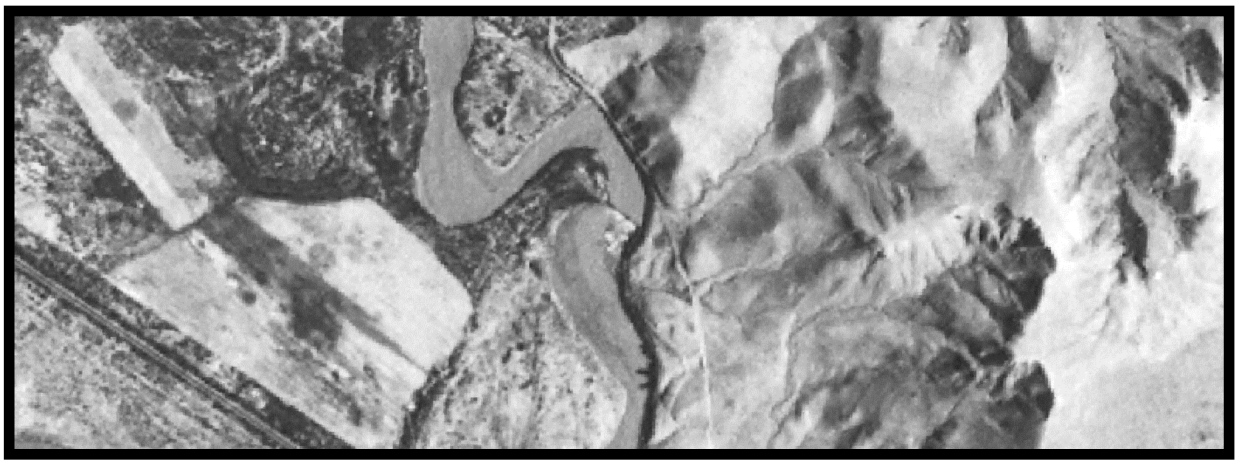
USING HISTORIC AERIAL PHOTOGRAPHS TO SUPPORT THE RESTORATION OF DRYLAND RIVER SYSTEMS: A CASE STUDY OF THE PRICE RIVER IN CENTRAL UTAH



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FRONT COVER IMAGES

Top image: Farnham Dam in foreground and stream bank protection in background, showing piling, cable, and net revetment, Fall 1940. Credit: U.S. Soil Conservation Service Photograph Collection, 1930s-1940s, Utah State Historical Society.
Middle image: Aerial photograph from 1938 collected under the direction of the U.S. Soil Conservation Service as part of the Upper Colorado and Green River regional inventory, showing the Price River and Farnham Dam. Credit: Utah Geological Survey.
Bottom image: National Agricultural Imagery Program (NAIP) aerial imagery acquired in 2014, showing the Price River and Farnham Dam. Credit: Utah Automated Geographic Reference Center (AGRC).

ABSTRACT

UtahView used funds from an AmericaView mini-grant program (USGS Grant G14AP00002) to evaluate the historic river conditions and riparian land cover distribution for the lower reaches of the Price River in central Utah. This project provides a foundation for developing an efficient and rapid process that will support restoration planning in dryland river systems. Historic aerial photographs serve as an invaluable source of information on historic landscape condition and they can provide baseline assessments. Knowledge of historic conditions can improve understanding, inform contemporary management decisions, and guide restoration activities. Through this mini-grant, UtahView downloaded and georeferenced historic aerial photographs from 1938 and compared them with aerial images from 1974, 1997, 2006, and 2014. River morphology characteristics, such as channel width and sinuosity, were measured; land cover changes were assessed and quantified; and stream gage data were evaluated.

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USING HISTORIC AERIAL PHOTOGRAPHS TO SUPPORT THE RESTORATION OF DRYLAND RIVER SYSTEMS: A CASE STUDY OF THE PRICE RIVER IN CENTRAL UTAH

INTRODUCTION

Dryland or desert ecosystems cover approximately half of the Earth's surface and are extremely diverse in terms of geology, ecology, hydrology, and human activities (Bull and Kirkby, 2002; FAO, 1989). Despite these varied differences, the common and central attribute of these systems is aridity. Aridity is a measure of dryness that is expressed as a ratio between average annual precipitation and total annual potential evapotranspiration (UN, 2011). Average annual precipitation in dryland ecosystems is generally defined as less than 50 centimeters (20 inches), with hyper-arid systems being classified by little or no precipitation, arid systems being classified by less than 25 centimeters (10 inches), and semi-arid systems being classified by 25 to 50 centimeters (10 to 20 inches) (Kingsford and Thompson, 2006; Walker, 1996). Within dryland ecosystems, the potential evapotranspiration (i.e. the amount of water evaporated from the ground surface and transpired from plants assuming that moisture is not limited) exceeds the average annual precipitation. Therefore, dryland ecosystems have permanent, seasonal, or fluctuating moisture deficits (Bull and Kirkby, 2002).

While dryland or desert ecosystems are generally characterized by limited, and perhaps unpredictable, precipitation, high rates of evapotranspiration, low levels of soils nutrients, and sparse vegetation, they are interspersed with highly productive, biologically diverse, and ecologically significant streams, rivers, and riparian corridors (Free et al., 2013). Streams and rivers are the dominant factor in shaping the ecology of dryland ecosystems because they control the distribution of organisms. They provide a valuable and scarce resource to numerous species of wildlife and vegetation and they are functionally important as corridors and refuges. Therefore, dryland river systems are considered to be one of the most productive and valuable natural resources (Burnette and Rauch, 2010; Free et al., 2013).

In the Southwestern United States, dryland river systems encompass less than 2 percent of the total land area (USGS, 2016), but they are integral components of arid ecosystems due to their role in providing habitat, supporting biodiversity, maintaining water quality and quantity, providing groundwater recharge, controlling erosion, and dissipating floods (Zaimes, 2007). Research has demonstrated that southwestern riparian zones support some of the most productive ecosystems in North America (Johnson and Haight, 1984). They provide habitat for approximately one-third of all plant species and they support endangered terrestrial and aquatic species (Poff et al. 2011). Johnson et al. (1977) determined that 47 percent of 166 bird species nesting in southwestern lowlands were entirely dependent on riparian and wetland habitat, and an additional 30 percent were partially dependent on these habitats. These dryland river systems have also historically sustained approximately one-third of the native fish fauna of North America, and they continue to support a highly endemic fauna that includes fish, aquatic insects, and mollusks (DFHPW, 2008; Kennedy et al., 2005).

Although these desert river systems have immense ecological importance, their value has not been widely acknowledged or appreciated. Within the past 100 years, an estimated 95 percent of arid system riparian habitat in the Southwestern United States have been altered, degraded, or destroyed through the construction of water infrastructure projects and incongruent land management practices, such as livestock overgrazing, agricultural land use conversion, and urbanization (Krueper, 1996). Water development projects, such as dam construction, water diversion, channelization, and groundwater withdrawal, have changed flow regimes and suppressed fluvial processes (Rinne, 1993; Stromberg et al., 2007). Changes in flood frequency, duration, and intensity have depressed floodplain water tables and impacted riparian species composition, distribution, and structure (Busch and Smith, 1995).

As flood frequency has decreased and groundwater tables have deepened, the diversity of riparian plant species has declined. In many dryland river systems in the Southwestern United States, species composition has shifted from pioneer phreatophytes, such as Fremont cottonwood (*Populus fremontii*) and black willow (*Salix gooddingii*), to more drought- and salt-tolerant invasive shrub species, such as tamarisk (*Tamarix ramosissima*) and Russian olive (*Elaeangnus angustifolia*). The suppression of flooding and moderation of peak flows has resulted in increased densities of riparian vegetation and often contributed to large monocultures of tamarisk (Stromberg et al., 2007). Tamarisk species have colonized large tracts of floodplains, reservoir margins, and wetlands in western North America and they have impacted desert river systems by channelizing rivers, displacing native vegetation, contributing to dewatering, reducing the quality of wildlife habitat, and altering soil salinity and water chemistry (Di Tomaso, 1998; Birdsey et al., 2010; Shafroth et al., 2005). Many fish species have been affected by the narrower, deeper, and more homogenous stream habitats that result from tamarisk invasion (Dudley et al., 2000).

Due to the severity and extent of these ecological impacts, restoration of dryland river systems in the Southwestern United States has become a priority for federal and state agencies. Many land and resource managers seek to reduce the abundance of tamarisk and other invasive plant species for the purpose of restoring native riparian vegetation and improving terrestrial and aquatic wildlife habitat (Shafroth et al., 2005). While restoration of these systems pose some formidable challenges due to multiple threats (Laub et al., 2015) and varying land management objectives, remote sensing and geospatial technologies can alleviate some of the complexity. Historic aerial photography and current aerial imagery provide viable alternatives to examining the distribution, extent, and changes of riparian vegetation, as well as characterizing past and present fluvial systems and evaluating changes in river morphology.

PROJECT BACKGROUND

In 2016, the Remote Sensing/GIS (RS/GIS) Laboratory, host of UtahView, partnered with the Fish Ecology Laboratory, the Ecogeomorphology and Topographic Analysis Laboratory at Utah State University (USU), and state agencies to a develop a high-resolution land cover dataset for the lower reaches of the Price River in central Utah. The Price River has become increasingly dominated by invasive plant species, including tamarisk and Russian olive. Changes in flow regimes have impacted the distribution of native vegetation and furthered the decline of native fish species, such as Colorado River cutthroat trout and Colorado pikeminnow. This high-resolution land cover dataset is currently being utilized by state agencies to support the design of a restoration plan for the Price River. While this dataset has been extremely valuable in identifying the current distribution of native and invasive plant species, the identification of targeted restoration sites remains uncertain due to limited knowledge of historic river conditions.

OBJECTIVES

Historic river conditions and riparian land cover distribution can be determined by evaluating historic aerial photographs that are presently available from state and federal agencies. In an effort to support land and resource managers, as well as private land owners, within dryland river systems, UtahView used funds from a mini-grant program to develop a process that would enable fairly rapid assessments of changes in river morphology and riparian land cover. Specifically, UtahView (1) downloaded and georeferenced historic aerial photographs spanning the lower reaches of the Price River; (2) analyzed river channel characteristics, such as channel width and sinuosity, for multiple years; (3) quantified riparian land cover changes for a segment of the Price River; and (4) briefly evaluated stream gage data from the National Water Information Systems (USGS 09314500 Price River at Woodside, Utah).

STUDY AREA

The Price River is a tributary of the Green River and it drains the Price sub-basin (HUC 14060007), an area of approximately 4,882 square kilometers (1,885 square miles) (USGS, 2017). Price River proper begins downstream from Scofield Reservoir in Carbon County, Utah. It flows southeast through Price Canyon, a physiographic break between the Wasatch Plateau and the Colorado Plateau; it parallels US Route 6; and passes through the towns of Helper, Price, and Wellington. The Price River enters into Emery County, flows along the northeastern edge of the San Rafael Swell, and passes through the ghost town of Woodside, where it then flows eastward to the confluence of the Green River (Waddell et al., 1986; USBR, 1998) (Figure 1).

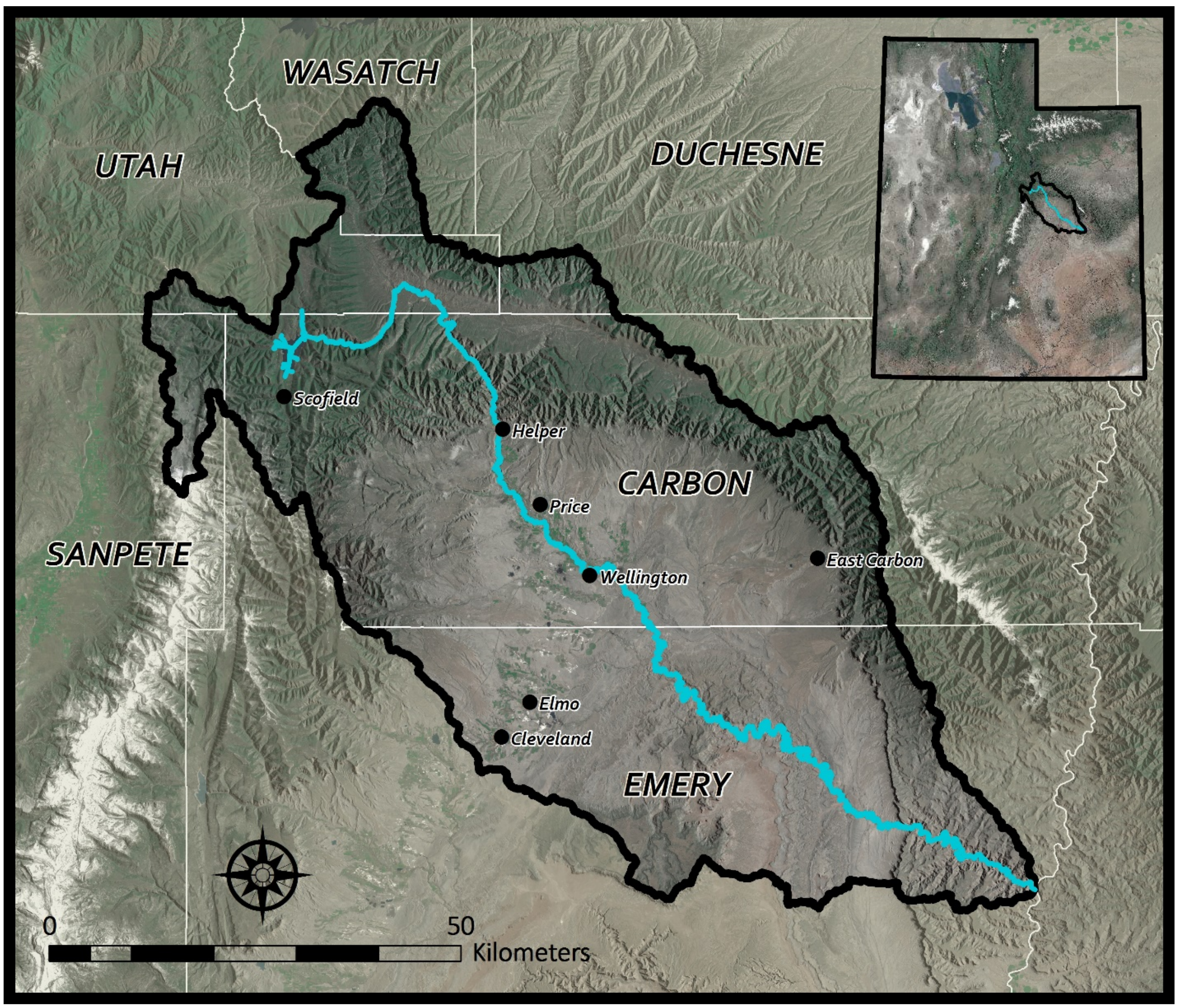

Figure 1. Price sub-basin (HUC 14060007), showing the Price River, major towns, and counties.

Average annual precipitation at Scofield Reservoir is 30 centimeters (12 inches), whereas average annual precipitation at Wellington, Utah, is 23 centimeters (9 inches) (UCC, 2017). The Price sub-basin is predominantly rural and includes seven cities and five census designated places (CDPs). The combined population of the cities and CDPs within the sub-basin is 18,330 (USCB, 2017). The largest municipality is Price City, with an estimated population of 8,371 (USCB, 2016). Land ownership within the sub-basin is predominantly federal (i.e. BLM and USFS) and includes 52 percent of the area. Thirty-five percent is privately owned and 13 percent is managed by state agencies. Due to the extensive private land ownership in the upper reaches of the Price River, restoration activities are planned for the lower reaches of the Price River. Therefore, the study area for this analysis, as well as the previous land cover analysis, encompasses the area from Wellington, Utah, to the confluence of the Green River (Figure 2).

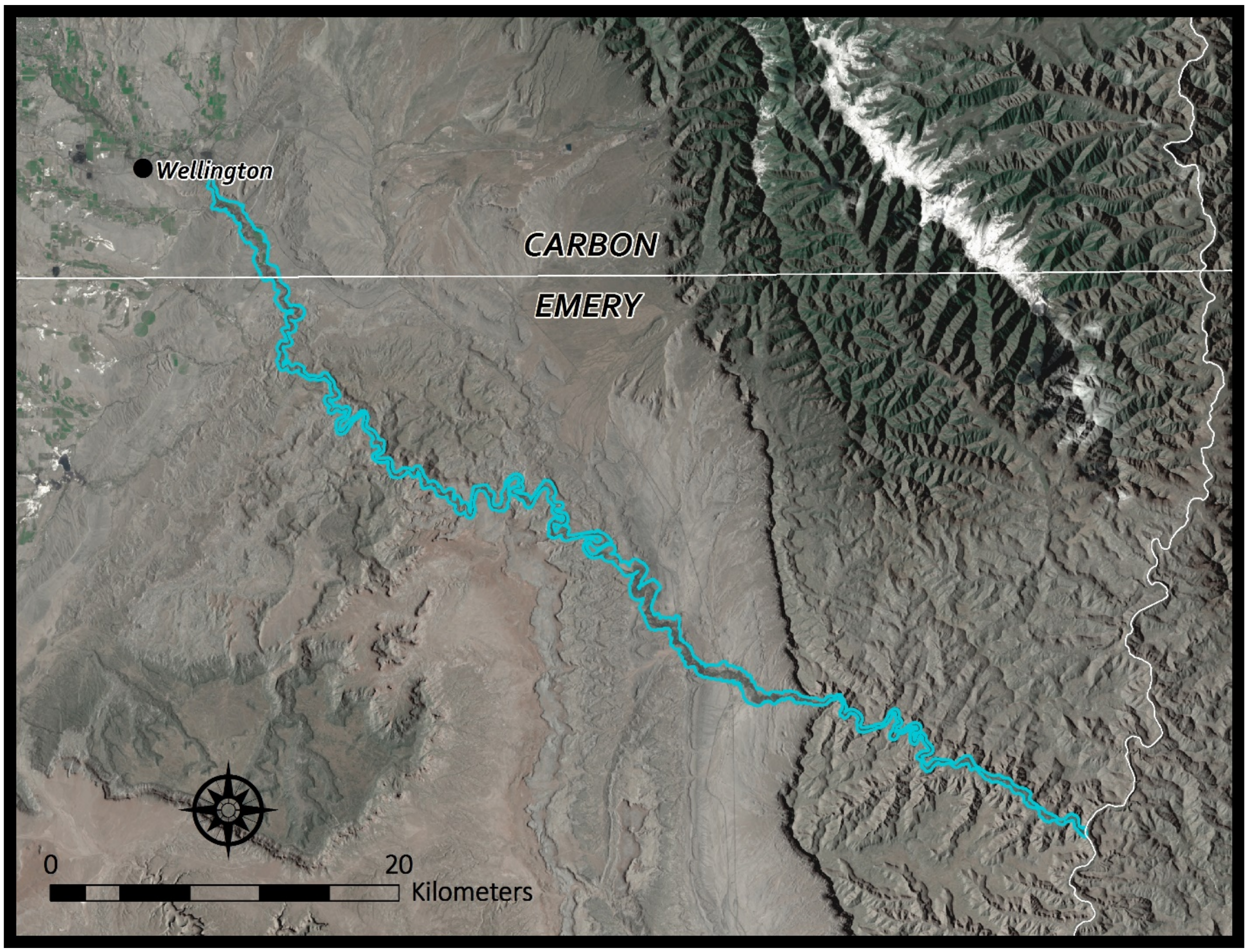

Figure 2. Price River study area, spanning the lower reaches of the Price River from Wellington to the confluence of the Green River. Study area delineated by the Ecogeomorphology and Topographic Analysis Laboratory at Utah State University.

