowlands—including bald cypress (*Taxodium distichum*), cottonwood (*Populus deltoides*), catalpa (*Catalpa* spp.), osage orange (*Maclura pomifera*), oak (*Quercus* spp.), and black locust (*Robinia pseudoacacia*)—with black locust in particular established for erosion control; these plantings generally succeeded in the lowlands but not in the uplands. He further noted the expansion of elm in pastures as grazing was reduced. Some riparian and lowland woody cover at KAEFS therefore reflects intentional planting and grazing withdrawal rather than unassisted encroachment—a distinction imagery alone cannot establish. Kessler (1980) also documented oil and gas infrastructure associated with the East Criner field, including producing wells, injection wells, buried pipelines, and localized surface disturbance, providing site-specific evidence of the kind of historical infrastructure the platform is designed to flag. Read alongside the mapped land-cover layers and change-index products, these narratives let users move from observing that a location was open, wooded, or disturbed at a given date toward understanding the processes that produced that condition.

3.2.3 From Historical Archive to Research Infrastructure

Historical geospatial data only becomes useful to a broad research community when it is accessible, interpretable, and applied. A collection of aerial photographs, classified rasters, change-detection maps, and GIS layers does not, on its own, function as research infrastructure. These data must be organized into a well-conceived, structured system that allows project team members to conduct analyses relevant to their research objectives. The platform developed here therefore organizes the KAEFS historical land-cover data into an interactive setting. This is different from simply producing a final map. A static map communicates one selected interpretation, whereas an interactive platform allows users to move between layers, locations, and time periods depending on their research questions. For a student learning the site, this may mean comparing historical imagery with recent conditions without needing to work directly in ArcGIS Pro or write code in R or Python. For a faculty member planning a field experiment, it allows for the identification of locations with, or without, overlapping historical criteria when selecting sites for soil, vegetation, microclimate, or soil-carbon research. Researchers can use the platform to decide where to place sample plots, how to compare sites, how to explain unexpected field patterns, and how to teach new users about the landscape. Web-based GIS tools are useful in this context because they allow spatial layers to be viewed, queried, and compared without requiring every user to manage the original GIS datasets or repeat the full analysis workflow (Peng & Tsou, 2003). Later sections build from this framework by showing how K-Viz can be used to interpret specific locations, compare land-cover histories, and support future work at KAEFS.

3.3 Platform Data Sources

The spatial data layers for K-Viz were derived from Chapter 2, which includes historical imagery, classified land-cover layers, and the change-index map for the 1871–2023 time series (Table 5). Additional KAEFS-specific layers connect the historical reconstruction to current field-station use. These include the KAEFS and watershed boundary, research plots or sampling locations, ERC tree points with allometric age data generated by Dr. Heather McCarthy (OU, Biology). Environmental context layers, such as topography (elevation, slope, and aspect), hydrology (USGS hydrographic dataset), vegetation indices calculated from NAIP imagery bands, and soil products from the Soil Survey Geographic Database (SSURGO), aid in the interpretation of modern-day ecological conditions.

3.4 Building K-Viz

3.4.1 Platform Purpose and Software Environment

K-Viz was built using ArcGIS Online and ArcGIS Experience Builder. ArcGIS Online serves as the primary web GIS environment for storing, managing, sharing, and visualizing spatial data as hosted layers and web maps (Esri, n.d.-a; Esri, n.d.-b). In this project, it was used to organize the historical imagery, land-cover maps, change-index data, and site-feature layers that form the spatial foundation of the application. ArcGIS Experience Builder was then used to translate those hosted layers and maps into a web application through configurable layouts, pages, and widgets that allow users to view, compare, and interact with the data (Esri, n.d.-c; Esri, n.d.-d). Both of these tools provided the hosting, mapping, and interface-design environment needed to present the KAEFS historical reconstruction as an accessible web-based platform. The platform is publicly available and can be accessed at https://experience.arcgis.com/experience/f63bec6092ae47b48c0fc05c955bc3a0.

3.4.2 Platform Design and Layer Organization

K-Viz anticipates the types of research questions users are likely to ask at KAEFS rather than around data format alone. For example, a user that wishes to reconnoiter KAEFS with the intention of establishing a research program can access K-Viz to locate a plot, check access routes, compare current conditions and historical imagery. A user interpreting ecological or atmospheric measurements may need to know whether a station or plot is located in persistent grassland, formerly cultivated site, an expanding forest patch, or an area near historical infrastructure. For this reason, the tool separates layers into different categories that support site orientation, research-location comparison, environmental context, and historical interpretation.

Boundary and reference layers provide the spatial framework for the platform. They include the KAEFS boundary, the UFCW bounding area, and the Township-Range Quarter Section reference layers from the Public Land Survey System. These layers show where KAEFS is located and how it relates to the larger watershed and historical land records.

Environmental context layers provide additional information that may influence how land-cover history is interpreted. These include SSURGO data, soil functional class, and surface-water features from the National Hydrography Dataset (NHD). These layers do not explain land-cover change by themselves, but they help users examine whether historical land-cover patterns overlap with soil or hydrologic differences that may be relevant for research design and interpretation.

Research and sampling layers connect the historical reconstruction to actual current field activities at KAEFS underway in a number of research groups at the University of Oklahoma including from Dr Tim Filley's lab and Dr Heather McCarthy's lab. These include weather stations, plot locations, and other site features used for research, monitoring, and field navigation. Displaying these locations alongside historical imagery and derived land-cover products allows users to evaluate whether present-day research locations share similar or different land-cover histories.

Derived data products summarize the historical reconstruction in forms that are easier to interpret at the site scale. These include the KAEFS chronosequence layer, classified land-cover products, and the change-index map that counts the number of times a parcel of land has switched land-use/land-cover since 1871. The change-index layer is especially useful because it identifies areas that remained relatively stable, changed once, or experienced repeated mapped transitions across the reconstructed time series. This allows users to move beyond a single-date interpretation of land cover and evaluate whether a current field location has a stable or complex land-cover history.

Historical imagery is organized into two time-period groups: 1871–1995 and 2003–2025 (Figure 12). This structure separates earlier historical sources and aerial photographs from more recent digital imagery and makes it easier for users to compare older site conditions with present-day patterns. The imagery layers allow users to visually inspect whether a plot, monitoring station, forest edge, grassland area, access route, or infrastructure feature has remained relatively stable, shifted gradually, or changed repeatedly through time.

Pop-ups, legends, and labels were configured where needed to make the platform easier to interpret (Figure 13). These interface elements provide basic information about layer meaning, date, source, and limitations. This was especially important because the platform is intended for users with different levels of GIS experience, including researchers who may want historical site context without opening GIS project files or working directly with raster datasets.

K-Viz allows users to toggle historical imagery, classified land-cover layers, change-index products, site features, and environmental context layers. Users can compare historical and recent conditions at specific locations (Figure 14) and use available map tools for basic spatial exploration (Figure 15). Measurement tools allow users to estimate distance and area, the elevation tool provides basic topographic context, and the add-data tool allows users to bring in additional layers when needed.

These functions support several common field-station questions. For example, a user can examine whether a monitoring station is located in persistent grassland, whether a forest patch expanded recently, whether a proposed plot overlaps with repeated land-cover change, or whether historical imagery shows former infrastructure near a current research location. In this way, the platform does not function only as a display of thesis outputs. It acts as a research-support tool that links present-day field locations with their mapped land-cover histories.

3.4.3 Platform product and documented outputs

K-Viz is the main product of this chapter. It brings together all the layers that have been collected in a format that can be explored by KAEFS users. The platform also documents the sources, dates, and limitations of the mapped products so that users can interpret the layers appropriately. Rather than replacing field observation or detailed GIS analysis, K-Viz provides an accessible entry point for asking site-specific historical questions before, during, or after field research at KAEFS.

3.5 Applications of K-Viz

Sections 3.1 and 3.2 established why land-cover history is necessary context for interpreting present-day research at KAEFS, and Sections 3.3 and 3.4 described how K-Viz organizes that history into an accessible platform. This section demonstrates the platform in use. It begins with a site-scale reading of the station's land-cover history, then presents three case studies, each addressing a type of question that a researcher, instructor, or site manager might bring to the station. Together they show how K-Viz supports a move from present-day observation toward historically informed interpretation. The examples are illustrative rather than exhaustive and they are intended to convey the range of questions the platform can support rather than to catalog every possible use. The first case study evaluates the land-use and disturbance history of a research location. The second uses the historical imagery archive to provide an independent temporal check on ERC ages already in use in ongoing site research. The third demonstrates the platform in a teaching setting, where a graduate class used K-Viz to support an applied restoration-planning exercise.

3.5.1 Site-Scale Land-Cover History Of KAEFS

Before turning to individual research locations, the platform can be used to read the land-cover history of the station as a whole. Applied within the KAEFS boundary, the change-index layer (Chapter 2) summarizes, for every location on the site, how many times its mapped land cover changed between 1871 and 2023 (Figure 16). This site-scale view provides the backdrop against which individual research locations are interpreted, and it directly addresses the change-index interpretation the platform is designed to support.

The change index shows that persistent land cover is the exception rather than the rule at KAEFS. Land in the lowest change class — zero to one mapped change since 1871 — accounts for about 22% of the site, and within that, land with no mapped change at all for roughly 14% (Table 6). The remainder falls in higher change classes: about 41% of the site changed two to three times, 31% four to five times, and 6% six or more times. In all, roughly 78% of the station was mapped in more than one land-cover state over the reconstructed period, consistent with the extensive spatial reorganization documented at the watershed scale in Chapter 2.