Riparian vegetation along the lower reaches of the Price River consists of willows (*Salix* sp.), cottonwood (*Populus fremontii*), sagebrush (*Artemisia* sp.), greasewood (*Sarcobates vermiculatus*), rabbitbrush (*Ericameria* sp.), Utah juniper (*Juniperus osteosperma*), and galleta grass (*Hilaria jamesii*) (Figure 3). From the town of Helper downstream to the confluence of the Green River, invasive tamarisk and Russian olive have increasingly dominated the riparian corridor. As with generalized impacts across the Southwestern United States, these species have impacted the Price River by narrowing the channel, displacing native vegetation, contributing to dewatering, reducing the quality of terrestrial and aquatic habitat, and altering soil salinity and water chemistry (Birdsey et al., 2010).

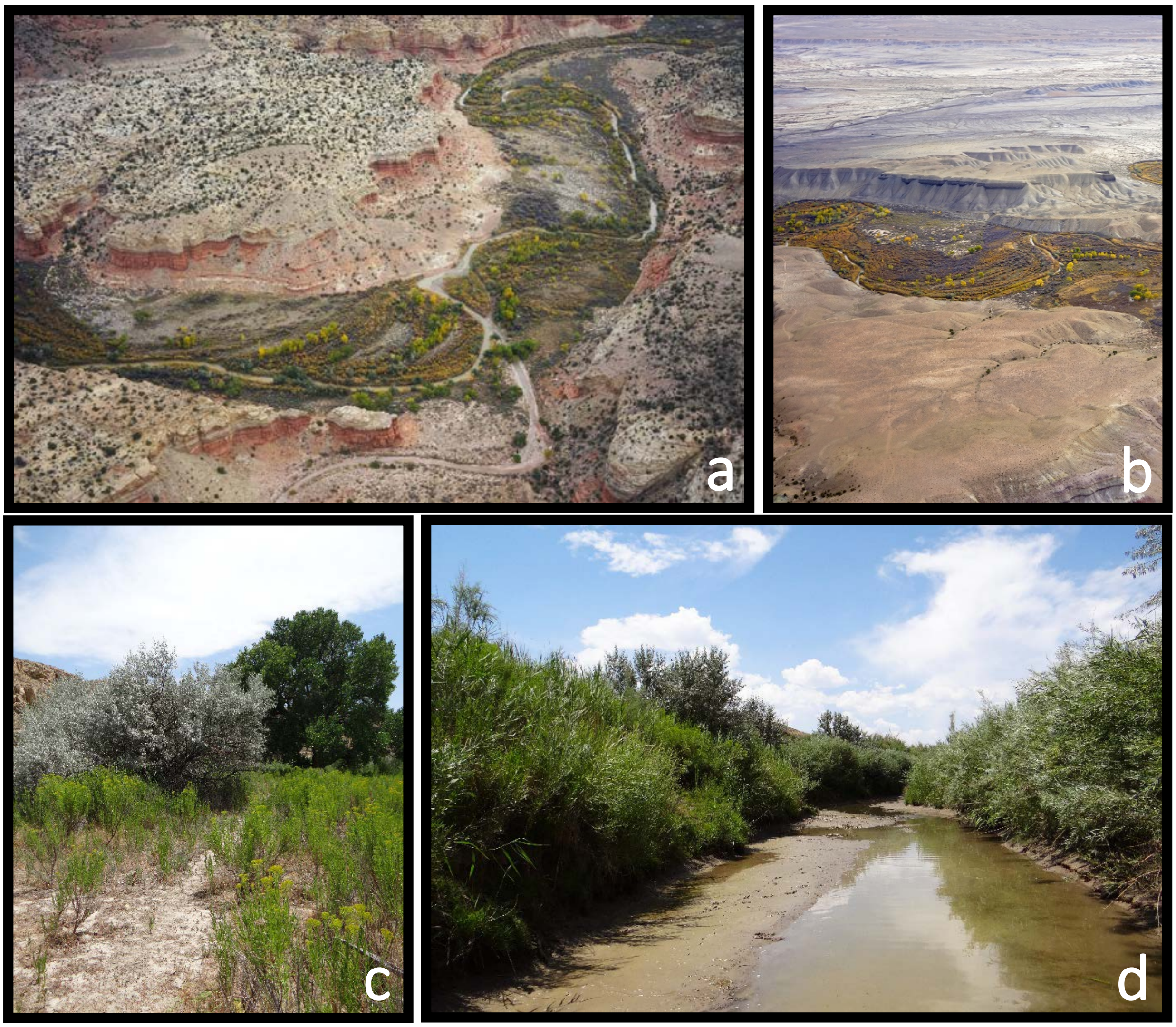

Figure 3. Vegetation within the Price River riparian corridor: a) and b) aerial oblique photographs of the Price River system; c) and d) ground photographs of the Price River system. Credit: Christopher McGinty.

Invasive species, dewatering, overgrazing, and sedimentation present some of the greatest threats to the ecology and hydrology of the Price River (Figure 4). These threats, along with the introduction of exotic fish species, have had significant impacts on native fish species within the Price River. Colorado River cutthroat trout (*Oncorhynchus clarkii pleuriticus*), a state-listed conservation species, Colorado pikeminnow (*Ptychocheilus Lucius*), a federally-listed endangered species, roundtail chub (*Gila robusta*), flannelmouth sucker (*Catostomus latipinnis*), and bluehead sucker (*Catostomus discobolus*) are native fish species that have experienced substantial declines. These species have required special management designations and are presently managed under interagency conservation agreements (Birdsey et al., 2010).

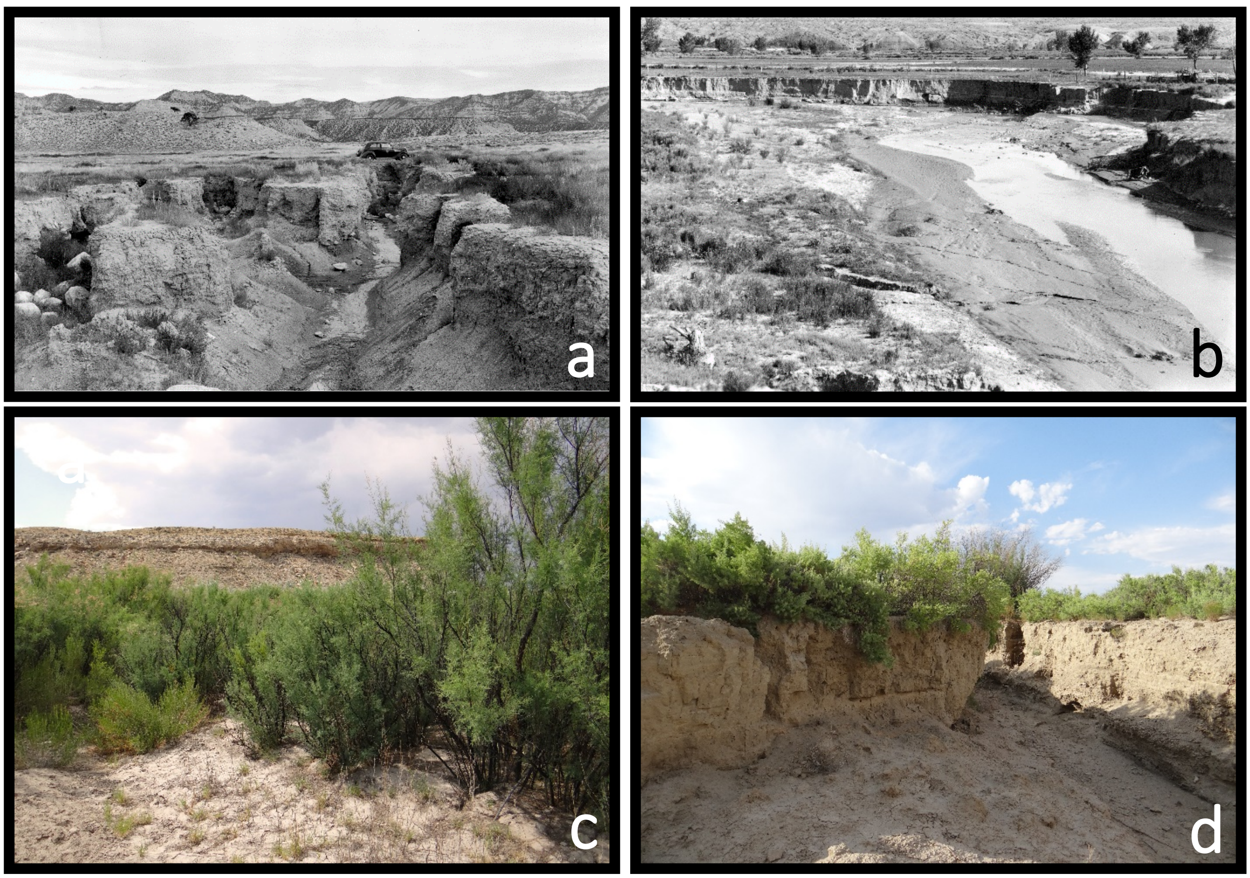

Figure 4. *Erosion and tamarisk are some of the ecological and hydrological threats to the Price River system: a) gully development due to livestock overgrazing, 1939; b) streambank erosion along the Price River, August 3, 1939 - photograph was taken to show the condition of the bank before stream bank construction work was completed in 1940. Credit: U.S. Soil Conservation Service Photograph Collection, 1930s-1940s, Utah State Historical Society; c) tamarisk invasion within the Price River floodplain; and d) headward erosion along the Price River. Credit: Christopher McGinty.*

GEOREFERENCING HISTORIC AERIAL PHOTOGRAPHS

Overview

Aerial photographs have been used by land managers and natural resource scientists for decades to evaluate agricultural, soil, hydrologic, and vegetative characteristics (Cohen et al., 1996; Lyon, 1987). In the 1930s, the acquisition of non-military aerial photographs was largely initiated by the Agricultural Adjustment Administration (AAA) and the Soil Conservation Service (SCS) to support agricultural and rangeland surveys (Magruder, 1949; Rango et al., 2008). The use of aerial photographs was born out of the need to support the several agricultural and conservation programs that emerged during the New Deal administration (Magruder, 1949). Aerial photographs provided a cost effective tool for adequately measuring agricultural and natural resources and they were routinely used to monitor compliance with agricultural programs. These historic aerial photographs provided the foundation for soil mapping, land use classification and planning, and natural resource conservation (Steiner, 1965; Monmonier, 2002).

Presently, historic aerial photographs serve as an invaluable source of information on historic landscape conditions (Morgan et al., 2010) and they can provide baseline assessments in land cover change studies (Browning et al., 2009). Knowledge of historic and baseline landscape conditions can improve understanding, inform contemporary management decisions, and guide restoration activities (Morgan et al., 2017). Specific to river restoration, historic aerial photographs can provide information on the historical distribution and relative abundance of land cover in the floodplain and riparian zone and they can provide information about historic channel features and characteristics (Tomlinson et al., 2011).

The United States Geological Survey (USGS) maintains an extensive collection of aerial photographs at the Earth Resources Observation and Science (EROS) Data Center. The Aerial Photography Single Frame Records Collection includes over 6.5 million frames of digitized aerial photographs that were acquired by federal organizations from 1937 to present (USGS, 2015). These digitized images are available from the USGS Earth Explorer (https://earthexplorer.usgs.gov/) as tagged image file format (.tif) files. These photographs have not be orthorectified or georeferenced.

Within Utah, the Utah Automated Geographic Reference Center (AGRC) and the Utah Geological Survey (UGS) maintain collections of current aerial imagery and historic aerial photographs. The state of Utah is a geospatial data-rich state and the Utah AGRC has been proactive is digitizing and georeferencing historic aerial photographs and map data. The AGRC maintains the National Agricultural Imagery Program (NAIP) aerial imagery from 2003, 2004, 2006, 2009, 2011, 2014, and 2016. They also maintain black and white digital orthophoto quadrangles (DOQs) from the mid-1990s, color and infrared DOQs from the 1970s, and some coarse-resolution SCS photomaps from 1936-1952 (https://gis.utah.gov/data/aerial-photography/doq/). These aerial images and photographs have been orthorectified and/or georeferenced. The UGS, a division within the Utah Department of Natural Resources, has digitized, but not georeferenced, a variety of historic aerial photographs from various programs. The UGS database contains over 230 data sets, which consists of over 110,000 individual photographs. This collection includes aerial images from 1935 to present (https://geodata.geology.utah.gov/imagery/).

Downloading Historic Aerial Photographs for the Price River

Historic aerial photographs for the Price River were downloaded from the UGS, USGS Earth Explorer, and Utah AGRC. For the Price River study area, the UGS collection contains aerial photographs that were acquired during the summer months of 1938 at scales of 1:12,000 and 1:31,680. These aerial photographs were collected under the direction of the SCS as part of an Upper Colorado River and Green River regional inventory. A total of 120 digitized photographs were downloaded to span the study area. Historic aerial photographs from USGS Earth Explorer within the Aerial Photography Single Frame Records Collection were also downloaded. For the Price River study area, this collection includes aerial photographs from 1951, 1952, 1955, 1968, 1972, 1976, 1977, and 1979. These aerial photographs were acquired by the USGS and Army Map Service and range in scale from 1:20,000 to 1:80,000. In addition to these historic aerial photographs, georeferenced and/or orthorectified image tiles were downloaded from the Utah AGRC and mosaicked. These include color and infrared DOQs from 1974, black and white DOQs from 1997, and four-band NAIP aerial imagery from 2006 and 2014.

Since georeferenced imagery is available for latter years from the Utah AGRC, the 1938 aerial photography from UGS and the 1950s aerial photography from USGS Earth Explorer were deemed most valuable for this study. However, complete coverage is somewhat limited for the 1950s imagery and scales between sets are different. The aerial photographs acquired during the late fall months of 1952 span the northwest portion of the study area, from Wellington to Woodside. The scale of these aerial photographs is 1:20,000. The aerial photographs acquired in October 1955 cover the southeast portion of the study area. The scale of these aerial photographs is 1:60,000. When combined, these two sets cover the majority of the study area. While both the 1938 and 1950s aerial photographs were deemed valuable, the financial and temporal constraints of the project eventually only allowed for the georeferencing of one set of historic aerial photographs. Therefore, the 1938 aerial photographs from UGS were preferentially selected due to the scale, complete coverage, and early date.

Generating Image Mosaics

The 1938 aerial photographs from the UGS were opened in Adobe Photoshop and were cropped to remove the collar and collar information. The cropped images were organized by date and scale to ensure that aerial photographs of differing scales and sun angles were not combined when creating image mosaics. Image mosaics were generated to reduce the processing time associated with georeferencing multiple individual images. Three different software programs, including Pix4D (https://pix4d.com/), Microsoft Image Composite Editor (ICE) (http://bit.ly/2n3FpOn), and Adobe Photoshop (https://adobe.ly/1g8lSDp), were evaluated to determine success in generating mosaics of historic aerial photographs.

Pix4D is a professional photogrammetry software that is primarily used for processing and mosaicking imagery acquired from drones and unmanned aircraft systems. Microsoft ICE is an advanced image stitching software that creates seamless panoramic photos and mosaics. Adobe Photoshop is a raster graphics and image editing software that includes automated photomerging tools that create seamless panoramic photos and mosaics. Of the three programs, Adobe Photoshop created superior image mosaics. While the algorithms within Pix4Dmapping are intended to remove distortion and create seamless images of uniform scale, issues, such as seamlines, gaps, and duplicate landscape features, were noted in the image mosaics. Microsoft ICE, while highly recommended as a free image mosaicking software by photographers and remote sensing scientists, presented problems in stitching together multiple adjacent images. Also, the more images within a mosaic, the greater the distortion. The automated photomerging function in Adobe Photoshop, while not faultless, provided seamless mosaics with minimal distortion. Based on the same dates and scales of the aerial photographs, 10 image mosaics were created in Photoshop (Figures 5 and 6) .