Persistence, where it occurs, is closely tied to current management rather than to an absence of human influence. A majority of the no-change land lies in the regularly mowed grassland of the eastern portion of the site, near the main access road (Section 3.1). This grassland reads as stable in the change index not because it escaped disturbance but because ongoing mowing has held it in a single cover type; its apparent persistence is a product of active management. Elsewhere, grasslands that receive little or no management show the repeated transitions associated with unassisted woody expansion and ERC encroachment, while the riparian and upland zones along Finn Creek show the transitions associated with the forest expansion noted in Part 1. Historical imagery in the platform additionally reveals localized infrastructure legacies — former wells, pipelines, and access tracks (Case Study 1) — that the change index alone does not capture. Together these patterns distinguish management-maintained stability in the east from the unmanaged, transition-prone land that makes up most of the station.

This site-scale reading illustrates the interpretive point that runs through the case studies that follow: a low change-index value does not by itself indicate an undisturbed or relict landscape, and a high value marks where land-cover history is most complex and most in need of interpretation. Each application below examines a specific location against this broader pattern of persistence, transition, and management.

3.5.2 Case Study 1: Land-Use Legacy and Disturbance History

A common first question at a specific research location is whether its present-day cover has persisted or reflects a more recent land-use legacy. K-Viz lets a user examine this directly at a single plot, before establishing it or interpreting measurements already collected there.

Consider a monitoring plot in the Finn Creek floodplain near the main Kessler farmhouse (Figure 17), which in the field presents as managed grassland. Its change-index value falls in the highest class (6–10 changes since 1871), placing it among the most repeatedly changed land on the site rather than the persistent grassland described above. Stepping back through the imagery archive shows why: the plot reads as grassland in the 2003 NAIP imagery and as cultivated ground in the 1981 aerial photograph, and earlier images record repeated alternation between the two — the sequence of transitions behind its high change-index value. The archival record then supplies the process context imagery cannot: as detailed in Section 3.2.2, the Finn Creek bottomland was cultivated and grazed for much of the twentieth century before being converted to planted grasses (Kessler, 1980). A plot in this setting therefore sits on formerly cultivated and grazed ground rather than persistent prairie — a distinction that would not be apparent from current cover or a single-date map, and one that bears directly on how its soils and vegetation are interpreted.

The same workflow allows a user to evaluate whether a research location carries a legacy of physical disturbance. As noted in Section 3.2.1, features such as former roads, pipeline rights-of-way, and well pads can leave localized legacies that current vegetation does not reveal. K-Viz enables users to locate their surface expression by comparing imagery across years, because pipeline scars, access tracks, and well pads are often visible in some images but not others depending on date, vegetation cover, and image quality. At KAEFS, these features correspond to oil and gas infrastructure of the East Criner field documented in the archival record (Kessler, 1980; Section 3.2.2). Figure 18 shows examples of former infrastructure identified across KAEFS at different locations and dates, including oil and gas features visible in 1963 imagery in the southeastern portion of the site. Flagging these features allows a user to determine whether a research plot, sensor, or sampling location falls on or near previously disturbed ground before interpreting present-day measurements.

Together, these two kinds of reading — land-use legacy and disturbance history — show how K-Viz supports interpretation that no single data source provides on its own. The change-index and imagery layers identify where and when change occurred, while the archival record supplies the process context that explains it. A user can therefore move from observing what a location looks like today toward understanding what happened there, and can carry that history into site selection, measurement interpretation, or long-term monitoring.

3.5.3 Case Study 2: An Independent Temporal Check on ERC Ages

The paired ERC–grassland plots at KAEFS support ongoing research on how ERC encroachment alters soil organic carbon and litter dynamics (Frentz, 2025). Interpreting that work depends in part on how long individual ERCs have occupied the site, because a tree's age bounds the period over which it could have influenced understory composition, litter accumulation, soil carbon, and fuel loading (Limb et al., 2010; Hoff et al., 2018; Sauer et al., 2023). These ages were estimated with an allometric equation developed at KAEFS from field measurements of individual trees (Giddens & McCarthy, unpublished). The historical imagery archive in K-Viz offers an independent way to estimate when an ERC first became detectable, because the date it first appears in the imagery marks when it grew large enough to be visible in aerial photographs. This case study demonstrates how the platform's imagery can inform an age estimate already in use in site research.

For a sample of 15 ERC trees drawn from the plots, a user located each tree in K-Viz and stepped backward through the imagery archive to identify the last image in which the tree was absent and the first in which it was present. The interval between those two dates marks the window in which each tree first became detectable and, referenced to early 2026, yields an age range rather than a single value. Interpretation relied primarily on NAIP imagery, which provided the temporal coverage and resolution needed to resolve these intervals. As established in Section 3.2.2, a first appearance marks detectability, not germination, so these ranges are read as detection windows rather than exact establishment dates.

The sampled trees formed a predominantly young cohort. First appearances ranged from 2008 to 2017 and were concentrated in the later part of that span, with two-thirds of the trees (10 of 15) first visible in 2013 or later (Figure 19; Table 7). Image-based age ranges extended from roughly 9–11 years for the youngest trees to 18–23 years for the oldest, with a mean interval midpoint of 14.0 years. For every tree in the sample, the allometric age was older than this image-based range (Figure 20; Table 7): the mean allometric age was 28.1 years against a mean image-based midpoint of 14.0 years, a mean paired difference of roughly 14 years, and the allometric ages remained older on average even when compared against the oldest plausible image-based bound. A Wilcoxon signed-rank test confirmed that the allometric ages were significantly older ($W = 120.0$, $p < 0.001$), and the two estimates corresponded only weakly in relative ranking (Pearson $r = 0.31$, $p = 0.26$; see Appendix III). The ecological implication is the substantive result: biomass in trees estimated at roughly 30 years by the allometric model may instead reflect on the order of 10–15 years of visible establishment, pointing to faster woody biomass accumulation than the allometric ages imply and adding context for interpreting ERC encroachment, carbon dynamics, and fuel development at the site. This also bears on the encroachment study itself: Frentz (2025) worked from an assumed encroachment window of roughly 25 years and cautioned that the trees may have been too recently established to strongly alter soil carbon — a caveat the imagery-based ages reinforce by placing much of the sample below that threshold.

Overlaying the sampled trees on the change-index surface placed them in moderate settings rather than the most stable or most repeatedly changing parts of KAEFS, with extracted values ranging from 2 to 4 (Figure 16; Table 8). The magnitude of disagreement between the two age estimates did not vary meaningfully across these classes, so within this sample the change index is better read as context for the landscape history surrounding the trees than as an explanation for the age mismatch.

This case study is a demonstration of platform capability rather than a formal validation of the allometric model. K-Viz does not resolve which estimate is correct: delayed detectability in older or coarser imagery means small trees may predate their first visible appearance, and the allometric estimates carry their own uncertainty. What the platform provides is a temporally explicit, independent line of evidence that a single-date field measurement cannot — one that flags a systematic offset worth accounting for in ongoing work, and that shows how the historical archive assembled in K-Viz extends from watershed-scale reconstruction to tree-scale questions at specific research locations.

3.5.4 Case Study 3: Teaching Application — Restoration Planning

Beyond individual research use, K-Viz can function as teaching infrastructure and as a decision-support tool for users with little or no prior GIS experience. The platform was used in this way in the graduate course 'GEOG 6240: CO_2 Removal Strategies' (Fall 2025), where students undertook an applied restoration-planning exercise at KAEFS. Because K-Viz delivers imagery and mapping tools through a web interface, students were able to work directly with high-resolution site imagery and produce quantitative spatial outputs without opening ArcGIS Pro, managing raster datasets, or reproducing any part of the underlying analysis — the accessibility rationale developed in Sections 3.2.3 and 3.4.2 realized in a classroom setting.

Working from the 2025 leaf-off aerial imagery in K-Viz, students digitized land-cover boundaries across the station and assigned them to functional classes defined by their management implications: grassland suitable for grazing, low-density grassland in transition to ERC that remains manageable with fire, closed-canopy ERC requiring mechanical removal, and closed-canopy deciduous woodland. From these digitized boundaries they calculated the area in each class, finding that grazable grassland accounted for roughly 39% of the site, transitional grassland for about 9%, closed-canopy ERC for about 22%, and deciduous woodland for about 29%. This classification was purpose-built for the restoration question rather than derived from the Chapter 2 land-cover reconstruction, illustrating that the platform supports user-defined mapping tailored to a specific applied objective.

These spatial outputs then anchored a four-year management plan. Rather than clearing woody cover wholesale, students designed a corridor approach that leaves closed-canopy stands largely in place and removes narrow corridors to connect restored and existing grasslands for cattle movement. The phased plan combined mechanical ERC removal, prescribed burning of transitional grassland, perimeter and interior fencing, and grazing leases, and it was paired with a cost-benefit analysis that drew on state cost figures and incentive programs, including ERC-removal cost-share from the Oklahoma Conservation Commission. The exercise thereby connected the platform's spatial products to concrete management decisions — grazing suitability, corridor placement, prescribed-burn scheduling, and cost projection.

The class relied chiefly on current imagery and the digitizing tools rather than on the historical reconstruction, but the same platform makes the historical layers available to inform exactly this kind of planning. Distinguishing recently encroached ERC from long-established or deliberately planted woody cover (Section 3.2.2), or identifying stands on formerly cultivated ground versus persistent prairie, could help prioritize which areas to restore, retain, or monitor. In this sense the teaching exercise both demonstrates the platform's present classroom value and points toward a fuller use in which current-condition mapping and land-cover history are read together.

This teaching application shows K-Viz moving from historical interpretation toward applied planning and instruction, with the platform's mapping tools placed directly in the hands of non-specialist users to inform a real management decision.

3.6 Discussion

The three case studies show that K-Viz functions as research-support and teaching infrastructure rather than as a static display of thesis outputs. Across the examples, the platform supported a consistent movement from present-day observation toward historically informed interpretation: reading the land-use and disturbance history of a research location, providing an independent line of evidence for tree ages already used in site research, and supporting an applied restoration-planning exercise carried out by students. These uses differ in purpose and in the expertise they require, but each depended on the same capability — the ability to view, query, and compare historical and current spatial information for specific locations at KAEFS without reproducing the underlying analysis.

These varied uses support the argument developed in Section 3.2.3 that historical geospatial data becomes useful to a research community only when it is organized into an accessible and interpretable form. The barrier is rarely the existence of data; it is more often the gap between those who produce spatial analyses and those who need to apply them. This producer–user gap is well documented for decision-support tools in ecology and land management, where the complexity and inaccessibility of model outputs can limit their use by managers and other non-specialists, and where user-centered, web-based tools have been advanced as a way to make scientific outputs more usable for applied decision-making (Cartwright et al., 2016; McIntosh et al., 2011; Engelstad et al., 2022). Comparable web GIS approaches have long been recommended for exactly this reason, because they allow spatial layers to be viewed, queried, and compared without requiring every user to manage the source datasets or repeat the analysis (Peng & Tsou, 2003). K-Viz applies this logic to a single field station: none of its layers is new to KAEFS, but their organization into one interactive environment is what makes the site's land-cover history usable. The teaching case study is the clearest evidence of this contribution, because students with limited GIS experience produced quantitative spatial outputs and used them in an applied plan, work that would ordinarily require direct use of desktop GIS.

The case studies also point toward uses beyond those demonstrated here. Because K-Viz connects current research locations to their land-cover histories, it can support site selection that incorporates historical criteria, allowing researchers to identify locations with or without particular land-use or disturbance legacies before establishing plots. Ongoing belowground carbon research at KAEFS (Kleinhoffer, unpublished) and microclimate monitoring (Cross, unpublished) are among the site-based studies for which this historical context is directly relevant. The broader value of reading a site's history before or alongside such work is illustrated by recent research in which historical aerial imagery was used to distinguish urban grassland sites by their prior agricultural or forested land use; the resulting land-use legacies were detectable in contemporary soil microbial communities, such that sites of agricultural origin retained an agricultural signature decades later (Thompson et al., 2023). That study and the present work rely on the same underlying premise — that present-day cover does not by itself reveal the trajectory that produced it — and both use historical imagery to recover that trajectory. K-Viz differs in packaging this capability as a reusable platform tied to a specific station rather than as a one-time analysis, so that the same history can inform site selection, measurement interpretation, and long-term monitoring as the station's research program develops. The platform is also extensible: additional layers, imagery, and research locations can be added over time, allowing K-Viz to reflect current work rather than a fixed snapshot.

Several limitations shape how the platform should be used. As emphasized throughout this chapter, imagery records what a location looked like at a given date but not the process that produced that condition, so the platform is best used alongside field knowledge and archival records rather than as a standalone explanation. Detectability further limits the imagery: small features and small tree crowns may be present before they become visible, particularly in older or coarser images, which is why the age estimates in Section 3.5.3 are read as detection windows rather than establishment dates. This constraint is consistent with the broader remote-sensing literature on ERC, in which the detection of individual trees and canopy cover is strongly conditioned by imagery resolution, acquisition method, and radiometric differences between images, and in which no single sensor or method resolves encroachment equally well across settings (Filippelli et al., 2020). The change-index layer inherits the assumptions of the Chapter 2 reconstruction, including its classification scheme and unevenly spaced image dates; because those dates are not evenly spaced, the index counts mapped changes rather than an annual rate, and management actions not resolved in the source imagery are not represented. Finally, K-Viz is built for a single site and depends on a hosted commercial platform, so its long-term usefulness relies on continued institutional maintenance — a recognized requirement for decision-support tools, whose credibility and relevance depend on sustained updating rather than one-time release (Engelstad et al., 2022; McIntosh et al., 2011). The underlying approach, however, is transferable to other field stations with comparable historical records.

Across these applications and their limitations, K-Viz extends a watershed-scale land-cover reconstruction to the site-scale and tree-scale questions that field-station users actually ask. Its value lies less in any single map than in making the site's land-cover history usable — available for interpretation, comparison, and planning at the locations where research is carried out.

3.7 Conclusion

This chapter developed K-Viz, a digital land-use and land-cover history platform for KAEFS, and demonstrated its use as research infrastructure. It established why land-cover history is necessary for interpreting present-day research at the station, organized the historical imagery, land-cover layers, change-index products, and site features from Chapter 2 into an accessible web-based platform, and demonstrated applied uses through three case studies: reading the land-use and disturbance history of a research location, providing an independent temporal reference for ERC ages used in ongoing site research, and supporting a graduate class's restoration-planning exercise. Across these examples, K-Viz drew together historical and current evidence in ways no single layer supplies alone, and it was used by people other than its developer for purposes beyond historical interpretation — the clearest indication that it functions as usable research and teaching infrastructure rather than a fixed set of thesis outputs.

More broadly, the chapter offers a model for linking a long-term, watershed-scale reconstruction to active ecological and biogeochemical research at the plot, tree, and feature scale. Although K-Viz is built for one station and depends on continued institutional maintenance, the underlying approach transfers readily to other field stations with comparable historical records.

Chapter 3 Figures and Tables

Layer group	Geospatial layer	Description	Data source
Boundaries	KAEFS Boundary		Modified from Oklahoma Biological Survey boundary layer
	Watershed Boundary		Chapter 2
	Township-Range-Section	Public Land Survey System reference grid	General Land Office; Bureau of Land Management; OKMaps
Research	Plot Locations	Paired ERC–grassland plots used in degraded grassland and woody plant encroachment research	Filley Biogeochemistry Lab
	Weather Stations	Stations collecting microclimate data for degraded grassland research	Filley Biogeochemistry Lab
	KAEFS Chronosequence	ERC locations used to develop the allometric age equation	Dr. Heather McCarthy
Historical	1871–1995 Maps	PLSS plats and single-band aerial imagery layers	USDA FSA; USGS; General Land Office
	2003–2025 Maps	Natural-color aerial imagery	USDA NAIP
Data Products	Change Index	Summarizes the number of land-cover changes observed across the historical reconstruction	Chapter 2
	SSURGO Soils	Soil map units and associated soil properties	USDA-NRCS
	Soil Functional Class	Soil functional classes used to support smart sampling and expert assessment of soil properties	VinSense
Hydrology	NHD Flowlines	Streams, drainage paths, and other surface-water flow features	USGS National Hydrography Dataset
	NHD Waterbodies	Ponds, lakes, and other waterbody features	USGS National Hydrography Dataset
	HUC12	Hydrologic Unit Code 12 watershed boundary	USGS National Hydrography Dataset
Topography	Elevation	Digital elevation information (m)	USGS DEM
	Slope	Slope values (°)	Derived from USGS DEM
	Aspect	Direction of slope	Derived from USGS DEM
Indices	NDVI	Represents vegetation greenness using the Normalized Difference Vegetation Index (-1 to +1)	Derived from 2025 NAIP imagery
	EVI	Represents vegetation condition using the Enhanced Vegetation Index	Derived from 2025 NAIP imagery
	SAVI	Represents vegetation greenness while reducing soil-background influence (-1 to +1)	Derived from 2025 NAIP imagery

Note. KAEFS = Kessler Atmospheric and Ecological Field Station; ERC = eastern redcedar; PLSS = Public Land Survey System; NAIP = National Agriculture Imagery Program; SSURGO = Soil Survey Geographic Database; NHD = National Hydrography Dataset; DEM = digital elevation model; NDVI = Normalized Difference Vegetation Index; EVI = Enhanced Vegetation Index; SAVI = Soil-Adjusted Vegetation Index.

Table 5. Geospatial layers included in K-Viz, organized by boundary, research, historical imagery and data product layer groups.

Change class (mapped transitions)	**Area (ha)**	**Share of site**
Low (0–1)	31.6	21.7%
Moderate (2–3)	60.1	41.3%
Repeated (4–5)	45.0	30.9%
High (6–10)	9.0	6.2%
Total	**145.6**	**100%**

Table 6. Land-cover change-index classes at KAEFS, 1871–2023

Metric	Detection interval width	Image lower age bound	Image upper age bound	Image midpoint age	Allometric age	Midpoint Δ age	Upper-bound Δ age
n	15.0	15.0	15.0	15.0	15.0	15.0	15.0
Mean	2.9	12.5	15.4	14.0	28.1	14.2	12.7
SD	1.3	3.9	5.1	4.5	1.5	4.3	4.9
Minimum	1.9	8.9	10.8	9.9	25.4	5.9	3.4
Maximum	4.9	17.9	22.8	20.4	30.6	19.9	19.0

Table 7. Summary statistics for image-based and allometric age comparisons

Change index class	n trees	% of sample	Mean midpoint Δ age (years)
2	1	6.7	13.6
3	10	66.7	14.4
4	4	26.7	13.8

Table 8. Distribution of sampled eastern redcedar trees across change-index classes and the mean image-to-allometric age difference within each class