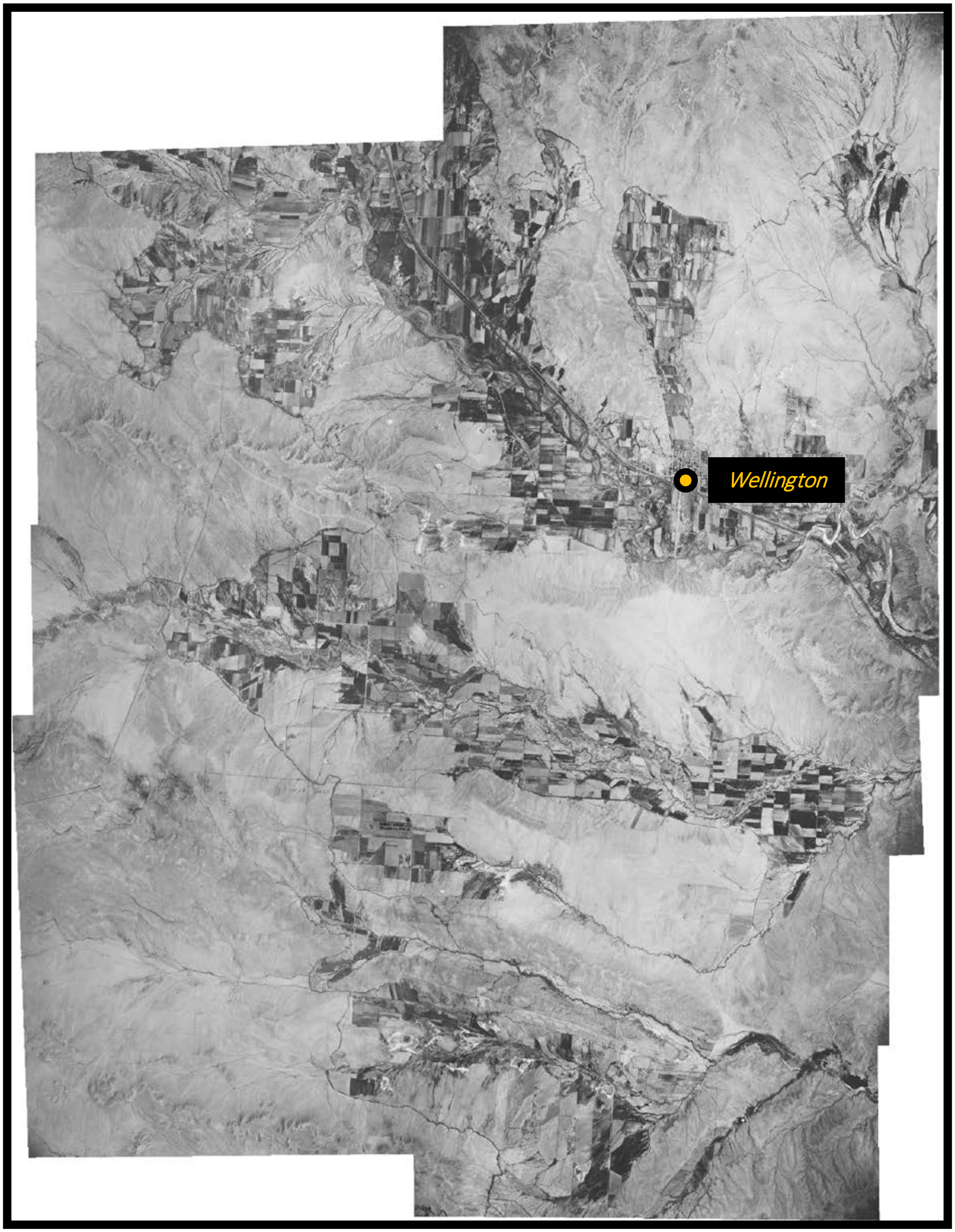

Figure 5. Photomosaic of image tiles spanning the northwestern portion of the study area and encompassing the town of Wellington.

Figure 6. Photomosaic of image tiles spanning the southeastern portion of the study area and encompassing the ghost town of Woodside and the south face of the Book Cliffs.

Georeferencing Images in ArcMap

Each image mosaic from 1938 was imported into Esri ArcMap 10.2.2 for georeferencing. Using the Fit to Display function within the Georeferencing Tools, each mosaic was roughly lined up with the 2014 NAIP aerial imagery. The 2014 NAIP aerial imagery served as the target data and spatially referenced data. The projection was defined as NAD 1983 UTM Zone 12 North. Georeferencing of images requires a number of ground control points to link locations on the image and with locations in the target data. With each image mosaic, a minimum of 200 control points were placed using static landscape features. A greater number of control points were placed due to the spatial distortion associated with historic aerial photographs. The control points were then used to build a transformation that shifted the image from its existing location to the spatially correct location. While ArcGIS offers a few different transformation options, the spline transformation was selected for these image mosaics. The spline transformation is a true rubber sheeting method that optimizes for local accuracy. This transformation matches the source control points exactly to the target control points (Esri, 2016). The 10 image mosaics were georeferenced using this process. Once georeferenced, they were mosaicked together to create one 1938 image for the study area (Figure 7).

Creating a Collection of Images for the Price River

The georeferenced 1938 image mosaic, along with the aerial photography and imagery available from the Utah AGRC, provide a collection of images for the Price River landscape from 1938 to 2014. This collection presently includes five years of aerial photography and imagery: 1938, 1974, 1997, 2006, and 2014 (Figures 8 and 9). Further and more detailed analyses could encompass the USGS Earth Explorer imagery from the 1950s and possibly other years. Additional NAIP aerial imagery (i.e. 2009, 2011, and 2016) from the Utah AGRC could also be incorporated into the collection.

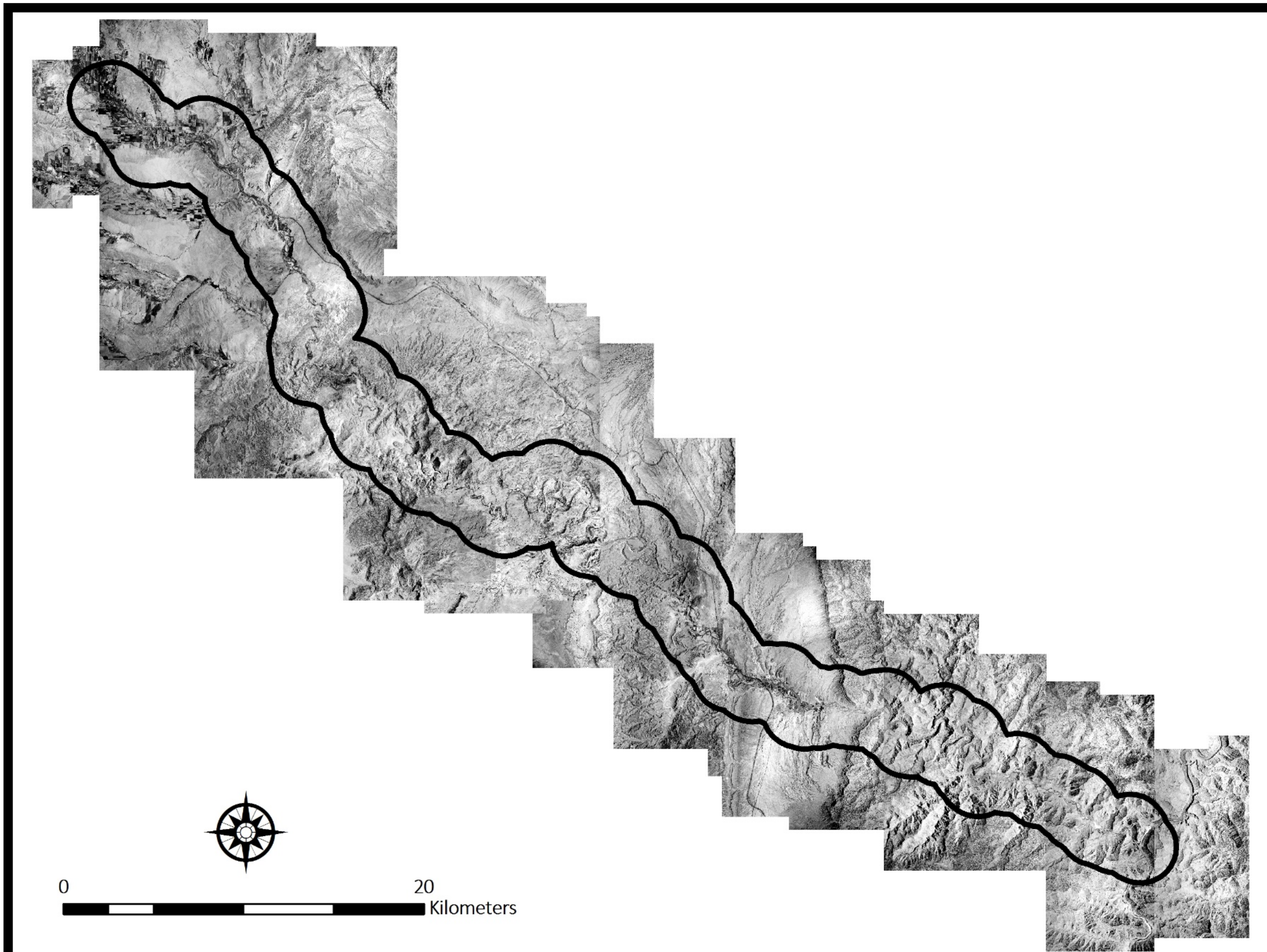

Figure 7. *1938 mosaic of the 10 georeferenced photomosaics, showing a 2,000 meter buffer around the river centerline.*

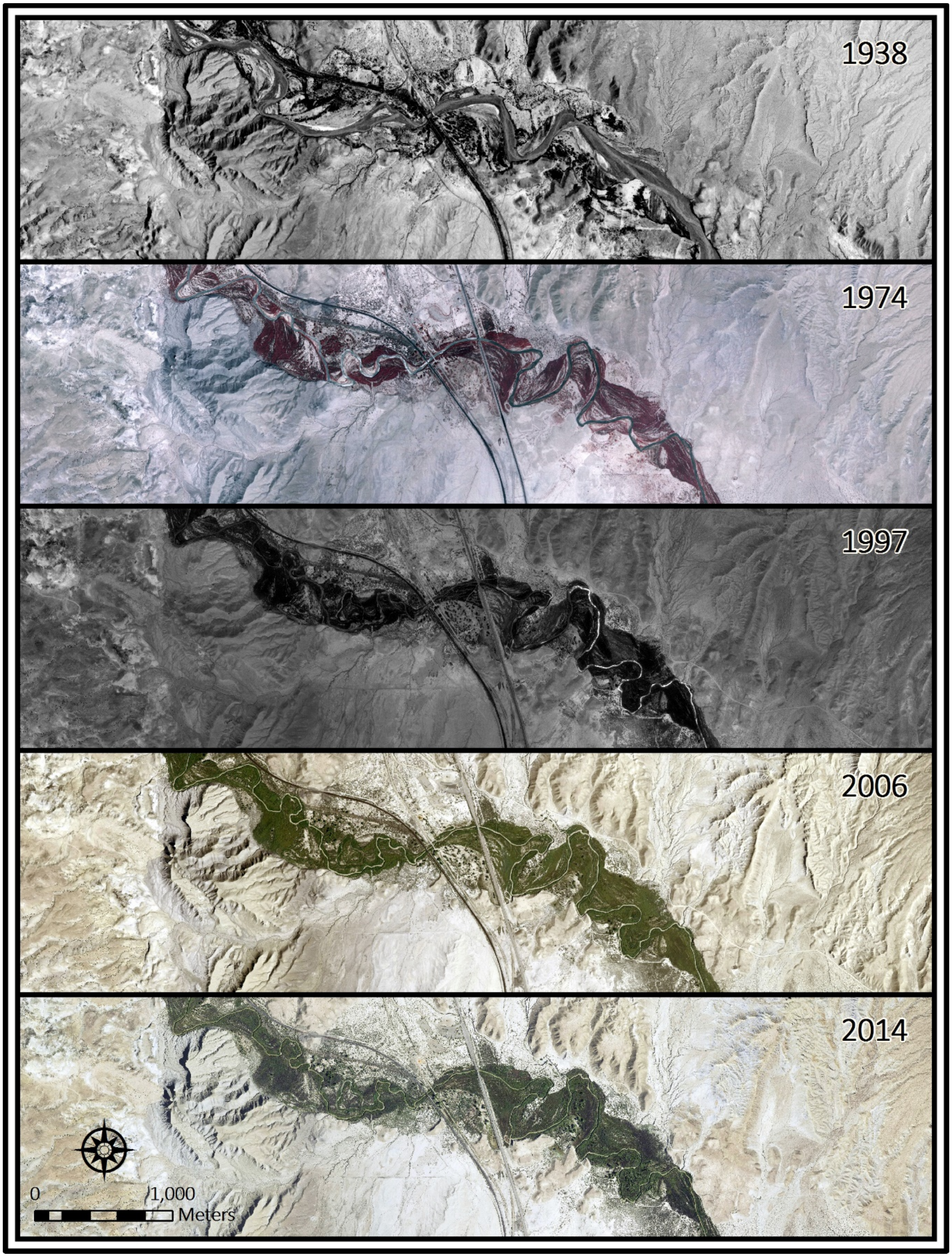

Figure 8. Five-year collection of aerial images for the Price River, spanning 1938 to 2014.

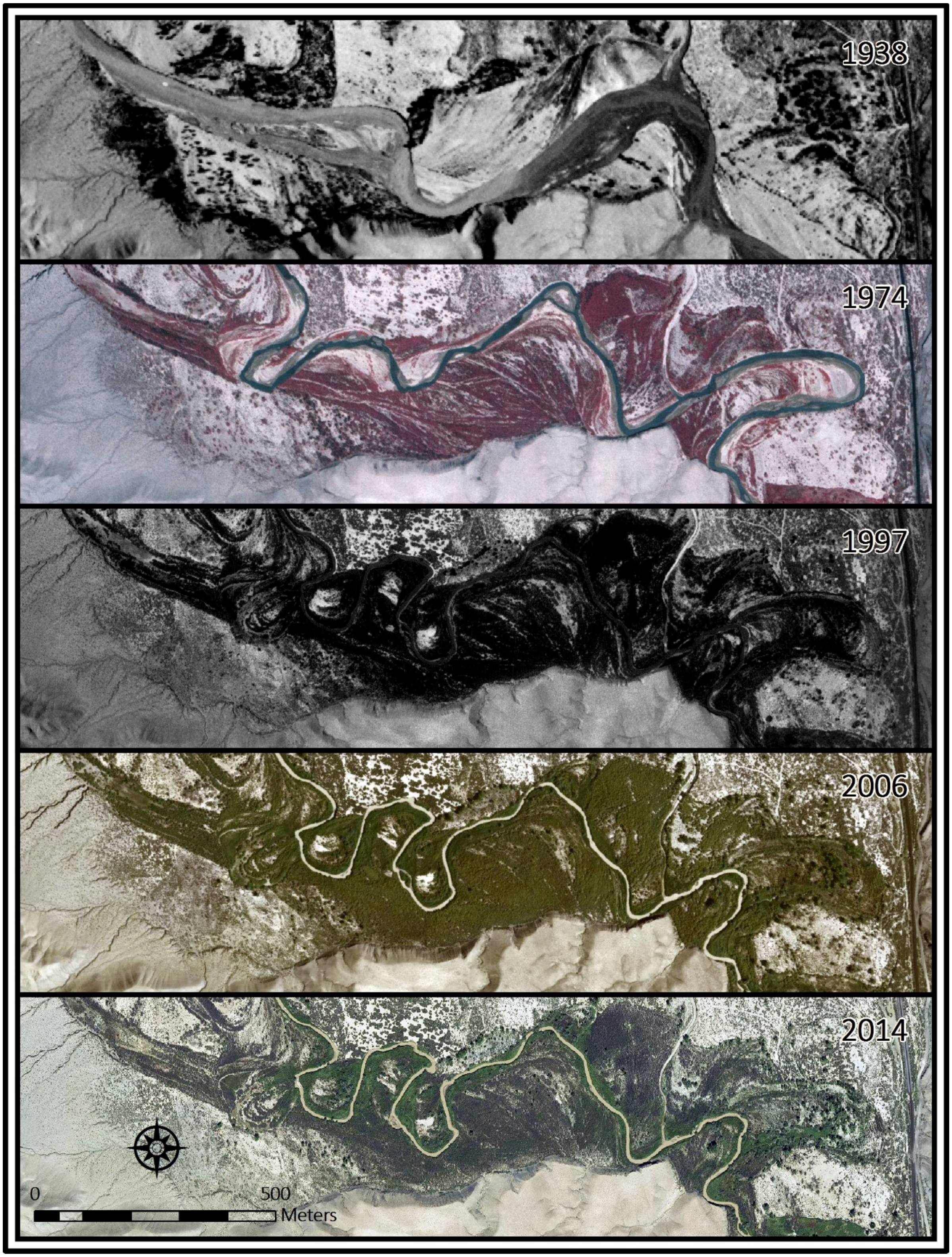

Figure 9. Five-year collection of aerial images for the Price River, spanning 1938 to 2014.

MEASURING CHANGES IN CHANNEL WIDTH AND RIVER SINUOSITY

Overview

Channel morphology and riparian vegetation structure are largely determined by the frequency, intensity, and duration of hydrologic events and the properties, amount, and timing of sediment input (Sullivan et al., 1987; Graf, 1988). Historically, natural flow regimes in dryland river systems were characterized by periods of drought (no-flow periods) and episodes of intense flooding (flood-flows). The no-flow periods and flood-flows promoted high plant species diversity, a variety of channel features, and landscape heterogeneity (Stromberg et al., 2007). However, anthropogenic disturbances have modified natural flow regimes and disrupted sediment transport and balance, thereby altering channel morphology and riparian vegetation structure (Busch and Smith, 1995; Sullivan et al., 1987). The construction of water storage and diversion facilities has had profound impacts on channel morphology due to the significant reductions in peak flow magnitudes. Moderated peak flow magnitudes, accompanied with more stable and regulated hydrologic regimes, have further affected channel morphology by inhibiting the regeneration of native riparian plant species and creating more favorable growing conditions for invasive species, such as tamarisk (Di Tomaso, 1998).

Tamarisk has transformed the channel morphology of many dryland river systems through induced sedimentation, bank aggradation, narrowing and deepening of channels, and increased sinuosity (Dudley et al., 2000; Graf, 1981). The extensive root systems of tamarisk have a high capacity to stabilize sediment, prevent bank erosion, and resist hydraulic stress (Goudie, 2013). As the density of tamarisk increases, channels become stabilized, immobile, and inflexible. The enhanced stability progressively restricts channel width by promoting additional sediment deposition (Graf, 1978; Di Tomaso, 1998). Additional sediment deposition can lead to filling in of backwaters, modification or elimination of riffle structure, and overgrown sand and gravel bars (Dudley et al., 2000). Therefore, a common outcome of tamarisk invasion is narrow and confined single-threaded channels characterized by steep banks, low width-to-depth ratios, minimal channel features, and higher sinuosity measures (Keller et al., 2014; Graf, 1981; Kui et al., 2017).

Measuring Changes in Channel Width

Numerous studies have revealed that channel narrowing is one the greatest impacts of tamarisk. Select studies involving historic aerial and ground photographs have demonstrated that tamarisk has contributed to narrowing of channels by 19 to 27 percent (Allred and Schmidt, 1999; Webb et al., 2007; Graf, 1978). Analysis of the San Rafael River, a system located to the south of the Price River, indicated some areas have decreased in channel width by 65 percent within relatively short time frames (Fortney, 2015). While this study demonstrated that channel narrowing within the San Rafael River system has been variable, the river has transitioned from a multi-threaded and laterally unstable system with high width-to-depth ratios to a confined single-threaded system with low width-to-depth ratios (Keller et al., 2014; Fortney, 2015).

Channel narrowing and confinement is problematic because it limits lateral migration of meandering streams. It increases the rate of water flow and the potential and severity of subsequent floods (Di Tomaso, 1998). These alterations may also inhibit the overland flooding that is required for native plant establishment (Shafroth et al., 1998). Narrowing can greatly influence spawning, rearing, and foraging habitat due to the loss of channel features, such as pools, riffles, and backwaters (Tomlinson et al., 2011; Keller et al., 2014). Measuring changes in channel width across time can provide information on causative factors, can assist in determining when transitions and thresholds of change occurred, and can support the identification of targeted restoration sites.

For the lower reaches of the Price River, channel widths were measured at 88 locations for 1938, 1974, 1997, 2006, and 2014. The River Bathymetry Toolkit (RBT) (http://essa.com/tools/river-bathymetry-toolkit-rbt/ and https://www.fs.fed.us/rm/boise/AWAE/projects/RBT/RBT_lidar_hydro_downloads.shtml) was used in this analysis. The RBT is an Esri ArcGIS 10.2 add-in that was created by the United States Forest Service (USFS) Rocky Mountain Research Station (Air, Water, and Aquatics Environment Program) and ESSA Technologies, Ltd. to enable efficient characterization of in-stream and floodplain geomorphology.

Using the Cross Section Layout tool, cross sections were created at 2,000 meter (1.24 mile) intervals for the entire length of the lower reaches of the Price River using a river centerline digitized from the 2014 NAIP aerial imagery. The total length of the 2014 river centerline was 176.7 kilometers (109.8 miles), thus yielding 88 cross sections. The first cross section is near Wellington, Utah, and the last cross section is the near the confluence of the Green River. While the cross sections were created using the 2014 river centerline, the location of each cross section was utilized to examine the channel widths for each of the years of interest. In cross sections where channel location was drastically different between years and not comparable, the cross section was slightly moved upstream or downstream to enable more accurate comparisons between years. At a minimum scale of 1:1,000, channel (i.e. bankfull) widths were measured for each of the 88 locations for the five years using the Measure Tool in ArcMap 10.2.2. The 1997 DOQs presented some issues due to shadows and minimal contrast in certain areas. Therefore, channel widths were not recorded for 18 channel cross sections in 1997.

These measurements indicate that the channel width of the Price River has significantly decreased over the timeframe from 1938 to 2014 (Figure 10). In 1938, the average channel width was 45.4 meters (149.0 feet) and the river system was comprised of multiple threads and several point and mid-channel bars. By 1974, the average channel width decreased to 20.1 meters (65.9 feet). This signifies a decrease of more than 55 percent in 36 years. By 1997, average channel width decreased to 10.6 meters (34.8 feet), and by 2006, it decreased to 8.5 meters (27.9 feet). By 2014, the Price River was characterized by a narrow, confined, and incised channel with an average channel width of 7.8 meters (25.6 feet). This represents a total decrease of nearly 83 percent since 1938. The measurements also indicate that the width of the channel was quite variable in 1938, ranging from 12 to 125 meters (39 to 410 feet). In 1974, channel widths ranged from 9 to 61 meters (30 to 200 feet). In 1997, channel widths ranged from 4 to 21 meters (13 to 69 feet). By 2006 and 2014, channel widths had markedly decreased since 1938 and the variability also declined, with a relatively narrow range of 4 to 18 meters (13 to 59 feet) (Figure 11).

The general channel changes associated with the Price River are fairly consistent with those identified in previous studies conducted in other southwestern dryland river system and they are quite comparable to those identified in the San Rafael study. However, recent and widespread quantifications of channel width change seem to be limited. Some of the previous estimates of channel width decrease, not including the San Rafael study, suggest much lesser degrees of change (i.e. channel width decreases of 19 to 27 percent). Some of these studies were conducted in previous decades or reflect changes from prior decades. Therefore, it is probable that channels have continued to decrease in width as tamarisk has continued to spread and increase in density, particularly in locations where control has been limited.

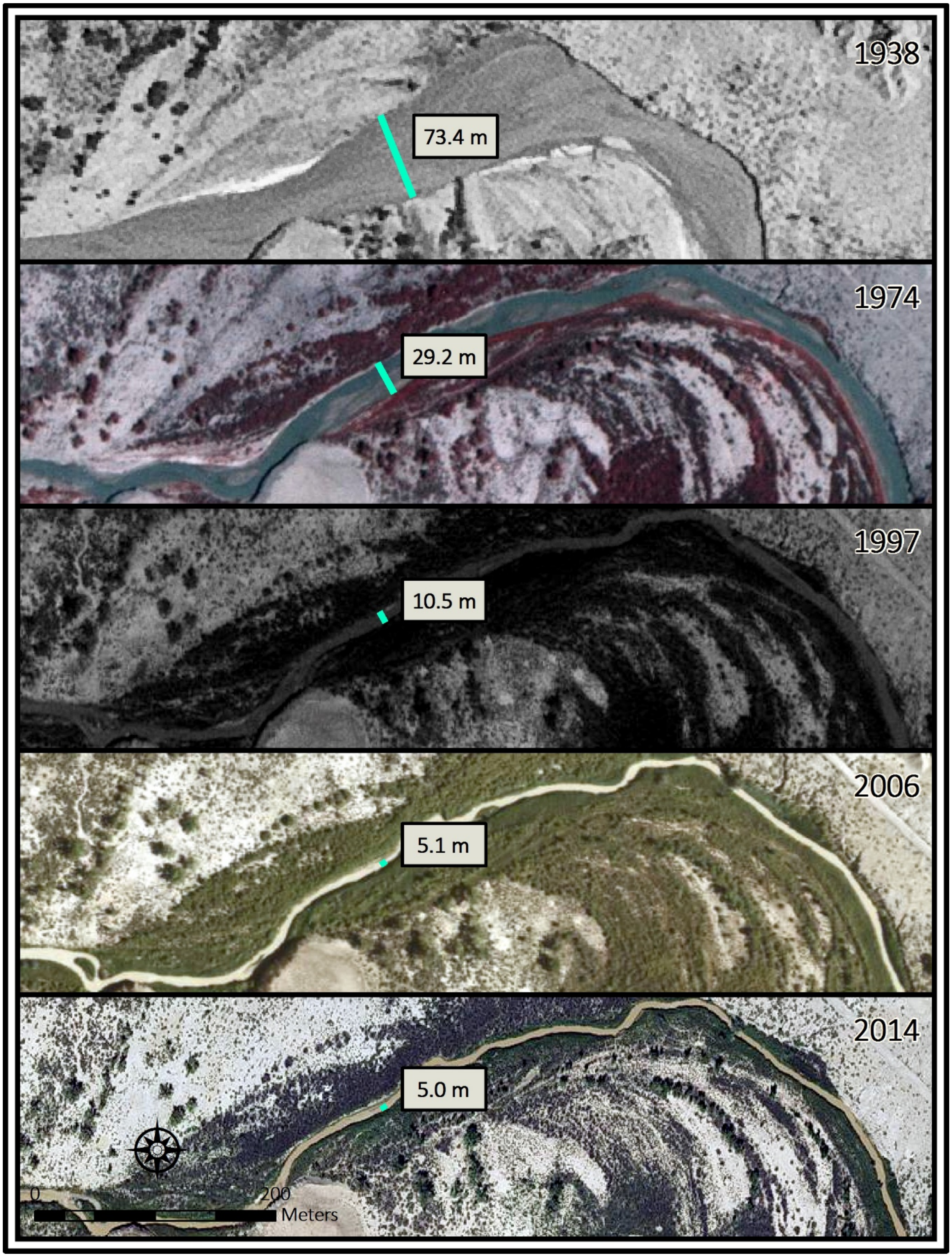

Figure 10. An example of decreasing channel widths between 1938 and 2014 for the Price River.

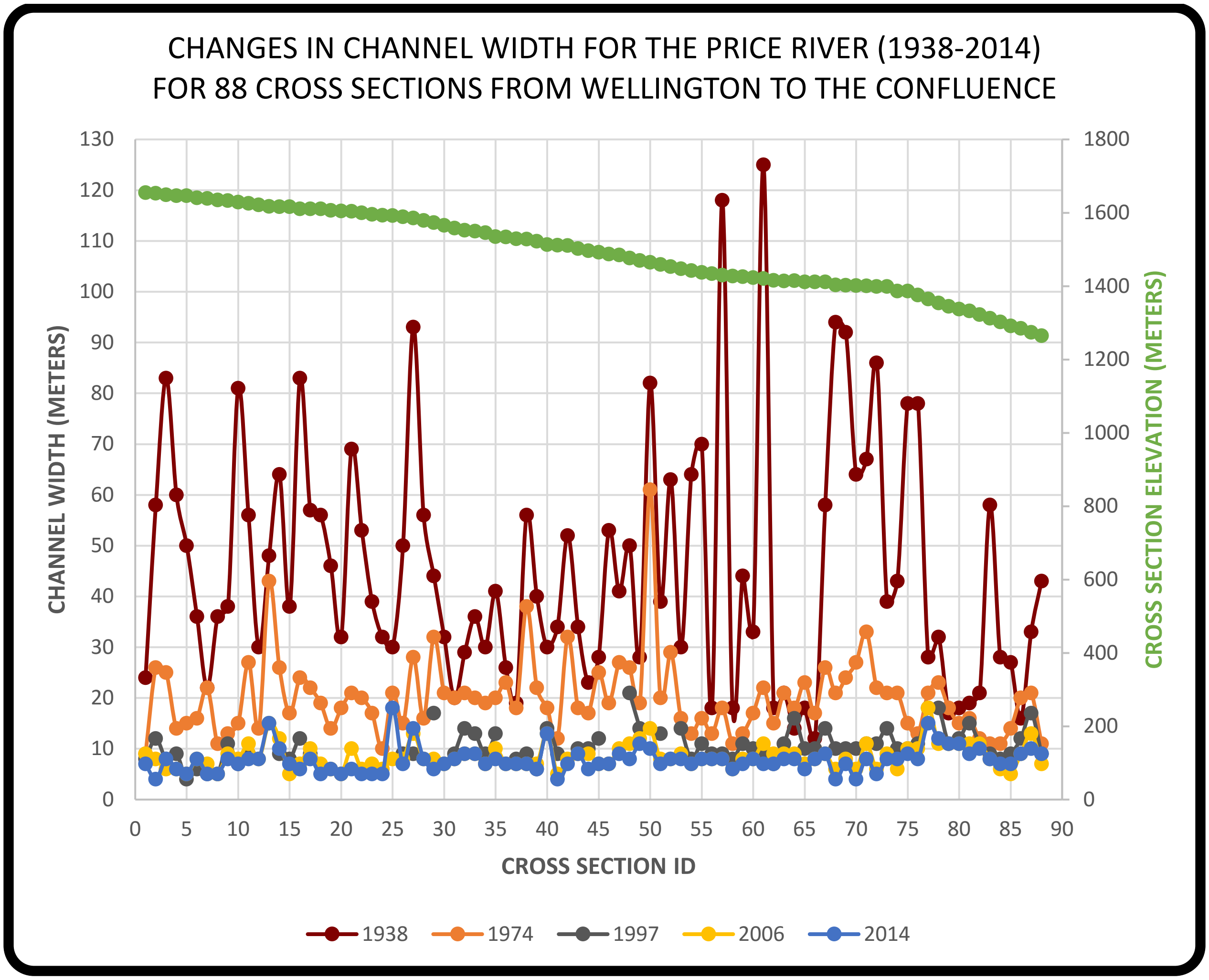

Figure 11. Changes in channel widths by year and elevations at 88 cross sections along the lower reaches of the Price River. The channel was much wider in 1938 and channel width was quite variable. By 2014, the channel was narrow and channel width variability was low. Elevations for the cross sections range from 1,654.8 meters (5,429.1 feet) near Wellington to 1,264.4 meters (4,148.3 feet) near the confluence of the Green River.

Measuring Changes in River Sinuosity

Sinuosity is a planform characteristic of rivers and streams which corresponds to the amount of curvature within a specified length or reach (Martin, 2014). It is expressed as a ratio of stream length (measured along the center of the channel) to valley length (measured along the axis of the valley) (Ritter et al., 2002). Typical values of sinuosity range from 1.0 for perfectly straight channels (i.e. perfect alignment with the shortest possible distance) to above 2.0 for highly meandering channels (i.e. channels with such high curvature that they are more than twice as long as the shortest possible distance) (Graf 1981; Graf, 1988). The transition between straight and meandering river systems is generally placed at a sinuosity of 1.5 (Ritter et al., 2002). Research has demonstrated that the sinuosity of rivers and streams tends to change as the frequency and magnitude of flooding decreases (Burkham, 1972) and as the density of phreatophytes, such as tamarisk, increases (Graf, 1981; Graf, 1988).

For the lower reaches of the Price River, the sinuosity of the river was calculated for 1938, 1974, 1997, 2006, and 2014. Channel centerlines were digitized for the five years at a scale of 1:1,500 in ArcMap 10.2.2. Using these centerlines, general sinuosity measures were calculated for each year using a basic sinuosity formula (i.e. channel length/straight line valley length) (Figure 12). The sinuosity for the entire length (i.e. Wellington to the confluence of the Green River) was calculated. The sinuosity for the upper northwest reaches (i.e. Wellington to Book Cliffs) and the sinuosity for the lower southeast reaches (i.e. Book Cliffs to the confluence of the Green River) were also calculated. Since sinuosity measures have been associated with valley width and alignment (Fortney, 2015; Graf, 1988), the latter calculations were generated to determine if the topographical constraints and features associated with the Book Cliffs have moderated changes in sinuosity. These sinuosity calculations are simplified measures due to the absence of specific topographical and hydraulic sinuosity measures. More accurate values of sinuosity between years could be generated by calculating the sinuosity for specific channel segments (i.e. using cross sections from the RBT or using segments specified by state agencies). Additionally, more sophisticated scripts have been developed that permit sinuosity calculations to be developed at numerous points along a river or stream using a weighted moving window (http://bit.ly/2Cpsdbb).

While these measures are simplified, they indicate that the sinuosity has increased from 1938 to 2014. In 1938, the sinuosity of the entire length of the river was 2.07, with the sinuosity of the upper northwest reaches measuring 2.16 and the sinuosity for the lower southeast reaches measuring 1.73. By 2014, the sinuosity of the entire length of the river was 2.43, with the sinuosity of the upper northwest reaches measuring 2.61 and the sinuosity for the lower southeast reaches measuring 1.81 (Tables 1-3). These values suggest that the Price River is a meandering river that has become more sinuous as flow regimes have been modified and as tamarisk has spread and increased in density. However, sinuosity measures have had greater increases in the upper northwest reaches, suggesting that the topographical features within the lower southeast reaches have possibly moderated changes in sinuosity.