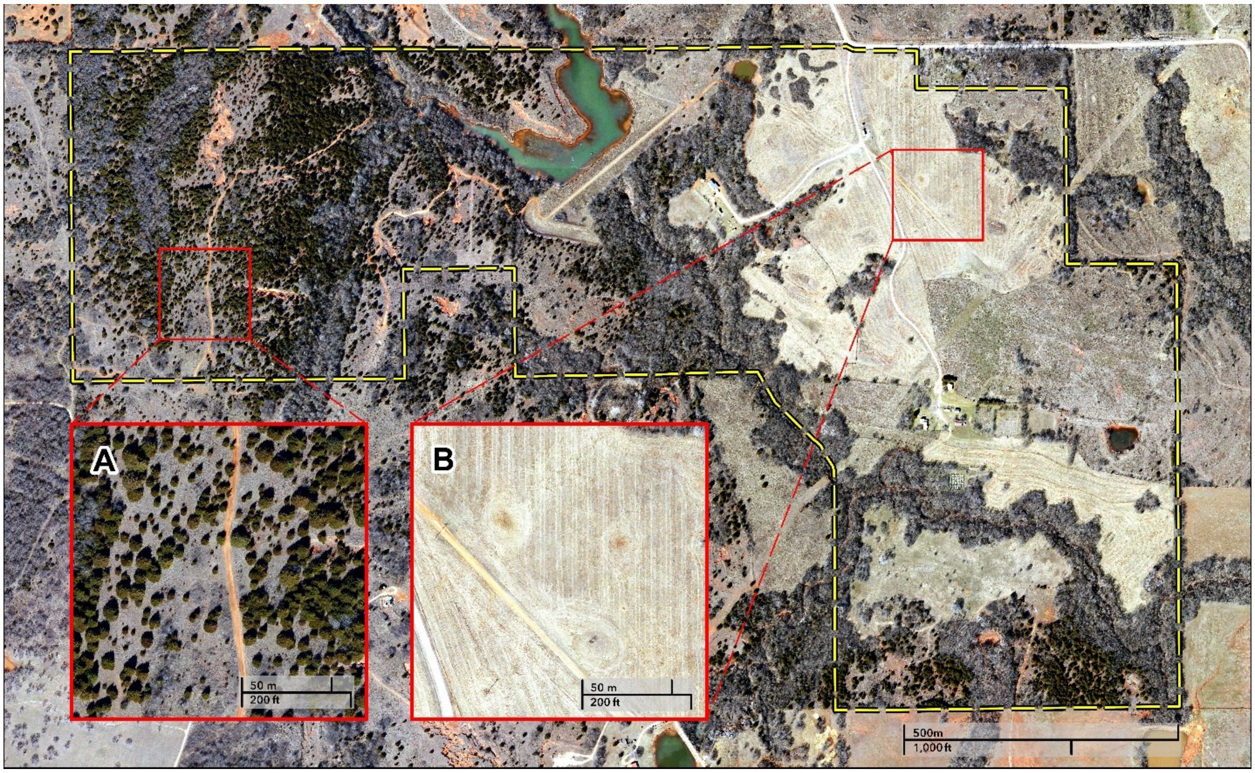

Figure 11. February 2025 imagery of KAEFS showing contrasting grassland management conditions: (A) unmanaged grassland in the western portion of the field station and (B) maintained, mowed grassland in the eastern portion.

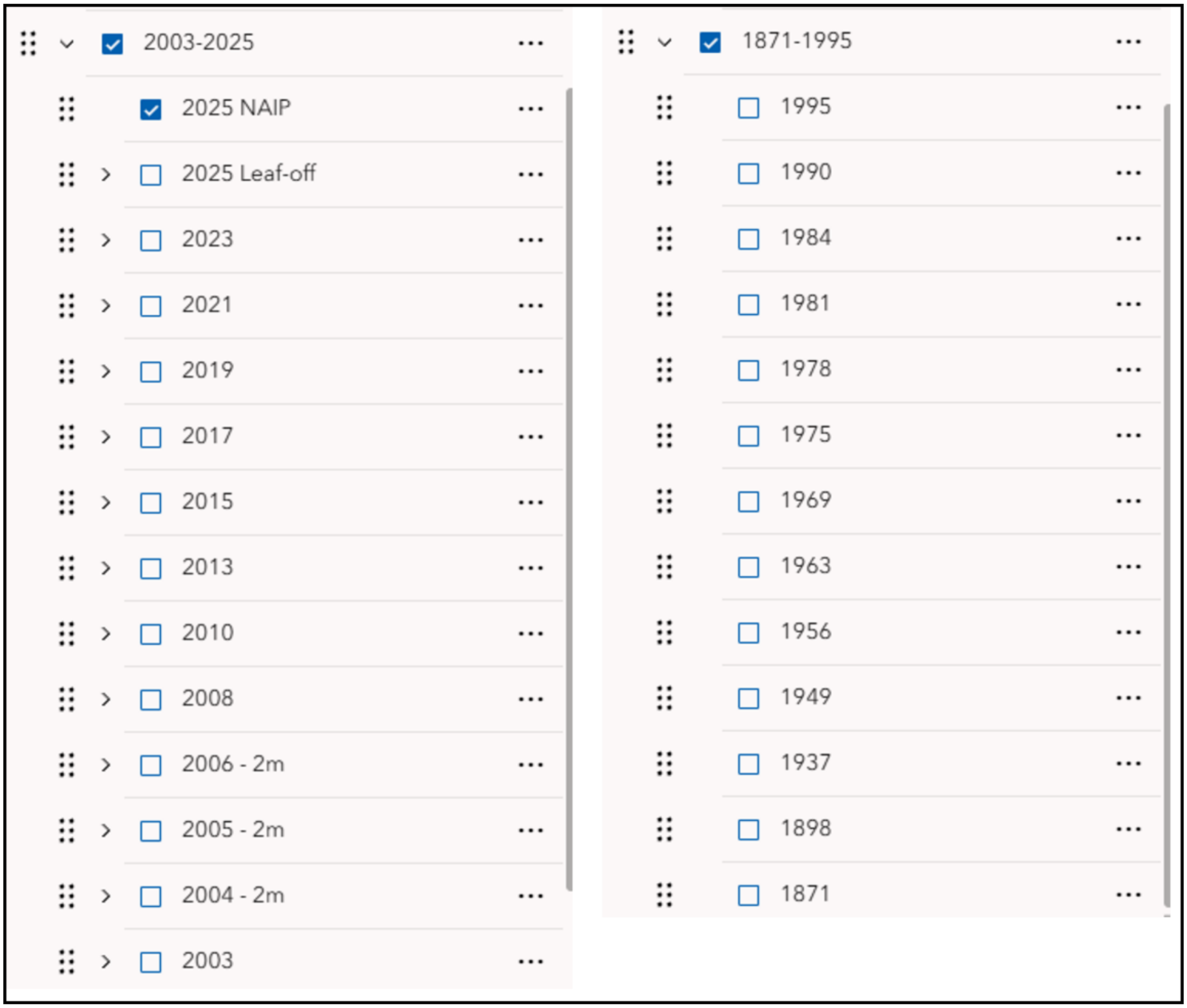

Figure 12. Organization of historical imagery layers, showing the scrollable layer list and toggle controls used to view imagery from different time periods.

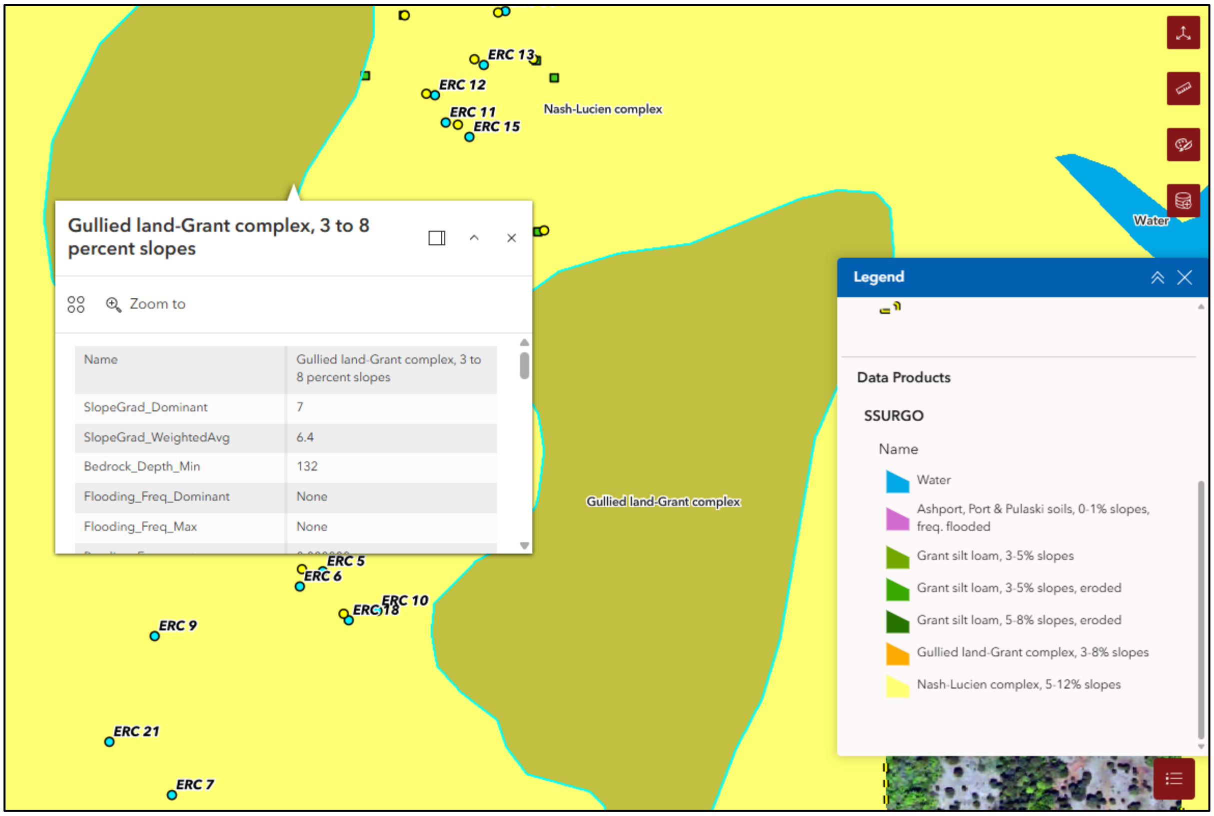

Figure 13. Example of pop-ups, legends, and labels used in the platform to help users identify layer attributes, extract information, and interpret symbology.