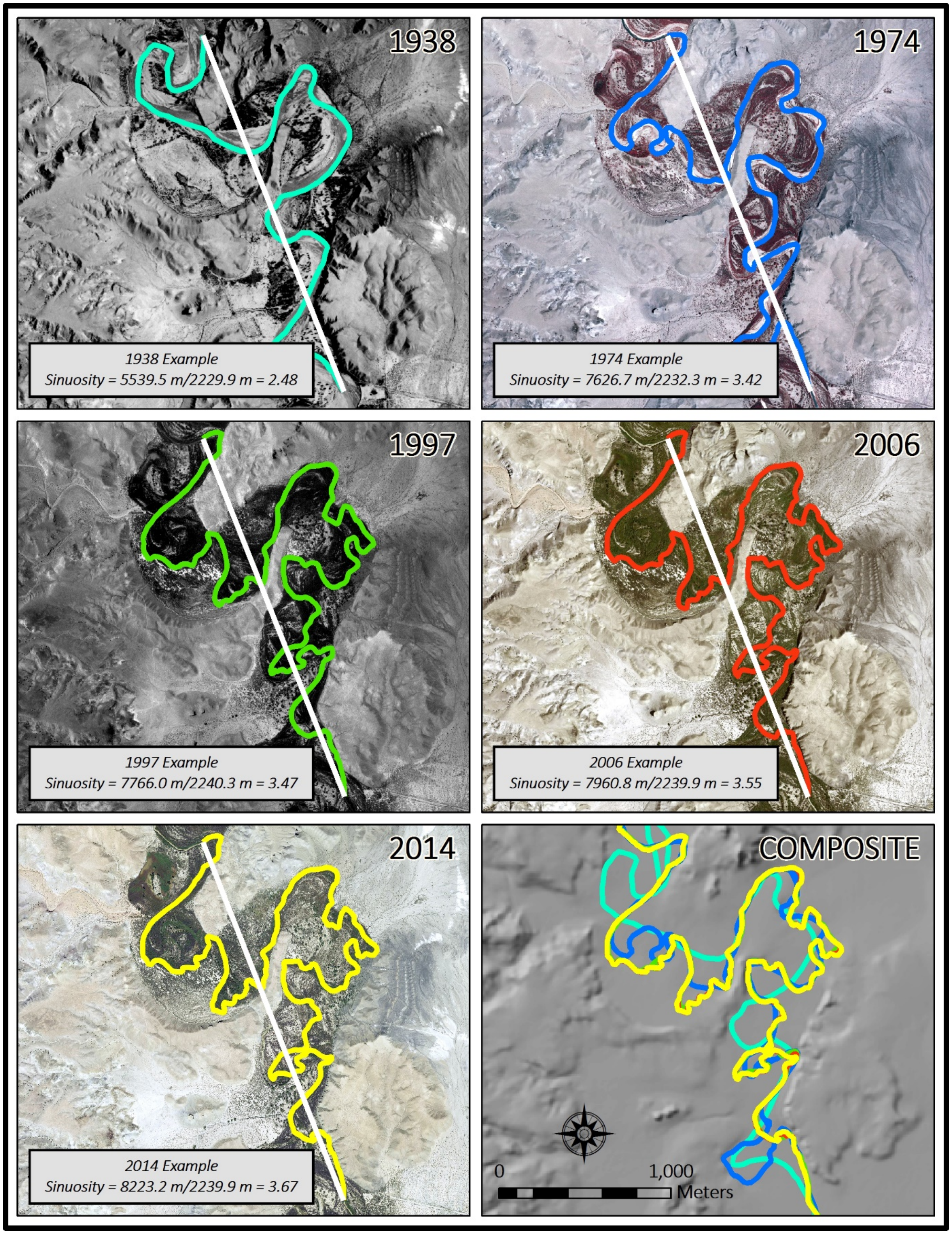

Figure 12. Example of sinuosity calculations for 1938, 1974, 1997, 2006, and 2014. A segment of the Price River was randomly selected for this example. As with the entire length of the Price River, this example shows that the sinuosity has increased between 1938 and 2014.

Table 1. Sinuosity measures for the entire length of the Price River within the study area.

YEAR	RIVER LENGTH (M)	STRAIGHT LINE LENGTH (M)	SINUOSITY
1938	150,617.81	72,751.48	2.07
1974	164,077.40	72,746.51	2.26
1997	174,143.70	72,743.29	2.39
2006	176,035.27	72,744.84	2.42
2014	176,713.07	72,744.10	2.43

Table 2. Sinuosity measures for the upper northwest reaches of the Price River, from Wellington to the Book Cliffs.

YEAR	RIVER LENGTH (M)	STRAIGHT LINE LENGTH (M)	SINUOSITY
1938	120,560.58	55,775.68	2.16
1974	133,121.25	55,766.62	2.39
1997	142,902.39	55,764.09	2.56
2006	144,731.82	55,766.65	2.60
2014	145,339.40	55,763.73	2.61

Table 3. Sinuosity measures for the lower southeast reaches of the Price River, from the Book Cliffs to the confluence of the Green River.

YEAR	RIVER LENGTH (M)	STRAIGHT LINE LENGTH (M)	SINUOSITY
1938	30,057.24	17,343.15	1.73
1974	30,956.16	17,342.32	1.79
1997	31,241.31	17,340.05	1.80
2006	31,303.45	17,338.42	1.81
2014	31,373.66	17,341.17	1.81

ASSESSING CHANGES IN RIPARIAN LAND COVER

Overview

The natural floodplains of many southwestern dryland river systems were historically comprised of lush cottonwood gallery forests and willow stands (Stromberg, 1993). These species depend on natural flooding regimes to maintain species diversity, community composition, structure, and distribution. Additionally, seed deposition, germination, and regeneration are highly dependent on flooding disturbances (Dudley et al., 2000). Changes in hydrologic regimes and the corresponding proliferation of tamarisk have negatively impacted these native riparian ecosystems (Poff et al., 2011).

Tamarisk has a competitive advantage over many native woody plant species for a number of reasons. First, tamarisk produces a continual supply of seeds during the growing season, which enables colonization of areas later in the season when seeds of native species are not present or viable (Di Tomaso, 1998). Second, tamarisk is more drought-tolerant than native species because it is a facultative phreatophyte. Facultative phreatophytes draw moisture from groundwater sources, but they are capable of utilizing soil moisture during drier periods (Dudley et al., 2000). In contrast, cottonwoods and willows are obligate phreatophytes, meaning that groundwater is a primary component of their water supply and it is essential for survival (Stromberg et al., 2007). Third, tamarisk, also known as saltcedar, is capable of growing in soils with higher soluble salt concentrations. Lastly, tamarisk is remarkably tolerant to environmental stress and extremes and it is can quickly recover from mechanical injury (Di Tomaso, 1998). These characteristics have enabled tamarisk to colonize large expanses of western and southwestern riparian areas and to replace large percentages of native riparian communities (Dudley et al., 2000; Di Tomaso, 1998).

Quantifying Changes in Riparian Land Cover

Historical accounts indicate that the Price River was lined with cottonwood trees prior to 1879 (Watts 1997) (Figure 13). However, with regional settlement beginning in 1878 and the initiation of the Scofield irrigation project in 1883, the Price River drainage began to change. Over the course of the last century, the riparian vegetation composition and distribution along the Price River has been transformed. Overgrazing, invasive species, dewatering, sedimentation, and declines in native fish species have prompted state and federal agencies to develop a restoration plan for the lower reaches of the Price River.

A high-resolution riparian land cover dataset for the Price River was identified as an integral component of restoration planning and management. Through the development of a land cover dataset, inventories can be generated, the spatial arrangement of the riparian vegetation and features can be assessed, environmental parameters can be quantified, and targeted restoration sites can be identified. In 2016, the RS/GIS Laboratory, in partnership with the Fish Ecology Laboratory and the Ecogeomorphology and Topographic Analysis Laboratory, at USU developed a high-resolution land cover dataset using Trimble eCognition, an object-based image analysis (OBIA) program. Based on aerial overflights, field data, and an evaluation of restoration objectives for the Price River, 12 land cover classes were identified and mapped using the 2014 four-band NAIP aerial imagery (Figures 14 and 15, http://bit.ly/2kOaNOd). This high-resolution land cover dataset is presently being utilized by state agencies to support the design of a restoration plan. While this dataset has been extremely valuable in assessing the current distribution of native and invasive plant species, the identification of targeted restoration sites remains unclear due to limited knowledge of historic river conditions and riparian land cover distribution.

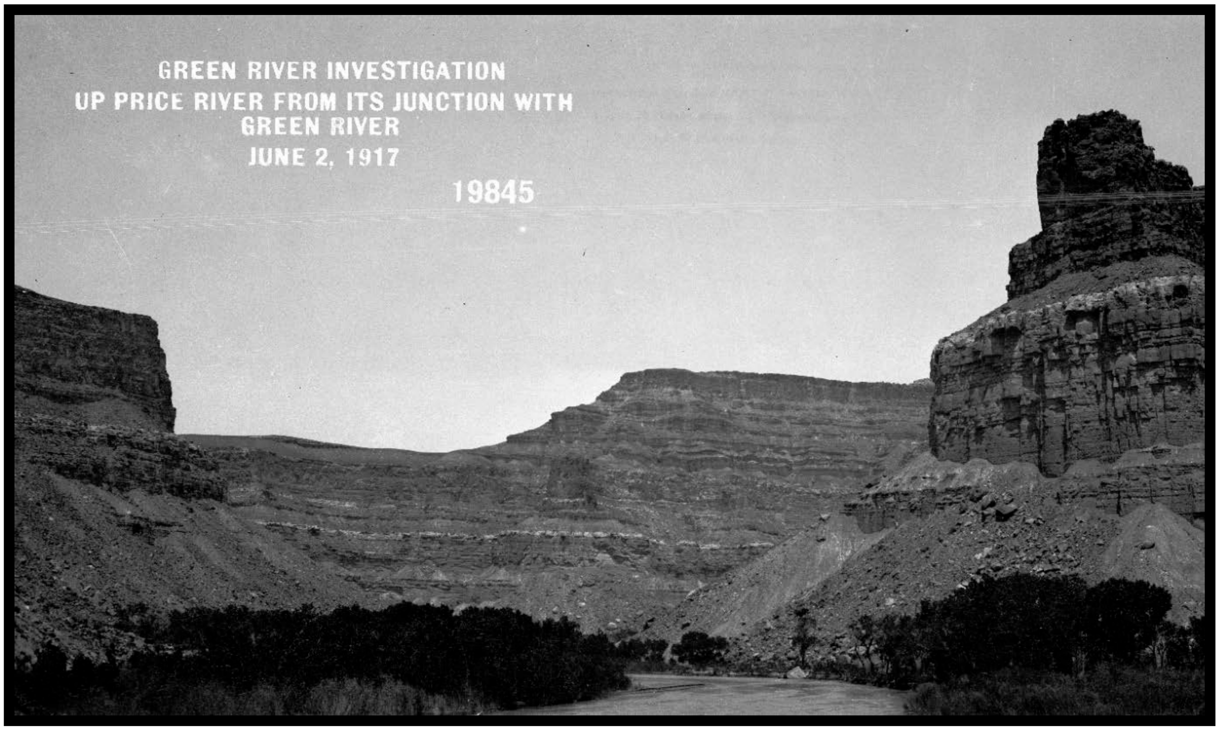

Figure 13. Cottonwood gallery forests along the lower reaches of the Price River near the confluence of the Green River, June 2, 1917. Credit: U.S. Reclamation Service (Rocky Mountain Power Company Photograph Collection), J. Willard Marriot Library, University of Utah.

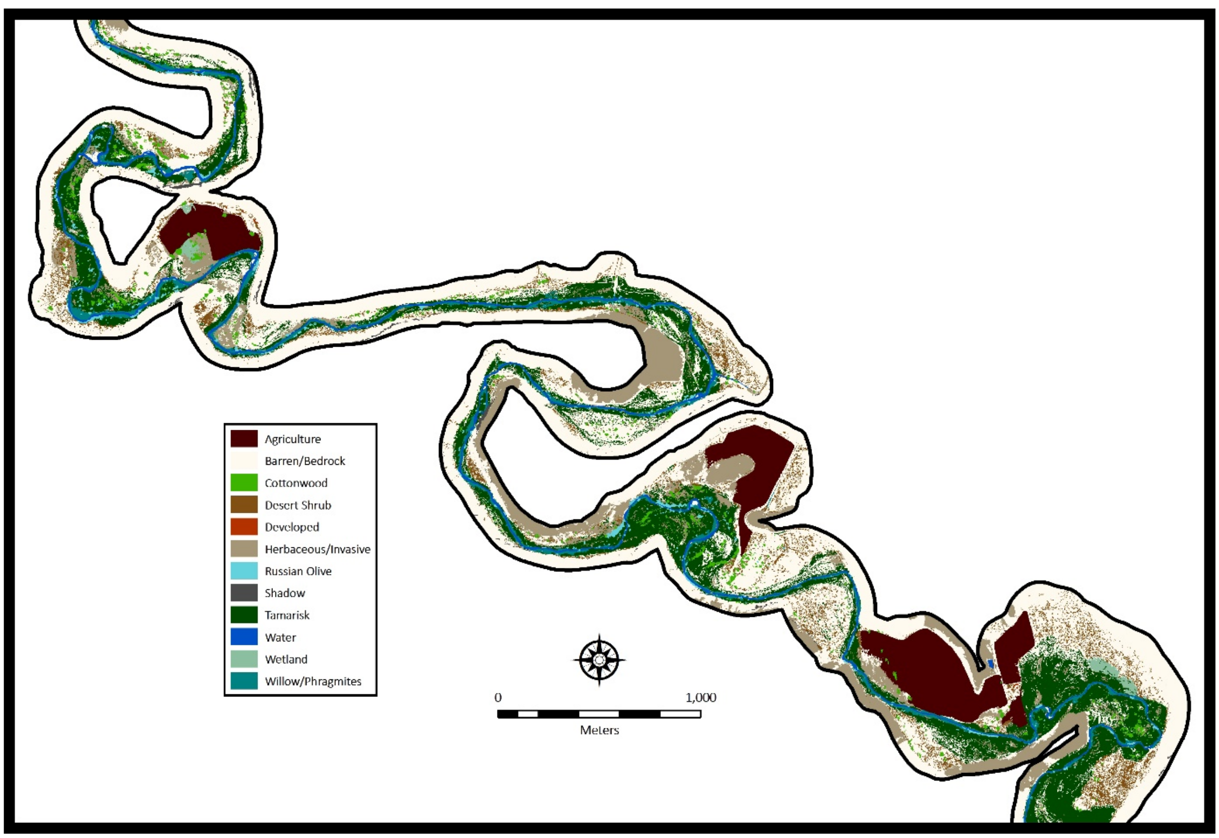

Figure 14. Segment of the Price River high-resolution land cover classification.

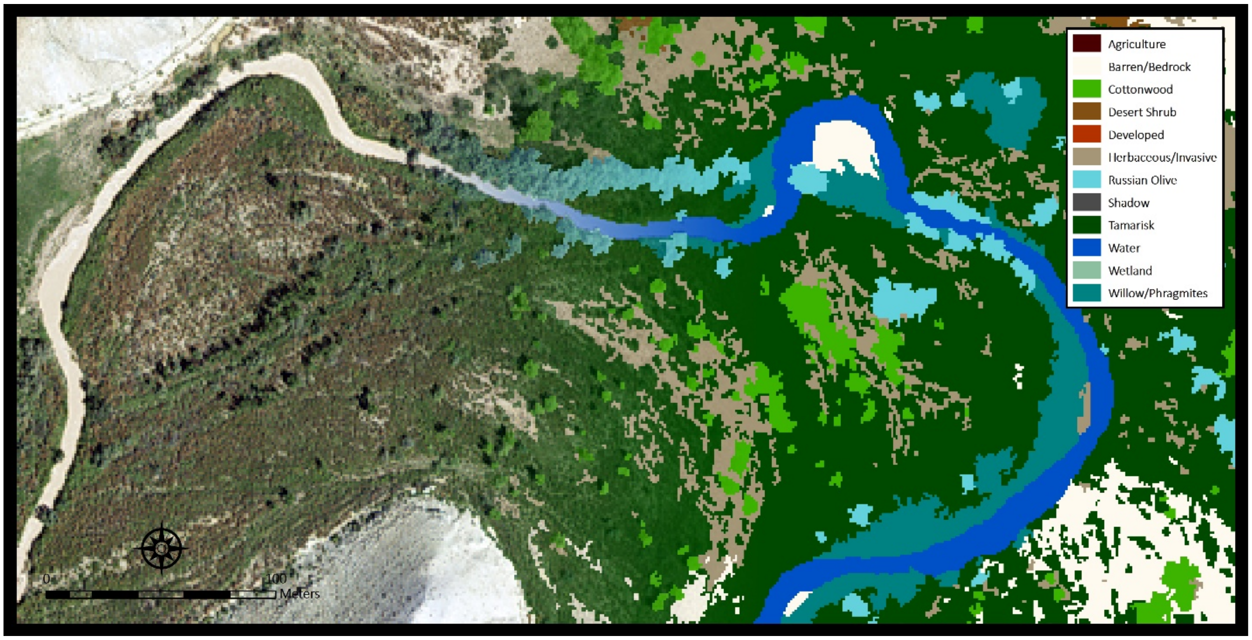

Figure 15. Detailed view of the high-resolution land cover dataset, displaying a gradient of the classification over the 2014 NAIP aerial imagery.

Historic river conditions and riparian land cover distribution for the Price River can be ascertained from the 1938 historic aerial photographs. Knowledge of these changes can improve understanding, inform management decisions, and guide restoration activities. Therefore, using the 1938 aerial photography and the high-resolution land cover dataset, a subset area was selected for temporal land cover change analysis. A 12 kilometer (7.5 mile) segment was identified based on clarity of the 1938 historic aerial imagery, high georeferencing alignment, and qualitative evaluations of land cover change. The 1938 aerial photograph mosaic was clipped to the subset area and imported into Trimble eCognition for analysis.

Trimble eCognition provides an iterative workflow that entails data integration, image segmentation, rule set development, image classification, and rule set refinement. First, imagery and thematic data are loaded into eCognition. Second, by defining a series of parameters in eCognition, such as image layer weights, scale parameter, shape, and compactness, the image is segmented into image objects, or groups of similar pixels. Third, once an image is segmented into meaningful image objects, rules based on spectral, spatial, textural, and contextual properties are developed in order to classify the image objects into discrete features.

Since the 1938 aerial photography is black and white imagery with limited spectral information and pixel depth, image classification was strictly based on brightness values. Classification rules were developed using brightness thresholds. Darker values were associated with riparian vegetation, while brighter values were associated with barren features, such as bedrock and river channel. The distinction between riparian species was very slight; therefore, one class was designated for all riparian species. While the focus of this study was to evaluate riparian land cover changes and to determine specific impacts to cottonwood gallery forests and willow stands, there are inherent limitations associated with historic aerial photographs. Even though there are shortcomings, seven classes were identified and mapped, including barren/bedrock, river channel, desert shrub, developed, herbaceous, riparian, and water.

The 1938 classification results were visually examined in detail and manually edited in Trimble eCognition to improve accuracy. The results were exported as a file geodatabase and added into ArcMap 10.2.2. The land cover dataset was then numerically coded and converted to a raster dataset. To enable comparison with the high-resolution land cover dataset that was developed using the 2014 NAIP aerial imagery, the riparian classes (i.e. cottonwood, Russian olive, tamarisk, and willow/phragmites) were merged and the dataset was reclassified (Figures 16 and 17).

Land cover calculations indicate a significant increase in total riparian land cover from 1938 to 2014. In 1938, the riparian vegetation was patchy and dispersed and encompassed 58.64 hectares (144.90 acres) or 14.3 percent of the study area. In 2014, the riparian land cover (predominantly tamarisk) blankets the riparian corridor and encompassed 136.47 hectares (337.22 acres) or 33.2 percent of the subset study area (Figures 18 and 19; Table 4). The classification also clearly suggests that the channel has significantly narrowed by 2014. The wider and less sinuous channel, the point bars and mid-channel bars, and the channel threads are absent in 2014. Visual evaluations of the 1938 and 2014 imagery suggest that the number of cottonwood trees within gallery forests has also declined (Figure 20).

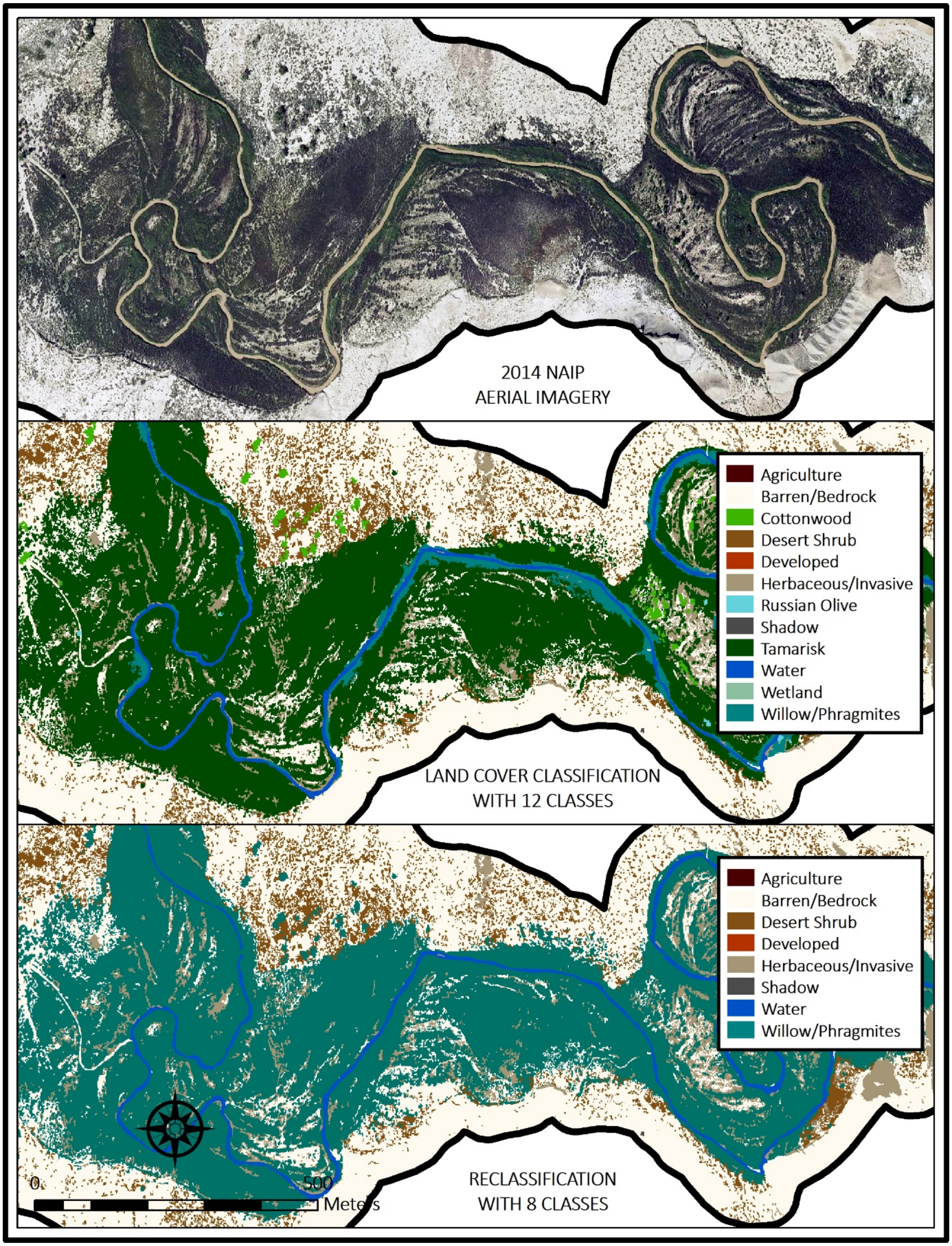

Figure 16. The high-resolution land cover dataset was reclassified to permit comparison with the 1938 image classification.

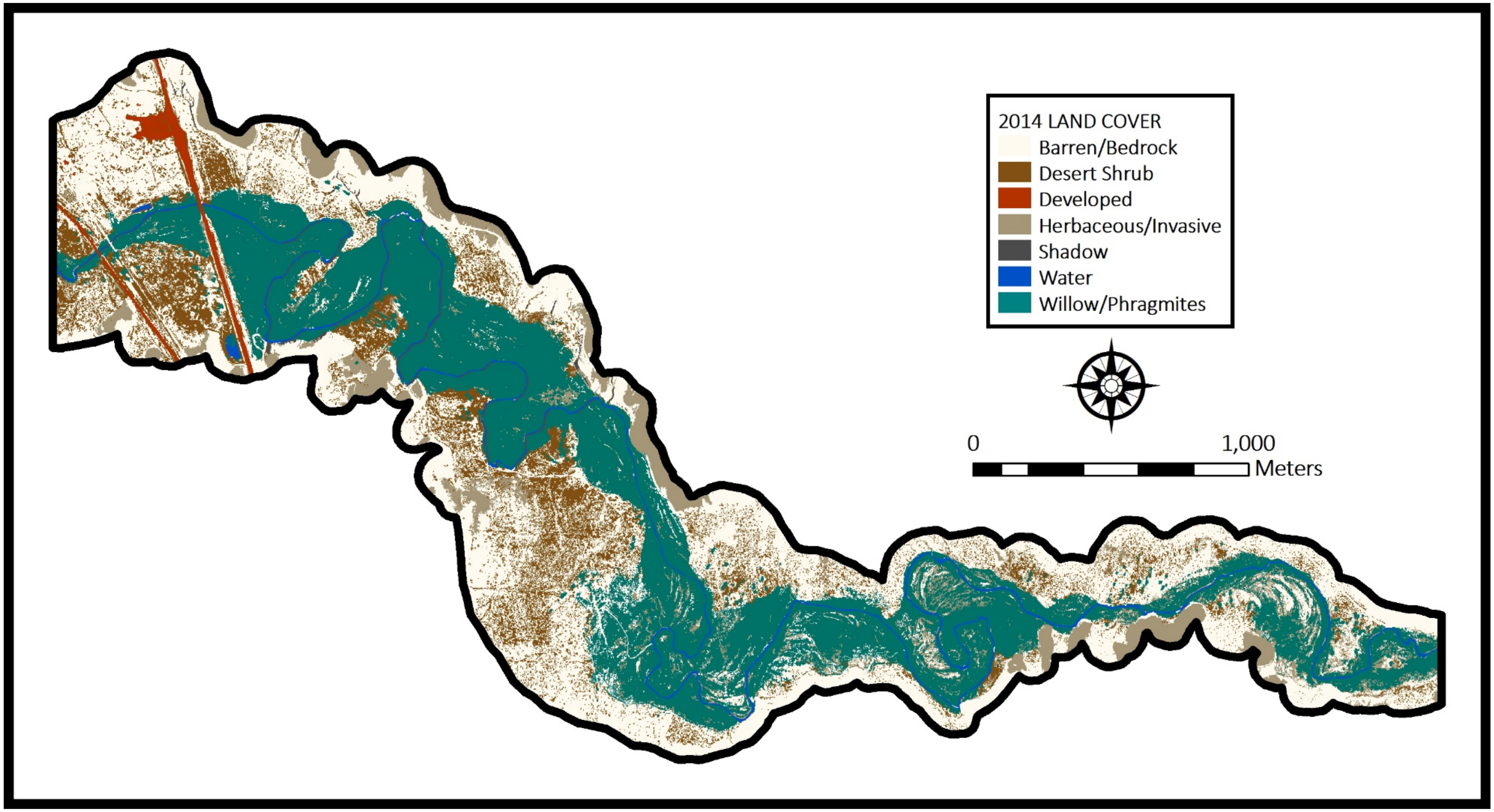

Figure 17. The reclassified 2014 high-resolution land cover dataset for the subset area of the Price River.

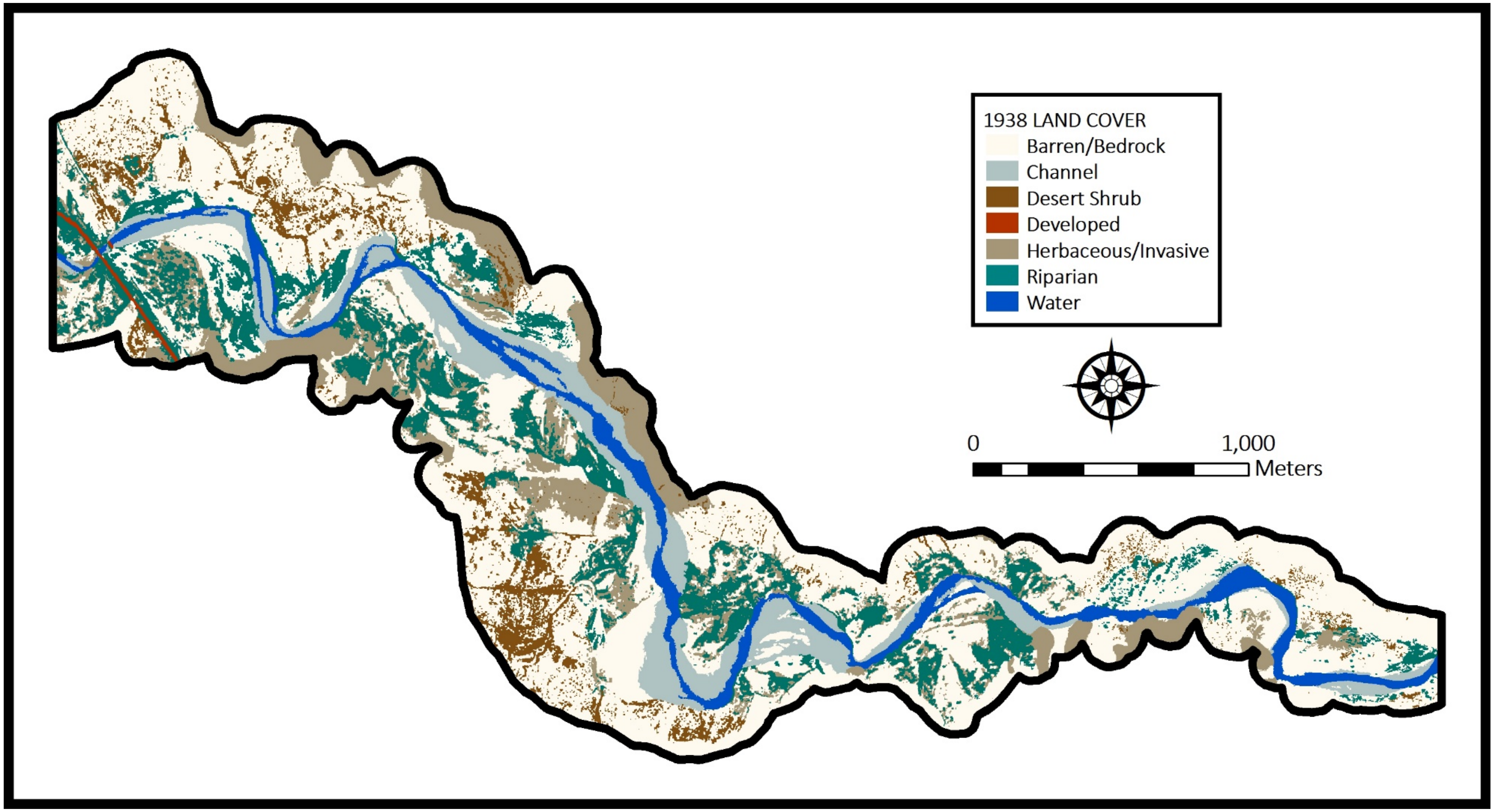

Figure 18. The 1938 land cover dataset for the subset area of the Price River.

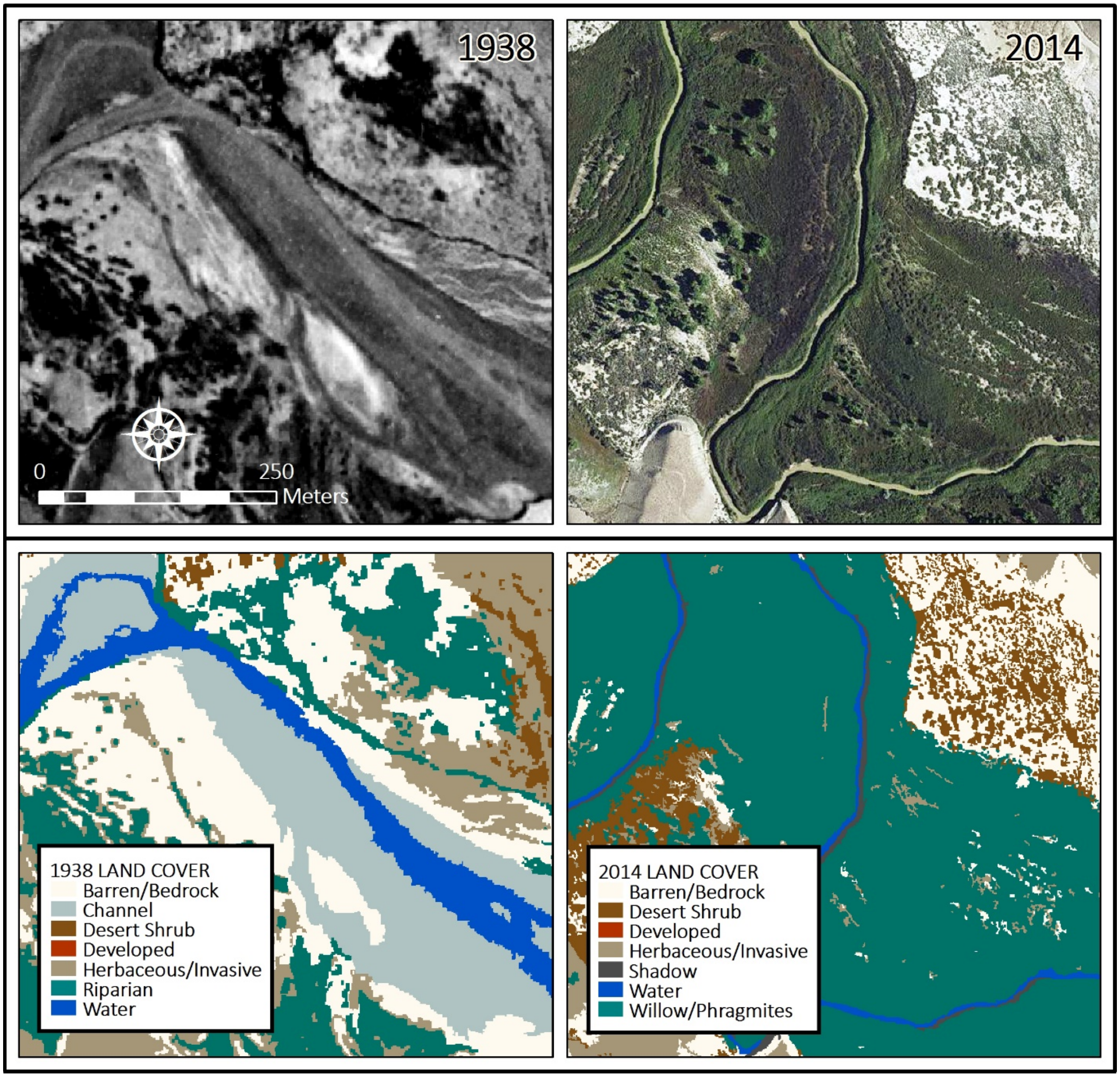

Figure 19. Detailed views of the 1938 and 2014 image classifications, showing differences in riparian land cover pattern and distribution, changes in channel width, and differences in sinuosity.

Table 4. Land cover quantifications of the 1938 and 2014 image classifications for the subset area of the Price River.