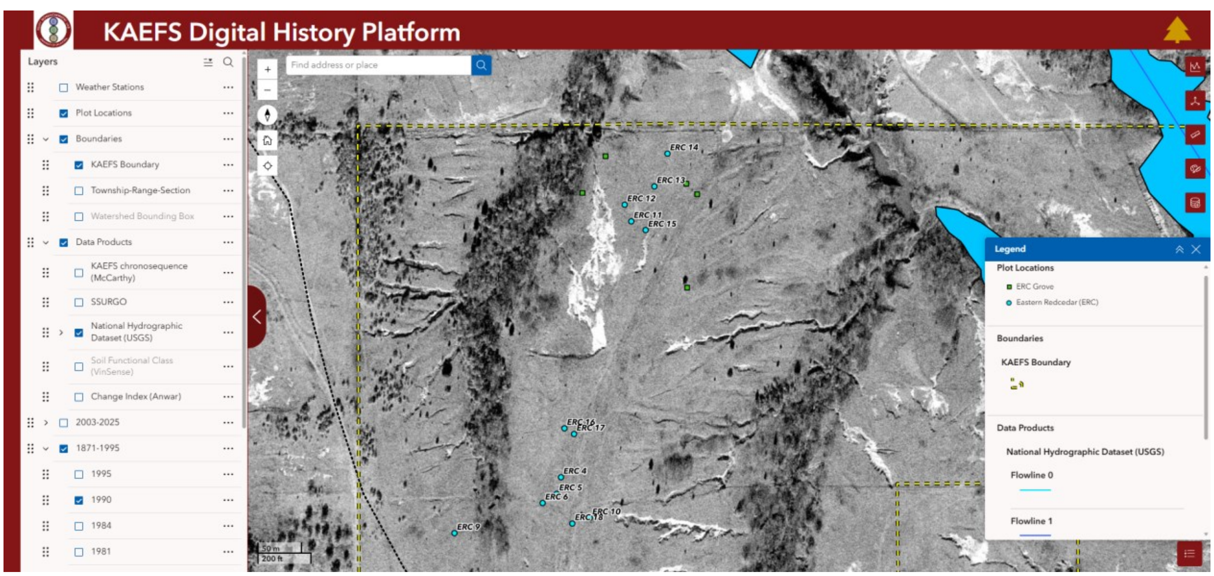

Figure 14. Example scenario showing how a user can compare historical imagery, sampling locations, and selected layers to evaluate site history and identify potential future sampling locations.

Figure 15. Map tool interface, showing examples of user functions, including elevation profile, coordinate pinning, drawing tool, measurement tool, and adding data.

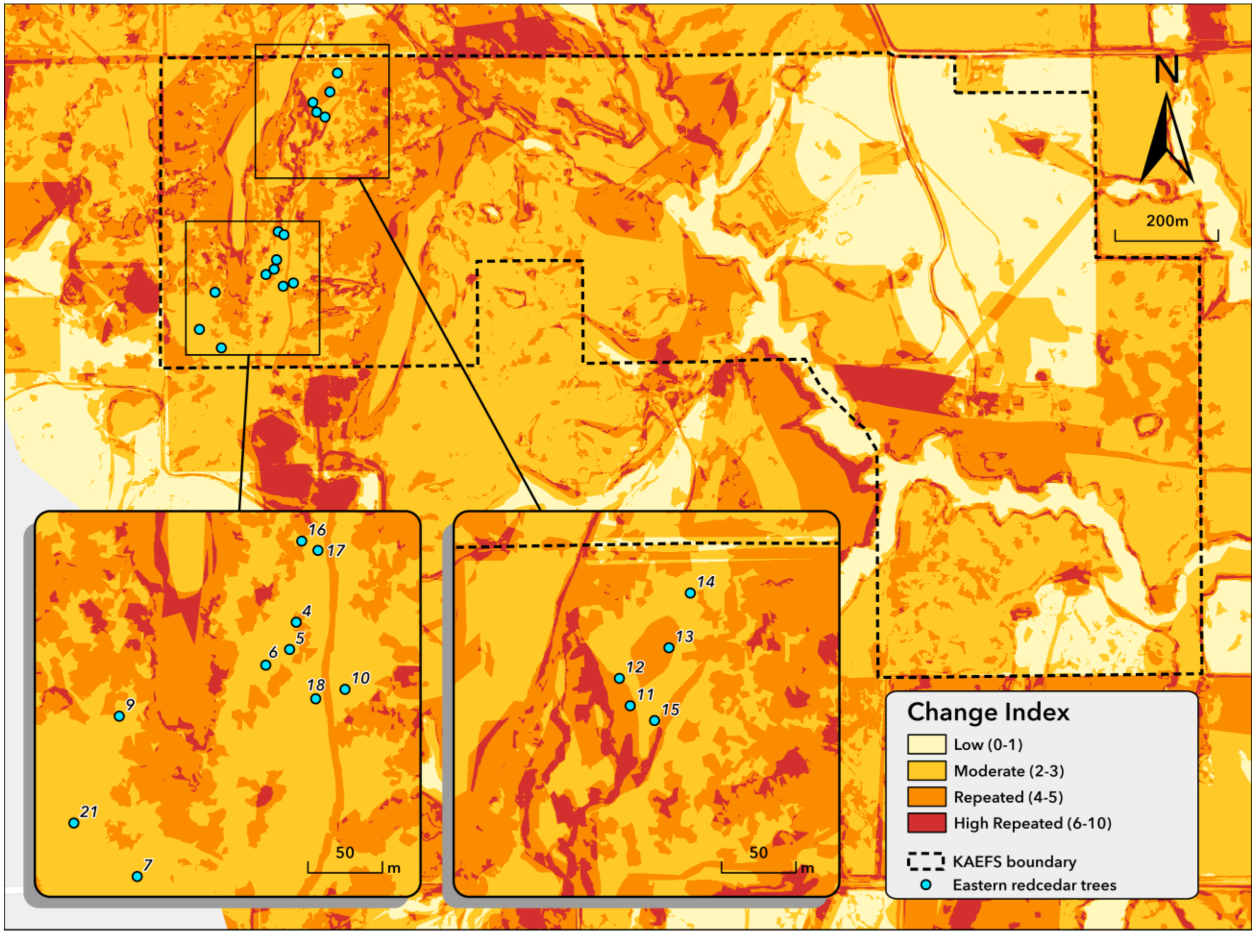

Figure 16. Change index map of KAEFS showing the number of mapped land-cover changes per pixel across the reconstructed time series (1871-2023). Lower values represent more persistent land-cover states, whereas higher values represent more repeated land-cover transitions. Cyan points represent sampled eastern redcedar trees. Terracing was not treated as land-use change in the reconstruction, and frequent grass mowing is also not reflected in the map, especially in the northeast portion of the study area.

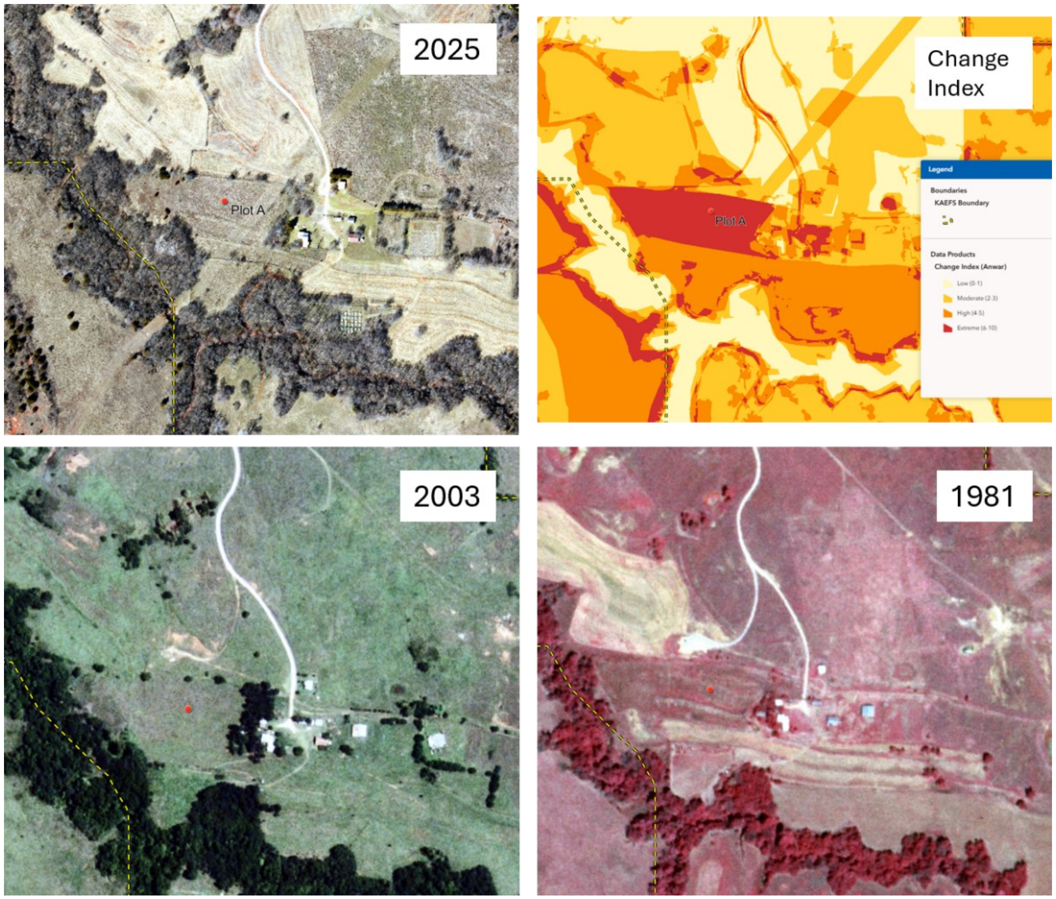

Figure 17. Change history of a monitoring plot (Plot A) in the Finn Creek floodplain. The plot presents as grassland in the 2025 leaf-off imagery (top left) and the 2003 NAIP imagery (bottom left) but appears as cultivated ground in the 1981 color-infrared aerial photograph (bottom right). The change-index panel (top right) places the plot in the highest change class (6–10 mapped changes since 1871), reflecting repeated alternation between cultivated and grassland cover over the record.

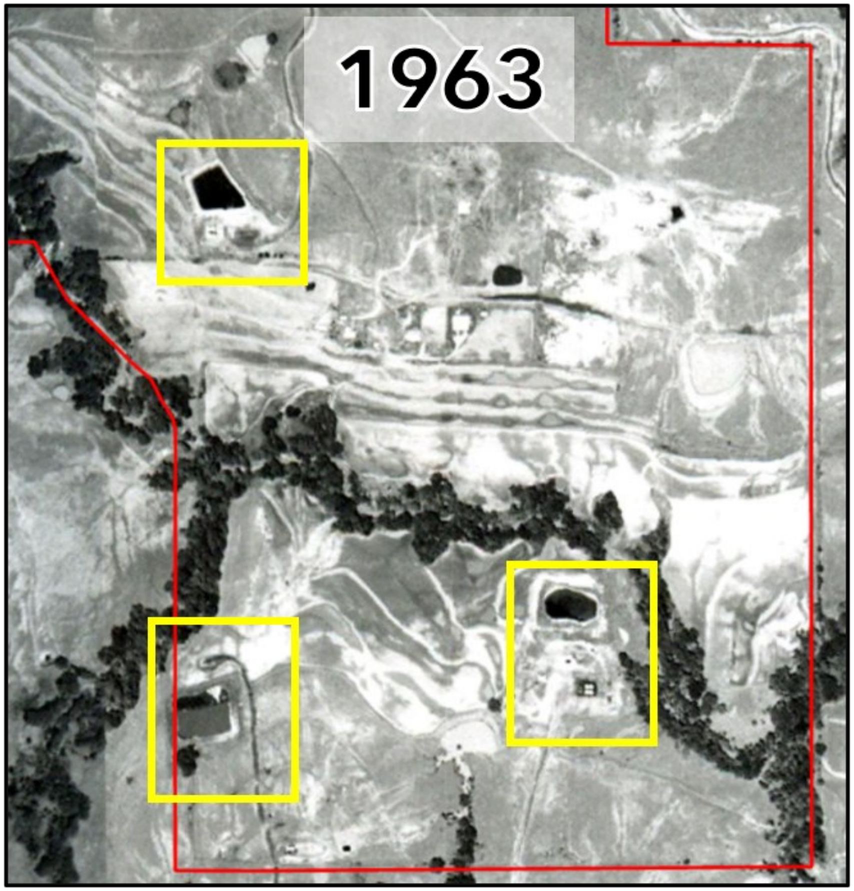

Figure 18. Several historical oil and gas features discovered in 1963 imagery in the southeastern portion of KAEFS (yellow boxes).

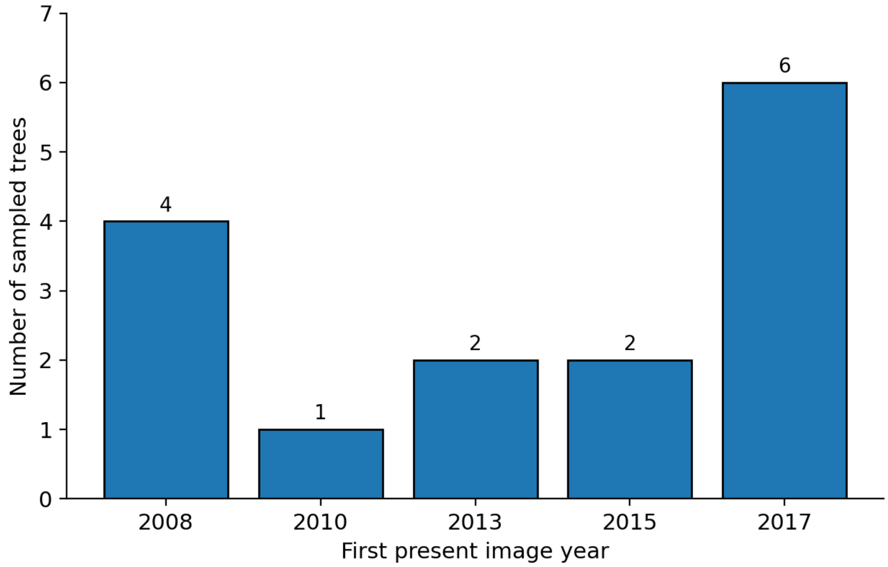

Figure 19. Frequency of first-present image years for the 15 sampled eastern redcedar trees at the Kessler Atmospheric and Ecological Field Station.

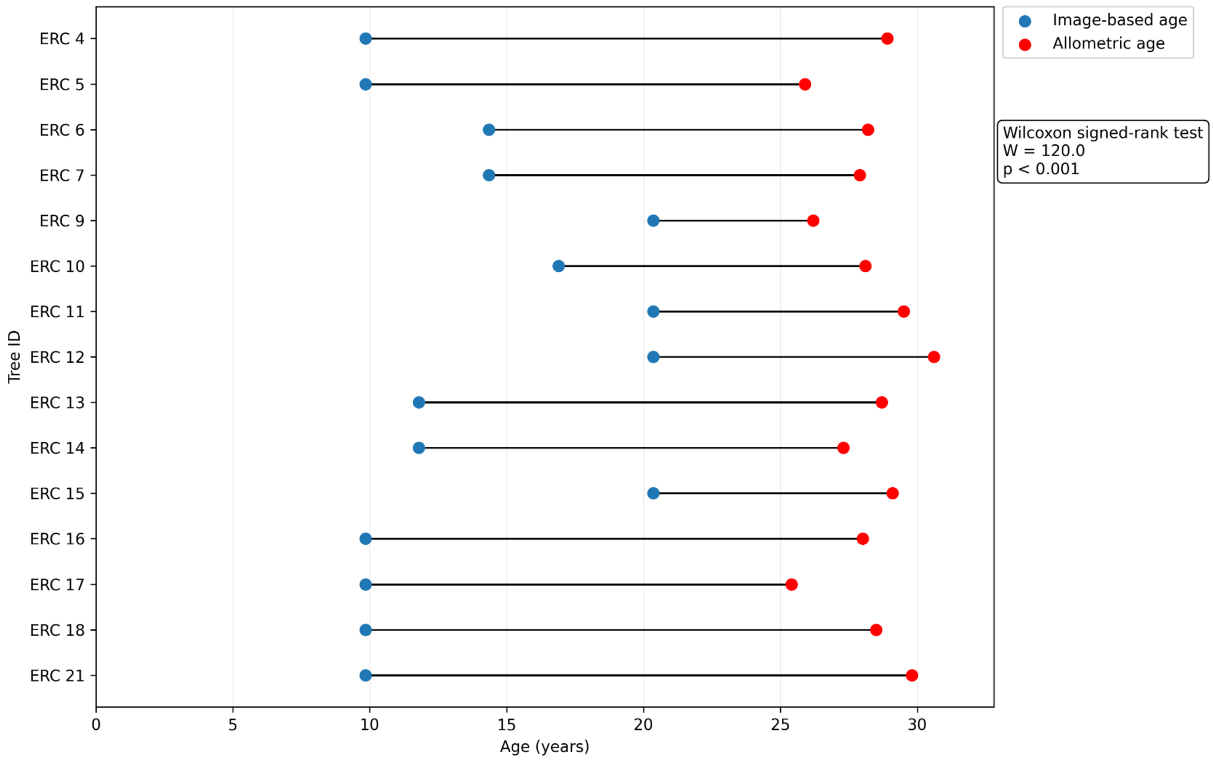

Figure 20. Comparison of image-based ages (midpoint) and allometric ages for the 15 sampled eastern redcedar trees at the Kessler Atmospheric and Ecological Field Station. The Wilcoxon signed-rank test indicated that allometric ages were significantly older than image-based ages ($W = 120.0$, $p < 0.001$).

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4. CONCLUSIONS, LIMITATIONS, AND FUTURE DIRECTIONS

4.1 Synthesis

This thesis set out to reconstruct long-term land-cover change in a heterogeneous Southern Great Plains watershed and to make that reconstruction usable at the scale where field research is actually conducted. The three chapters address that aim in sequence. Chapter 1 established why no single archive captures more than a century of fine-grained landscape change, and why integrating survey records, historical aerial photography, and modern orthophotography is necessary rather than merely convenient. Chapter 2 carried out that integration, producing a continuous 1871–2023 reconstruction of the Upper Finn Creek Watershed that traces not only net change in grassland, forest, and cultivation but the transition pathways and repeated turnover behind them. Chapter 3 brought the watershed reconstruction down to the site scale at KAEFS, organizing it into an accessible platform (K-Viz) and demonstrating its use for reading land-use legacies, checking ERC ages against historical imagery, and supporting teaching and planning.

The chapters make a single argument: present-day landscape conditions cannot be interpreted from present-day cover alone, and the historical record needed to interpret them becomes useful only when it is both fine enough in resolution and accessible enough in form to reach the people asking site-level questions. The watershed analysis supplies the resolution; the platform supplies the access. Across scales, the recurring finding is that present-day landscapes reflect historical trajectories, with both persistence and change shaped by past land use.

4.2 Limitations

The limitations specific to each analysis are discussed in their respective chapters; three broader constraints apply to the thesis as a whole. First, the reconstruction depends on sources that differ in kind, and no amount of standardization fully removes that heterogeneity. Survey plats, black-and-white aerial photography, and modern orthophotography differ in resolution, geometry, and information content, so mapped transitions carry more interpretive uncertainty in the earliest years than the later ones, and fine differences in area are less reliable than multi-decadal direction. The nineteenth-century baseline in particular is an interpreted historical reference rather than a classification product equivalent to the imagery-based years.

Second, imagery records condition, not process. Throughout the thesis, historical sources can show that a location was open, wooded, cultivated, or disturbed at a given date, but not why. This constraint is why the reconstruction is most defensible when read alongside archival and field knowledge, and why the ERC ages in Chapter 3 are treated as detection windows rather than establishment dates: a tree's first appearance marks when it became visible, not when it germinated.