CLASS	1938 AREA (HECTARES)	1938 AREA % OF SUBSET STUDY AREA	2014 AREA (HECTARES)	2014 AREA % OF SUBSET STUDY AREA
Barren/Bedrock	200.07	48.7%	163.65	39.8%
Channel	38.23	9.3%	N/A	N/A
Desert Shrub	24.69	6.0%	55.46	13.5%
Developed	0.97	0.2%	4.10	1.0%
Herbaceous	65.03	15.8%	42.23	10.3%
Riparian	58.64	14.3%	136.47	33.2%
Shadow	N/A	N/A	2.08	0.5%
Water	23.59	5.7%	7.04	1.7%
TOTAL	411.21	100.0%	411.04	100.0%

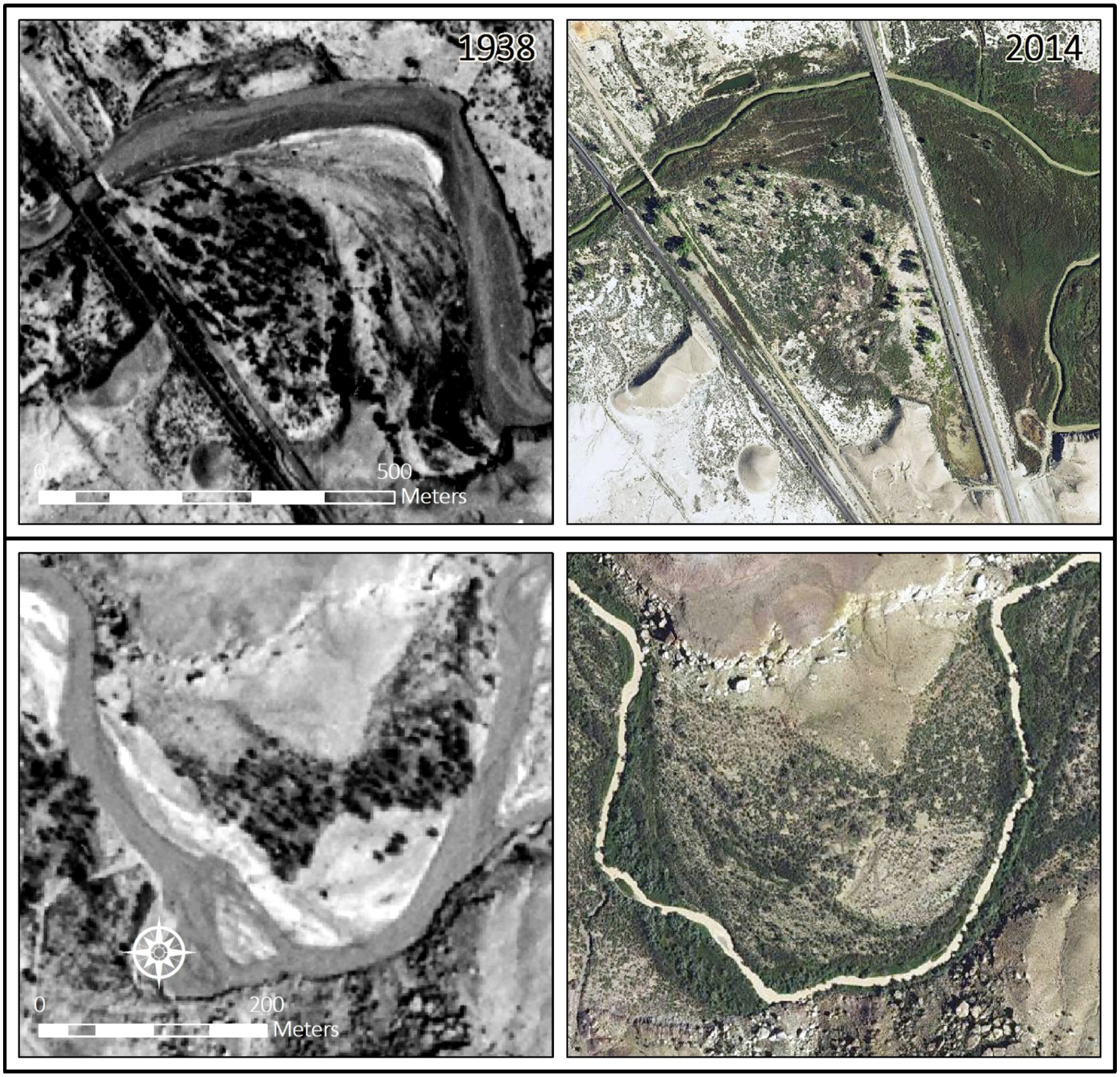

Figure 20. Detailed views of the 1938 aerial photographs and 2014 aerial images, showing differences in cottonwood gallery forests. Qualitative evaluations indicate declines in the number of cottonwood trees within gallery forests.

EVALUATING STREAM GAGE DATA

Overview

The hydrology of dryland river systems is exceptionally variable; however, hydrographs in these systems are generally characterized by large floods that are separated by periods of minimal flow, smaller irregular floods, or no flow (Boulton et al., 2006). The unpredictability of precipitation and the physical characteristics of landforms in these systems frequently produce flashy hydrographs that are defined by short lag times, high peak discharges, and steep rising and falling limbs (McConvill, 2017). The hydrographs associated with the Price River are no exception.

Streamflow discharge has been recorded at 29 locations within the Price sub-basin since 1931 (AGRC, 2017, Waddell et al., 1986). While some of these records are long-term and continuous, many are limited in terms of time frame and continuity. The USGS stream gage stations 09310000 (Gooseberry Creek near Scofield) and 09310500 (Fish Creek above Reservoir, near Scofield) provide some of the longest continuous records of streamflow within the sub-basin, spanning from 1931 to present. These records provide meaningful information about the hydrology of the upper reaches of the Price River since they are located near Scofield Reservoir and Soldier Summit. However, long-term and continuous streamflow discharge data for the lower reaches of the Price River are limited. The USGS stream gage station at Woodside, Utah (09314500), provides the most intact and continuous record for the lower reaches. Daily discharge data are available for the time period of 1945 to present; however, the station was inoperable between October 1992 and July 2000.

Evaluating Stream Discharge Data at Woodside, Utah

Discharge data for stream gage station 09314500 at Woodside, Utah, were downloaded from the USGS National Water Information System (https://on.doi.gov/2Bisq3K). Average annual discharge data, based on the water year (i.e. October through September), indicate that 1983 (478.8 cubic feet/second (cfs)), 1984 (389.5 cfs), and 1952 (341.3 cfs) had the highest average annual discharges, whereas 1990 (25.9 cfs), 2004 (27.1 cfs), and 2003 (30.2 cfs) had the lowest discharges (Figures 21 and 22). The month of May has the highest mean average discharge based on data from 1947 to 2016 (Figure 23 and Table 5). Maximum monthly discharge occurred in June 1983, with a record of 2,023 cfs, whereas minimum monthly discharge occurred in 1961, with a record of 1.5 cfs (Table 5).

Mean monthly discharge data, grouped by decade, indicate that the 1980s had the highest discharge levels, whereas the 1990s had the lowest discharge levels (Figure 24). However, since the station was inoperable between October 1992 and July 2000, the latter indication is inconclusive. Mean daily discharge, also grouped by decade, provide a more comprehensive representation of stream flow for the lower reaches of the Price River (Figure 25). Sustained peak flows occur in May and June during runoff season, low flows occur during the winter months, and smaller irregular floods with periods of minimal flows occur from August through early November.

While sustained peak flows occur during the spring runoff season, general peak flows have historically occurred anywhere from the end of May to the first half of November (Figure 26). In 1983, the peak flow occurred on May 30, and in 1978, the peak flow occurred on November 12. The peak flow data suggest that the window in which peak flows have occurred has become more constrained in recent decades. Since 2001, peak flows have been limited to early August through early- to mid-October. Also, the average peak flow discharge appears to be decreasing, while the gage height is simultaneously increasing.

The gage height, or stage height, refers to the height of the water in the stream above a reference point (USGS, 2011). While the gage height is only representative of the height of the water surface at the stream gage station, this could be one more indication that proves deepening and narrowing of the river channel. These inferences and patterns could be evaluated in further detail by conducting specific statistical analyses.

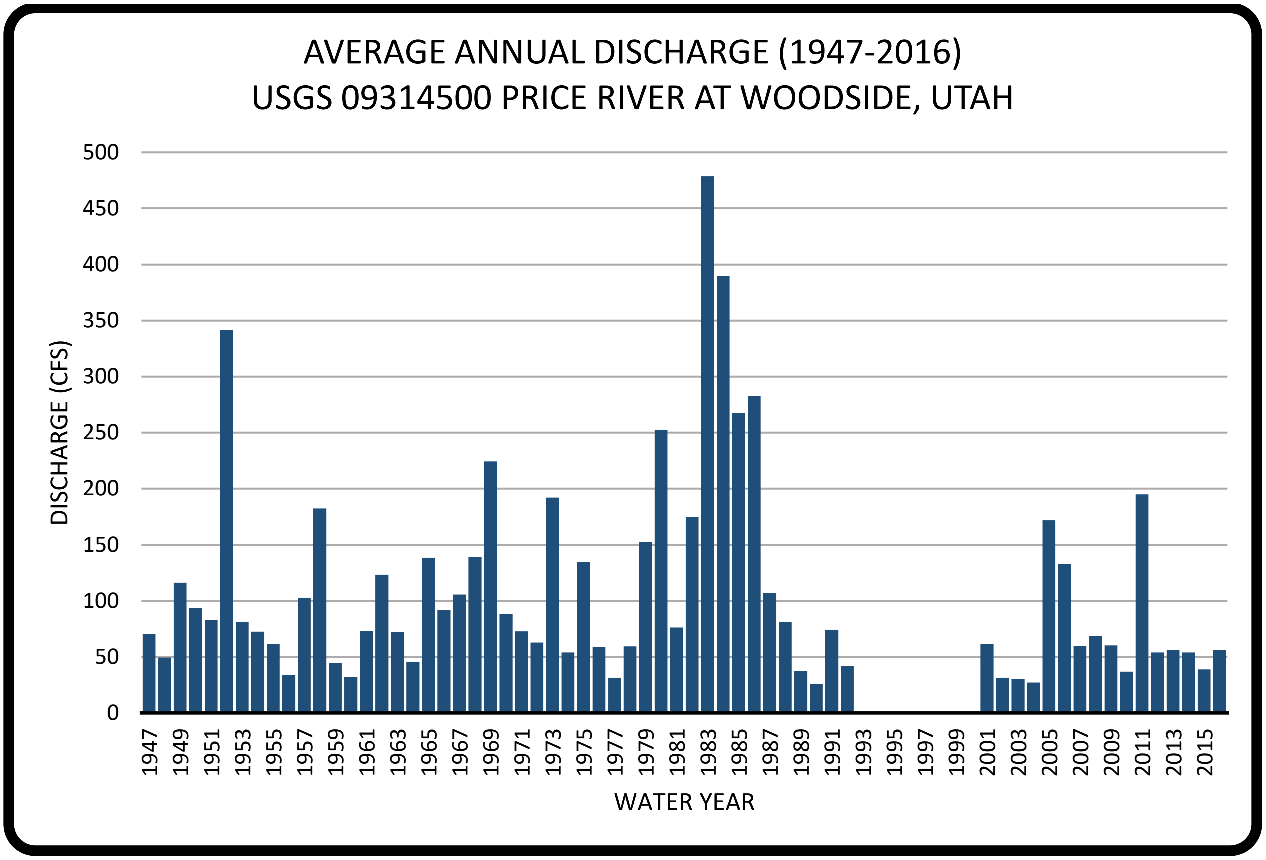

Figure 21. Average annual discharge, 1947-2016, for the Price River at Woodside, Utah. Based on the water year record, average annual discharge was highest in 1983 and lowest in 1990. The water year is the 12-month period from October 1 to September 30. The water year is designated by the calendar year in which it ends and which includes nine of the 12 months.

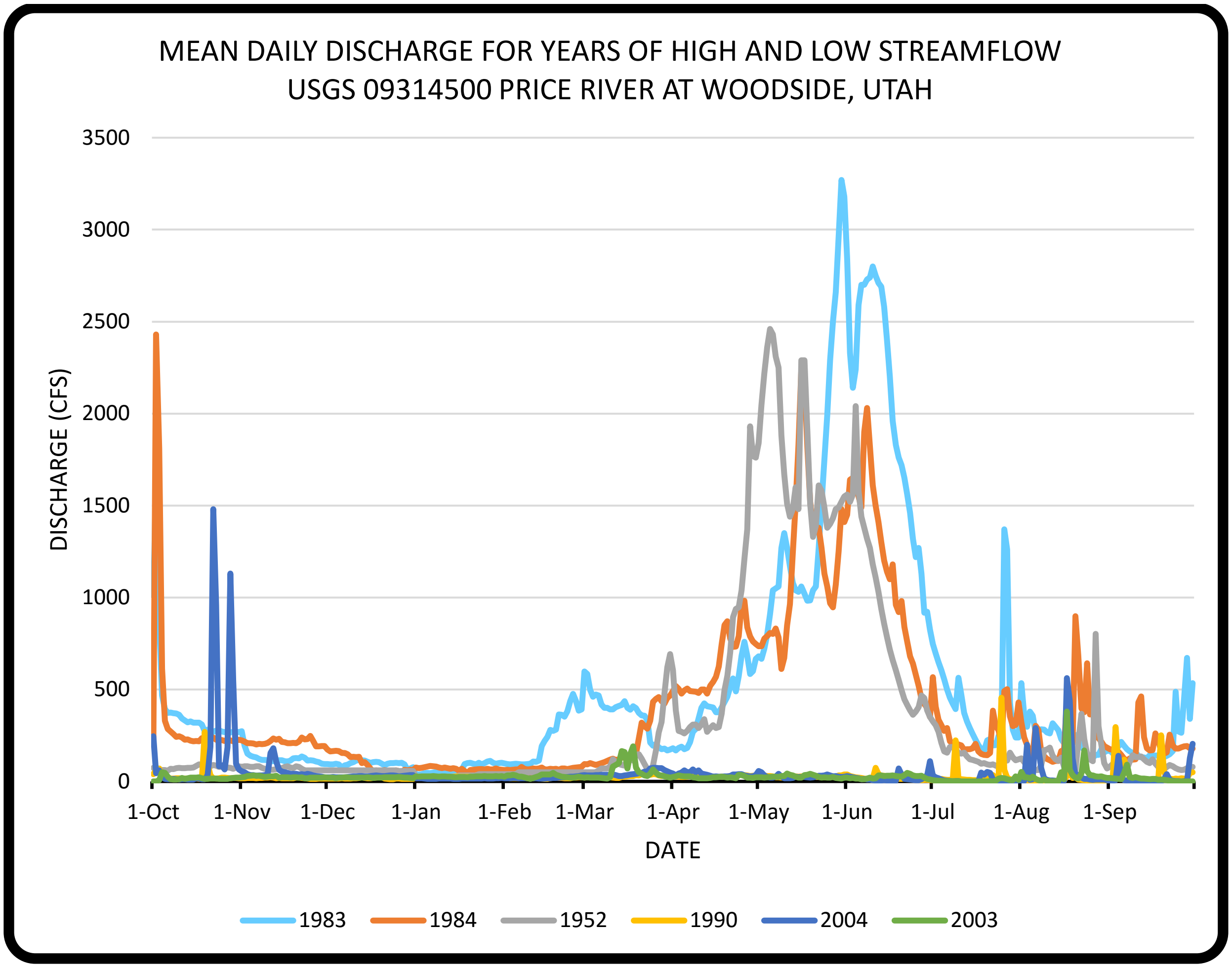

Figure 22. *Mean daily discharge for top three years with highest discharge and bottom three years with lowest discharge for the Price River at Woodside, Utah.*

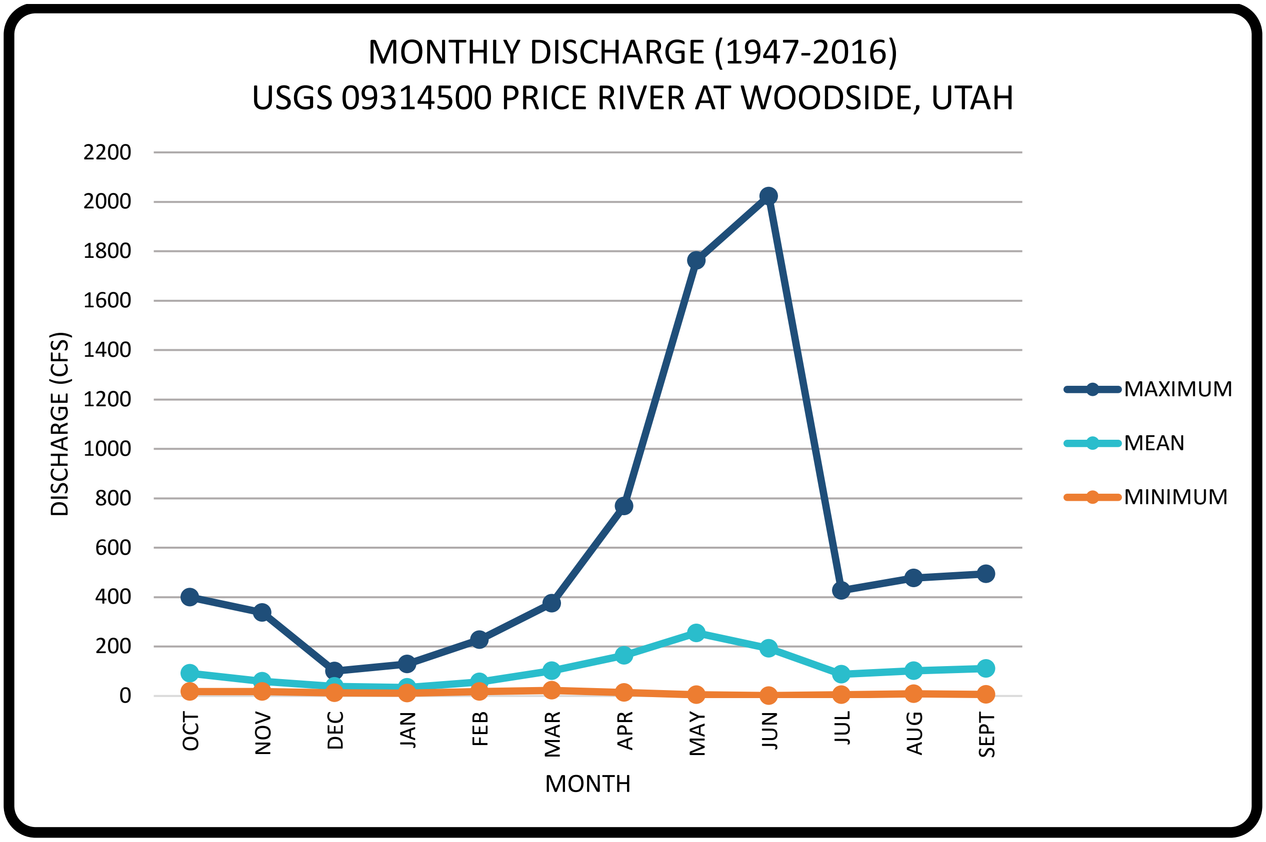

Figure 23. Maximum, minimum, and mean monthly discharge, based on water years 1947-2016, for the Price River at Woodside, Utah.

Table 5. Maximum, minimum, and mean monthly discharge, based on water years 1947-2016, for the Price River at Woodside, Utah.