Third, the applied products are bounded in scope. The reconstruction covers a single ~1,300 ha watershed, and the platform is built for one field station on a hosted commercial system, so its continued usefulness depends on institutional maintenance rather than on the analysis alone. The workflow is transferable, but the specific outputs are local.

4.3 Recommendations and Future Directions

Several directions follow from this work. The most immediate is validation and extension of the ERC age comparison. The image-based ages in Chapter 3 flag a systematic offset from allometric estimates but cannot resolve which is correct; pairing image-derived establishment windows with field measurements such as ring counts or basal cross-sections on a subset of trees (Copenheaver et al., 2005) would test the offset directly and refine both methods. Because the finding bears on how long encroachment is assumed to have influenced site conditions, it has direct implications for the biogeochemical work the plots support.

A second direction is incorporating sources that fall between the archives used here. Declassified CORONA imagery could help close the gap between the mid-century aerial photographs and the nineteenth-century survey baseline (Shahbandeh et al., 2023), and leaf-off or higher-resolution recent imagery could sharpen detection of early woody establishment that leaf-on NAIP tends to obscure. Each would reduce the interpretive uncertainty concentrated in the earliest and the most recent transitions.

A third direction concerns the platform. K-Viz currently organizes a completed reconstruction; its greater long-term value lies in becoming a living record that incorporates new imagery, new research locations, and monitoring data as the station's program develops. Linking the change-index and historical layers to ongoing soil, microclimate, and carbon measurements would let researchers move from using history to interpret existing data toward using it to design new sampling. The same approach could be applied at other field stations with comparable historical records, testing whether the nested, watershed-to-site workflow developed here generalizes beyond KAEFS.

Finally, the reconstruction offers a foundation for questions this thesis did not pursue. The transition and change-index products are suited to quantitative landscape-pattern analysis, to modeling where future woody expansion is most likely given past trajectories (Yang et al., 2024), and to examining how land-use legacies relate to present-day soil, hydrologic, and vegetation patterns across the watershed. In each case, the contribution of this work is the same: a historically grounded, spatially explicit basis for interpreting a landscape that, like much of the SGP, is far more a product of its past than its present appearance suggests.

References (Chapter 4)

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APPENDIX I

Kessler, E. (1980). *Brief History of This Homestead*. Unpublished manuscript. Documents the ownership history of the parcels forming present-day KAEFS, from the 1830 Treaty of Dancing Rabbit Creek and the 1904 Choctaw allotment patent through the Plaster, Aetna Insurance, Schneider, Stephens, and Kessler ownerships, and describes the dairy operation, East Criner oil field development, pipeline network, and post-1976 conversion of tilled land to native grass.

E Kessler, 1976 Revised, November 12, 1980

BRIEF HISTORY OF THIS HOMESTEAD

In accordance with provisions of the 1830 Treaty of Dancing Rabbit Creek, between representatives of the United States and the Choctaw Nation, the land now owned by Edwin and Lottie Kessler became part of that set aside for allotment to the Choctaw and Chickasaw tribes. A homestead patent covering 80 acres, dated January 12, 1904, was granted to Josephine Mathis, Choctaw, born in 1888. Her father was Dan Mathis, her mother was Angie Riggs, and her husband was Henry Plaster. The Plasters lived in a tent until they moved into the home they built themselves later in 1904.

The original home consisted of the present bedroom, living room and kitchen. Basic wall construction is two layers of 1 x 12 inch boards, one layer running vertically, the other horizontally; the walls are fastened to corner posts and rest on a foundation of sandstone gathered in these fields. The Plasters raised seven children in their home; some relatives and descendants reside in this area and some now live in California. In 1908, the Plasters purchased 80 acres of unallotted Choctaw and Chickasaw land adjoining the homestead for $12.75 per acre, and the combination with the original patent nearly defines the boundaries of the present farm.* The Plasters started a dairy in 1925 and milked about 50 Jersey cows and they raised cotton, broom corn and various sorghums on the bottom land. In 1929, Henry Plaster and his boys assembled and erected the windmill, purchased at Berringer's Hardware in Purcell, and hauled it to the farm in a Model T Ford truck. The Plasters also dug the path across Finn Creek, a path which for many years was the only outlet from the farm to county roads.

The Plasters had mortgaged their property with the Aetna Life Insurance Company in 1919, and subsequent hard times made it impossible to repay the loan. Aetna

*The Plasters also owned some adjoining land that was later bought by Masterson, formerly our neighbor to the south. The record of these ownerships is not part of the abstract on the land discussed here.

filed for foreclosure in 1932 and following involved proceedings, a judgement was obtained in 1938. On December 27, 1938, Aetna itself purchased the farm (210 acres) at a sheriff's sale. Aetna leased the farm to Russell McGee for a year and then sold it in 1940 to Glen Orvil Schneider and his wife Mary Elizabeth on favorable terms to them. In the late 1930's, about half the farm land in Oklahoma was possessed by companies which had taken mortgages in exchange for cash, and the sale by Aetna was encouraged by a law which required divestiture of loan company ownerships.

Development of the East Criner Oil field, party underlying this homestead, began shortly after the Schneider purchase, and oil lease money helped the Schneiders to complete their payments to Aetna. The Schneiders improved the water supply system to the kitchen and built the dairy barn with rock from southeast of Ada, shaped on site with chisels as the barn was built. But the distance of the dairy barn from the main road impeded marketing of milk and in 1945 the Schneiders sold the farm to Roy E. and Ora E. Stephens, and bought another better suited to their purpose in Chickasha.

The Stephens raised cotton, grain, broomcorn, peanuts and watermelons on their acreage and on adjoining lands which they leased. With improved roads, dairying here became more practical, and the Stephens developed a dairy herd which they maintained until 1972. In 1949, they added to the back of the house a bathroom and two other small rooms, one now used as a study, the other as an extension to the kitchen and as a laundry. The Stephens also further improved the kitchen and porch and storm cellar. They raised a family of four boys now engaged in agriculture and construction. The farm ponds, including the large reservoir (371 acre feet) whose dam touches the northwest corner of the property, were built by the Soil Conservation Service in the late 1960's.

In 1973, the present owners, Edwin and Lottie Kessler, purchased the farm from the Stephens. Most of the land was leased until 1976 to Alex Glenn Stephens for cattle and calf raising. Wheat and millet was raised on the tillable land for grazing and for hay and grain, and cattle graze the native grasses during the summer. After 1976, about 25 acres of formerly tilled land was converted in stages to native grass pastures, and several erosion control projects have been undertaken, usually with participation of the Soil Conservation Service. The Kesslers keep bees and raise vegetables and rice on a half-acre set aside for gardening. The Kesslers remodeled and added to the house, adding insulation and, in the old section, studded walls inside the old and new ceiling below the old. Charles Myers of Chickasha repaired the windmill in 1974. Shortly thereafter, its capacity was measured at about 40 gallons per day, but by 1980, this had increased to about 60 gallons per day. Quality of water from the windmill is excellent, though the water is somewhat hard. In contrast, the south well provides extremely hard water. A third source of water is Finn Creek, from which an irrigation system has been extended. Finn Creek water is not very hard, and is excellent for irrigating the garden and watering stock. It is not generally potable, however, because of some bacterial content.

The oil field that underlies the property at a depth of about two miles is now being processed by the Sunray DX Oil Company for secondary recovery. There are three significant wells on the property, one on its boundary, and others nearby. One well in the southeast corner produces oil from two zones more or less continuously. Some waste oil from that well was sprayed on the drive which connects the house with the county road on the north border of the property. In 1979, this road was improved by Sun Oil Company with many loads of crushed rock. The well on the southwest boundary does not produce oil now, but is labeled for deepening before the 21st century. Northeast of the house a pump well operated by an engine fueled with natural gas was tested occasionally until mid-1979 and produced a mixture of brine and oil. At this writing it is not being operated, in order to conserve gas pressure in the oil bearing formation. The fourth well northwest of the house is used to inject brine from a salt water supply well about two miles south of the property, into the same stratum from which the producing well on the property and other nearby producers are extracting oil. The salt water replaces oil in the underground formation and increases oil recovery. According to Mr. Rogez in 1975 or 1976, Sun Oil Company expects to be collecting oil from this field until the year 2005.

The property is traversed by numerous pipelines, some inactive. However, there are two 24-inch lines which carry oil from Texas and New Mexico to Tulsa and other points northeast, an oil field collector line operated by Mid Continent Oil Company, a low pressure gas line operated by Warren Petroleum Company, and several active lines of the Sun Oil Company.

The farm lies 3W and 5S of Washington and midway between the pioneer communities of Woody Chapel and Criner. The house remodeling was done by Herbert Prater, carpenter and part-time Baptist minister, whose home in Criner two and one-half miles southwest of here he also remodeled from its former use as a cotton gin (Mr. Prater moved to Holdenville in the late 1970's). Across the road was Binks Graham's store, which operated under the same management for 30 years, and was a convenient place for light shopping until it was sold and dismantled in 1976. In 1979, Tom's Country Store opened at Woody Chapel, four miles from the homestead - at this writing, this store is the closest place where gasoline and a small assortment of refreshments and canned goods can be purchased.

APPENDIX II

Kessler, E. (1989). *Great Plains Apiaries: An Activities Report*. Unpublished manuscript. A numbered report of management activities on the farm, covering energy conservation measures, sewage sludge and wood-ash application for erosion control and soil amendment, water system improvements drawing on Finn Creek and two wells, and low-water crossing construction.

Edwin Kessler
June 1983

Great Plains Apiaries - - An Activities Report

This farm of 220 acres, located in Oklahoma between the historic communities of Criner and Woody Chapel, derives from a homestead established in 1904 following the allocation to individuals of land previously held as a unit for the Choctaw and Chickasaw Indian tribes. Successive owners of the major part of the present farm were Josephine (Matthis) Plaster and her husband Henry Plaster, Aetna Insurance Co., Glen Orville Schneider and his wife Mary Elizabeth Schneider, and Roy E. and Ora E. Stephens. Edwin and Lottie Kessler purchased the farm in 1973.

The following activities have been prominent recently at the farm.

1) Erosion control - With advice and financial aid from the U.S. Soil Conservation Service, several areas formerly severely eroding have been brought under control. The control process on the most severely affected sites involved grading, planting, and reduced grazing. On some sites, a dam with a controlled outlet was constructed. Erosion has been reduced in some formerly cultivated fields through conversion of their crop to native grasses. Fences have been built on both sides of Finn Creek to prevent cattle from grazing in the creek bottom.

2) Special plantings - We have tried to increase diversity of species and the cover available for wildlife through various plantings, including multiflora rose, bald cypress, catalpa, cottonwood, osage orange, and some species of oak. Black locust has been planted extensively, and crown vetch has done very well.Most trees have done well in lowland areas, but not generally on the uplands. Many evergreens were planted along fences, but all died.

3) Grassland improvement - Fences have been installed to control access to pasture by cattle, cattle numbers have been limited for compatibility with lush growth of grasses, and grasses have been planted in some areas formerly cultivated. Most forbs tend to be suppressed in competition with native grasses on upland prairie when grazing is restricted.

4) Energy conservation - The farm house, whose core was built in 1904, has been fitted with the following features for conservation of nonrenewable sources of energy: insulation in walls, floor, and ceilings; stoppage of drafts from small openings; cast iron stove for

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heating with wood; evaporative cooling in summer; solar space heater for winter use; solar water heater and solar oven for summer use; extra insulation on a freezer; and a generator for producing electricity from the wind. These measures have been associated with marked reduction of usage of propane and electricity. Present purchases of electricity amount to about 400 kwh per month, and yearly consumption of propane is about 375 gallons. About 2½ cords of wood are burned annually during the cold season.

5) Sludge to control erosion and stimulate plant growth - Sludge accumulated in large quantities at sewage treatment plants is a potential resource, but has represented a disposal problem because of a regulatory maze and inadequate data on the fate of a wide range of elements characteristically present in municipal sludges in trace amounts. In an experiment supported by the National Science Foundation through Grant NSF/ISP-8014715 with Kansas State University (M.B.Kirkham Principal Investigator), and coordinated with the Oklahoma State Department of Health, 400 cubic yards of anaerobically digested, dried sewage sludge were brought to GPA during March and April 1981 from the Southside Plant in Oklahoma City, and deposited on four acres involving 7 test plots. The test plots demonstrate reduced erosion and enhanced growth of grasses and other plants. The migration of trace elements in soil, plants, and cattle was monitored in order to help verify or redefine baseline criteria for applications of municipal sludges to Oklahoma lands. The test has contributed to wider usage of municipal sludges in Oklahoma.

6) Wind power - The availability of wind power in Oklahoma, and its relationship to demand is being assessed with the aid of a commercial generator (Bergey Windpower, Inc.) on a 100' (formerly 60') tower, with recording of wind at two levels on the tower and recording of wind and other parameters at a base station. The Rural Electric Cooperative and Oklahoma Electric Cooperative are assisting at this and at two other sites through provision of special meters for monitoring wind generator output and related electricity flows. The Oklahoma Corporation Commission is cognizant and has influenced the study through its indication of kinds of data needed to help establish a proper regulatory environment for small and large generators in relation to the public utilities.

7) Acid rain - A station of the National Air Deposition Program was established on the farm in February 1983.

8) Water System - The farm water system has been improved to match requirements more closely to water quality and quantity. Water is drawn from Finn Creek for cattle watering and irrigation of the garden, and from two wells, drilled by previous owners, for household purposes. Water from one of the wells is lifted by the wind and distributed by gravity.

9) Agricultural Practices -

A) Garden: A garden with most common vegetables is developed annually, with chicken and cow manure as the major fertilizer inputs. "Organic" methods are used.

B) Orchard: There is a small orchard, mainly of apple, pear, and peach trees. It is fertilized with straw and manure accumulated during the winter where the cows are fed, and the trees are sprayed during the cold season with dormant spray (lime and sulfur in mineral oil and water).

C) Rice paddy: Rice has beeen grown since 1975 in a low area, about 1/50 acre. This has furnished more than enough rice for the family.

D) Small grains: Up to 20 acres of wheat, rye, and oats are grown, principally for grazing, but a few acres are harvested. The fields are not sprayed or fertilized with manufactured chemicals, so yields are typically about 20 bushels per acre of grain grown for harvest. Some of the wheat has been marketed to health food stores.

E) Cattle raising: There are approximately 25 animals at this writing, including a dozen calves. Most are crosses between Hereford and Black Angus, but some include admixtures of other varieties. Calves are raised here from birth through slaughter, and usually sold to individuals shortly after weaning, when they weigh between 400 and 500 pounds. The animals' basic diet is range grasses both summer and winter, but during late winter they are fed supplements of hay cut and baled the previous summer and, occasionally, a feed concentrate. No hormones or chemical supplements are implanted or fed. It is expected that the herd will be maintained in the future at about its present size.

F) Honey: Bee hives have provided 200 to 300 pounds of honey each year. This has been marketed to individuals, health food stores, and a restaurant.

G) Chickens: Approximately 20 chickens were kept for several years for eggs and, perhaps equally important, manure. Surplus eggs, occasionally as many as 4 dozen per week, were sold to individuals, but all chickens were sold in 1982 because they were pests in the flower beds and generally seemed to be more trouble than they were worth.

H) Wood ashes: Ashes produced during the heating season benefit the garden and the fields where small grains are grown through their provision of potassium and phosphorus, and through a raising of the pH from somewhat depressed levels (about 5.5) which may be associated with former annual applications of ammonium nitrate. Perhaps 30 years would pass at current rates of application before all parts of the cultivated fields receive an application of ashes; it is interesting to observe positive effects on yields along the swaths where ashes have been applied. Wood ashes are also used in the garden to discourage squash bugs, and in the orchard to discourage peach borers.

I) Low water crossing: A low water crossing was constructed of rocks and concrete and a 12" diameter conduit. It has provided much improved access to portions of the farm south of Finn Creek.

Some references to the practices described above

(Papers by E. Kessler, except where otherwise indicated)

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APPENDIX III

Supporting analysis for the eastern redcedar age comparison (Section 3.5.3)

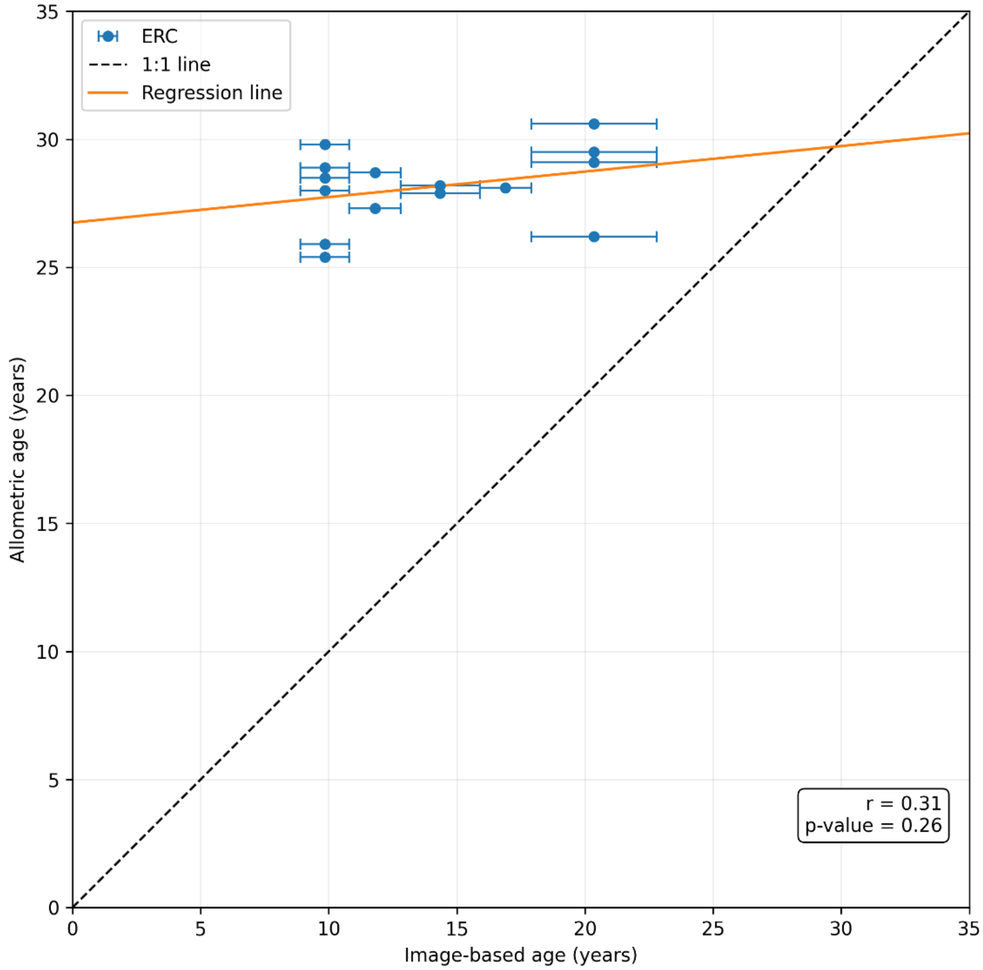

Figure A1. Relationship between image-based ages and allometric ages for the 15 sampled eastern redcedar trees at KAEFS. Points represent individual ERC trees, horizontal error bars show the image-based age range around the midpoint, the dashed line indicates 1:1 agreement, and the regression line summarizes the overall trend. Pearson correlation showed a weak positive association between the two age estimates ($r = 0.31$, $p = 0.26$).