MONTH	MAXIMUM DISCHARGE (CFS)	WATER YEAR	MINIMUM DISCHARGE (CFS)	WATER YEAR	MEAN DISCHARGE (CFS)	PERCENT OF ANNUAL DISCHARGE
October	399.1	1984	17.3	2004	91.0	7.0
November	337.0	1958	17.9	1991	59.2	4.6
December	100.7	1967	12.2	1978	38.7	3.0
January	128.8	2005	10.7	1961	34.1	2.6
February	226.9	1983	18.0	1964	56.5	4.4
March	375.0	1979	22.3	2015	102.2	7.9
April	768.3	1986	13.6	2015	164.3	12.7
May	1762.0	1952	5.3	1961	255.1	19.7
June	2023.0	1983	1.5	1961	192.8	14.9
July	426.5	1983	4.2	1960	88.1	6.8
August	477.7	1957	8.6	1990	102.3	7.9
September	494.1	1991	5.7	1992	110.4	8.5
ANNUAL	5749.2	1983	310.1	1990	107.9	100.0

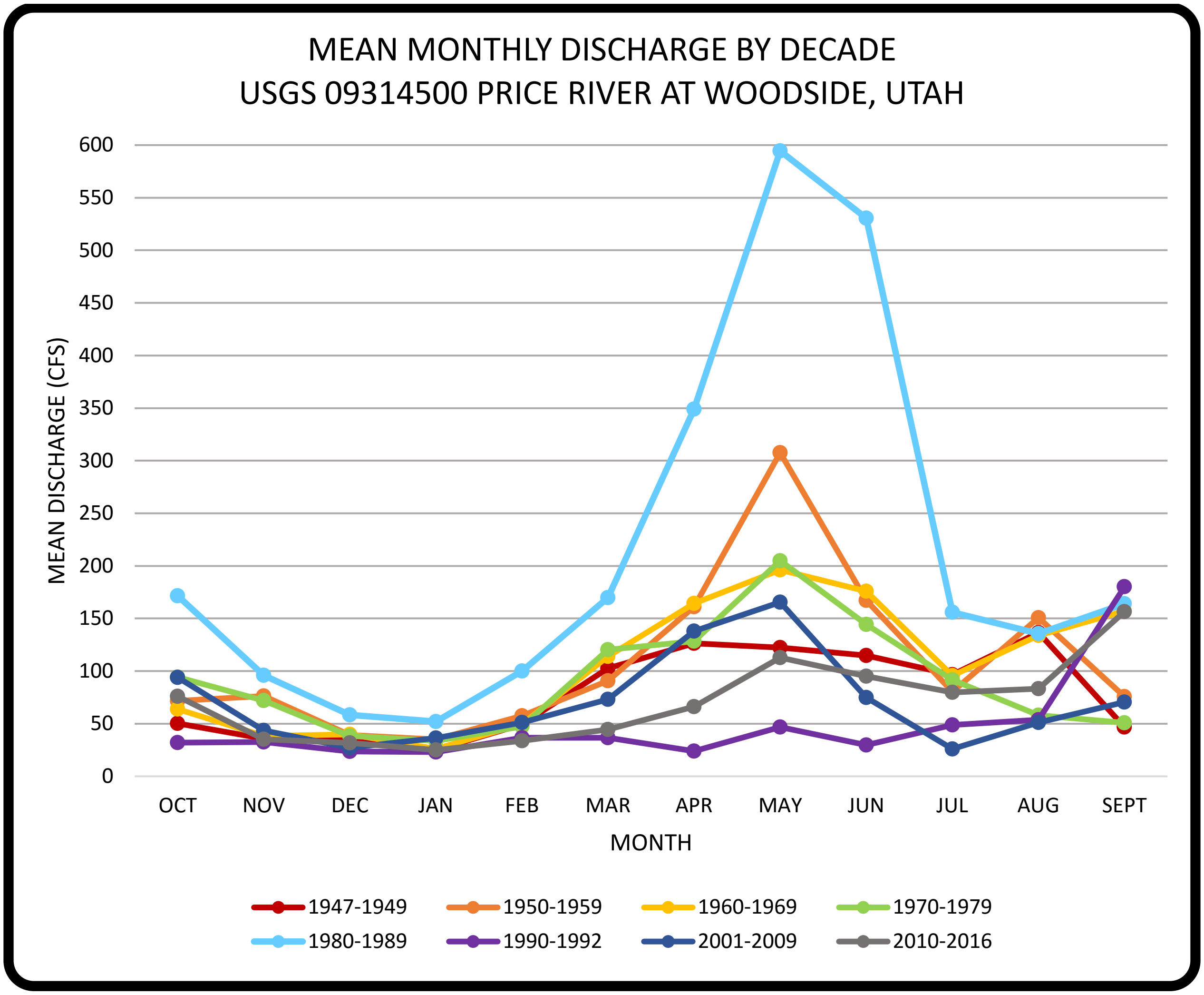

Figure 24. Mean monthly discharge by decade, based on water years 1947-2016, for the Price River at Woodside, Utah.

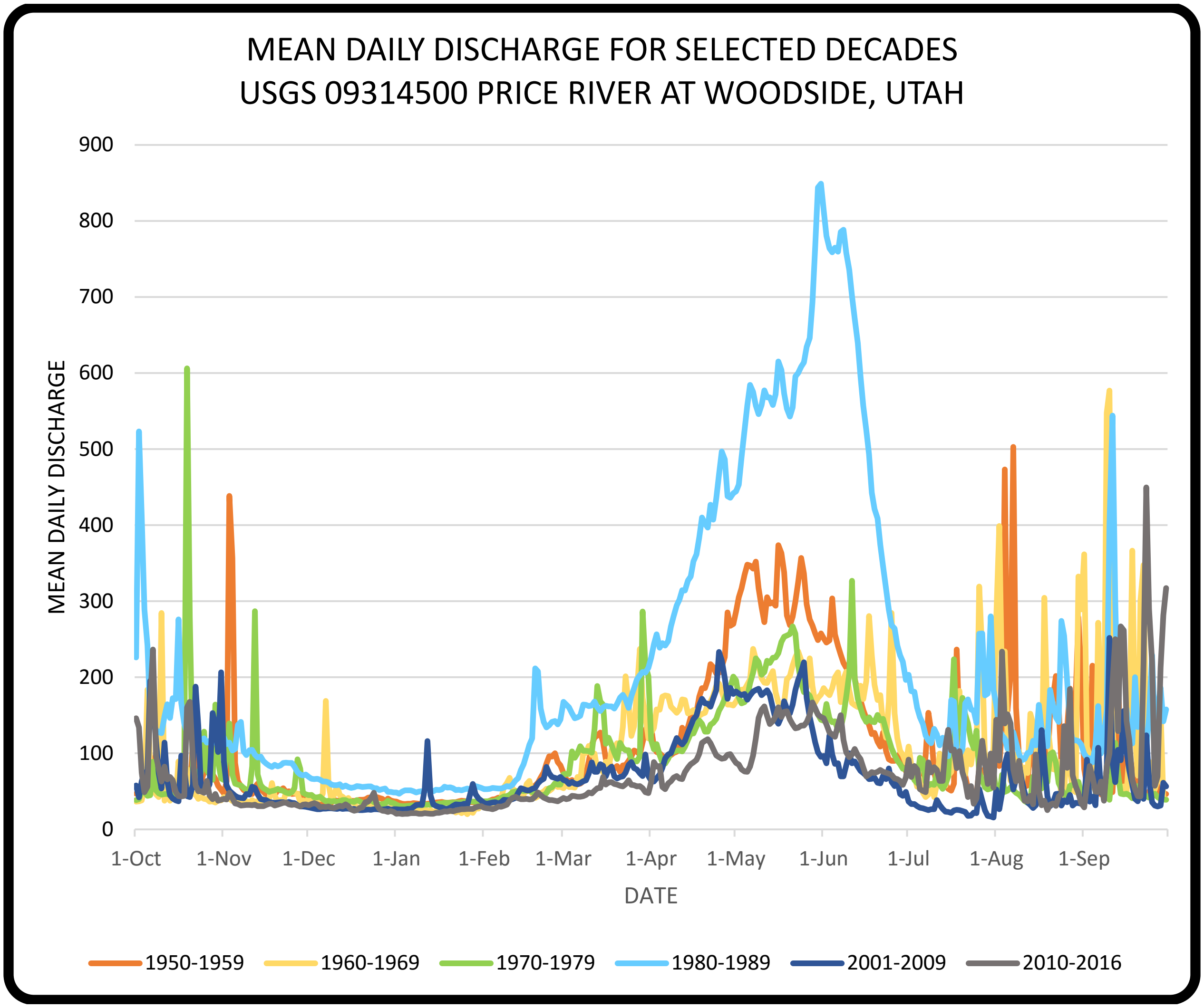

Figure 25. *Mean daily discharge for selected decades. Decades with limited and incomplete data, including the 1940s and 1990s, were not graphed.*

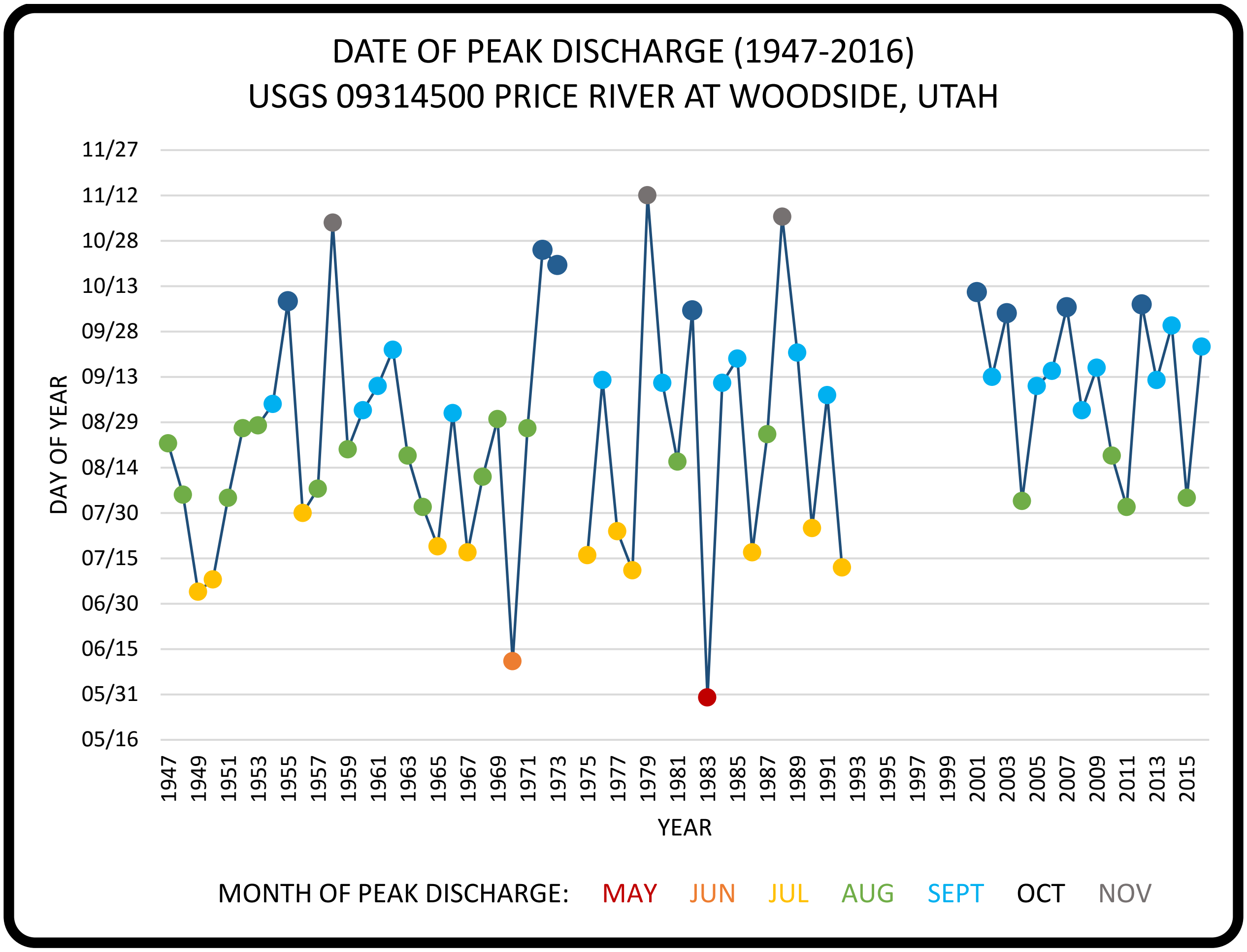

Figure 26. Date of peak discharge, for water years 1947-2016, for the Price River at Woodside, Utah. Since 2001, the window of peak flows appears to be narrower.

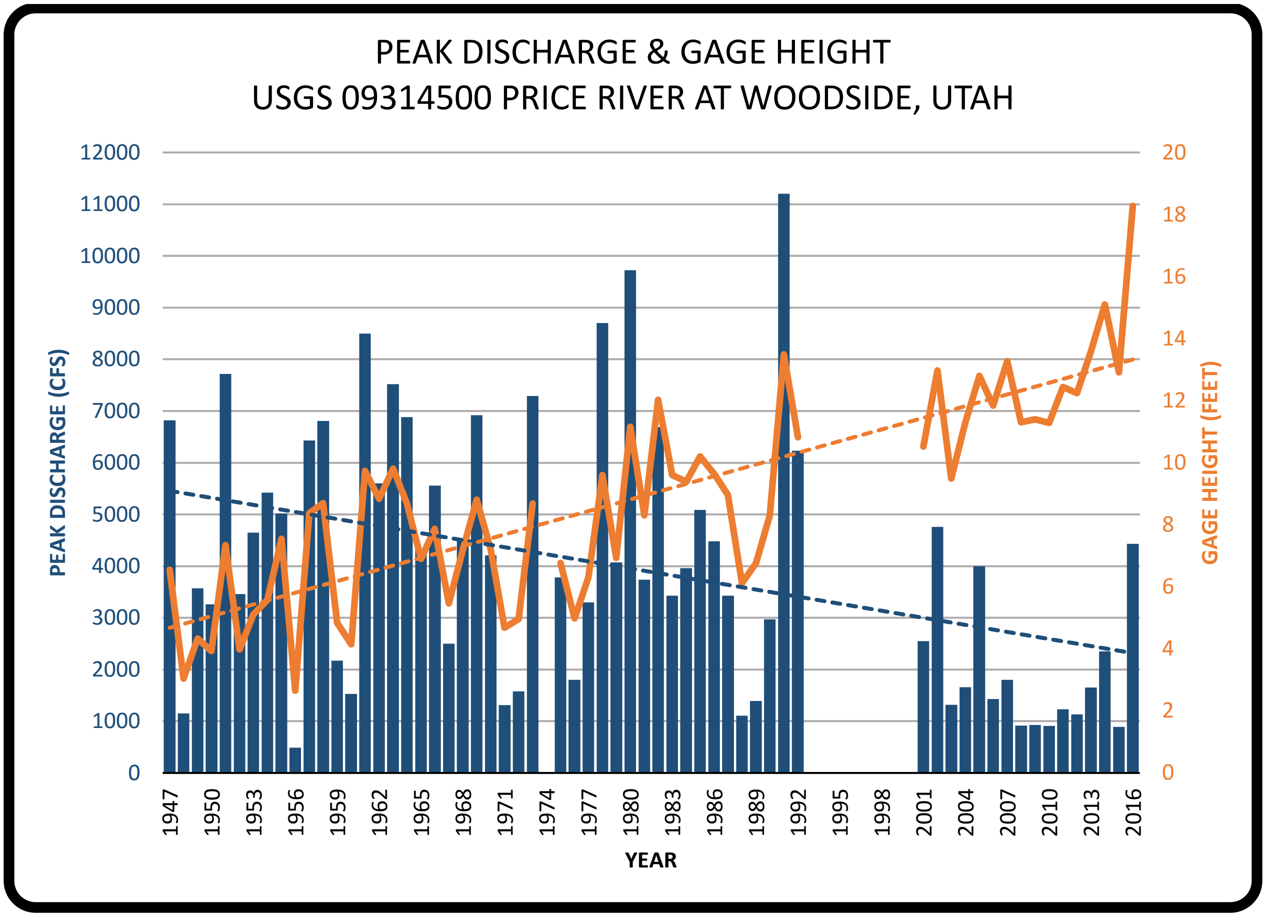

Figure 27. Peak discharge by year, 1947-2016, compared with gage height for the Price River at Woodside, Utah.

CONCLUSION

Historic aerial photographs serve as an invaluable source of information on historic landscape conditions and they can provide baseline assessments in land cover change studies. Knowledge of historic landscape condition can improve understanding of critical ecosystems, inform contemporary management decisions, and guide restoration activities. In threatened dryland river systems, historic aerial photographs can provide information on the historical distribution and relative abundance of riparian land cover and they can provide information about historic channel features and characteristics.

In an effort to support land and resource managers, as well as private land owners within dryland river systems, UtahView developed a process that would enable fairly rapid assessments of changes in river morphology and riparian land cover distribution. Using the Price River in central Utah as a case study, historic aerial photographs from 1938 were downloaded from the UGS, mosaicked in Adobe Photoshop, and georeferenced in Esri ArcGIS. The georeferenced images permitted evaluations of historic river channel characteristics, such as channel width and sinuosity, and land cover pattern and distribution. These assessments provided a baseline inventory that could then be compared to other years, including 1974, 1997, 2006, and 2014.

The baseline inventory of channel characteristics suggests that the Price River was historically characterized as a wide system with multiple threads, variable channel widths, and several channel features. Comparisons with recent years indicate that the Price River has transitioned into a confined single-threaded system with low width-to-depth ratios and higher sinuosity measures. Historic land cover evaluations indicate that riparian land cover was patchy and dispersed and largely consisted of cottonwood gallery forests and willow stands. Recent land cover analyses and quantifications reveal that invasive species, predominantly tamarisk, have blanketed the riparian corridor and replaced native plant species.

While this process was developed to support the restoration of dryland river systems in the Southwestern United States, these methods can be applied to other classes of river systems. Additionally, researchers and resource managers across multiple disciplines can utilize this approach to create inventories, develop baseline assessments, and to evaluate temporal changes.

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