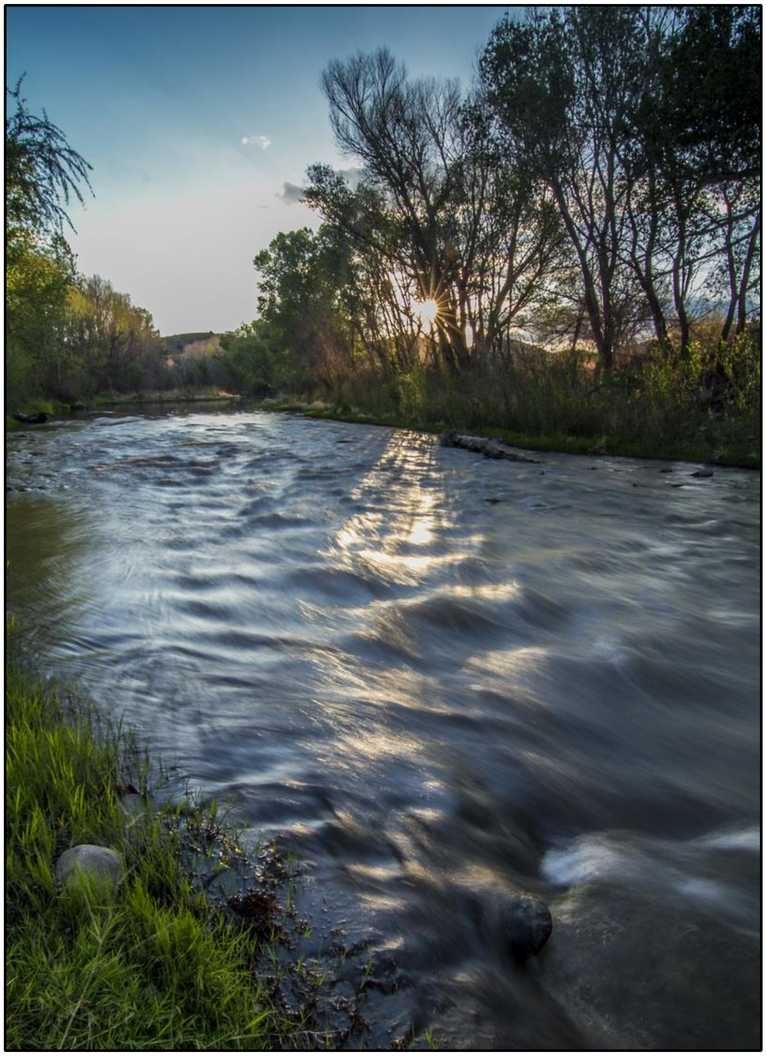
Gila River Flow Needs Assessment



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Gila River Flow Needs Assessment

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Table of Contents

List of Appendices

Acknowledgments

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Chapter 8. Riparian Vegetation of the Upper Gila River and Southwestern Streams

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Summary

This chapter provides an overview of riparian vegetation in the southwestern United States with emphasis on characteristics of vegetation in the Cliff-Gila Valley of the Gila River in New Mexico. More specifically, this work focuses on how these riparian corridors may be affected by future reductions in streamflow. Riparian vegetation in the Cliff-Gila Valley comprises several plant community types that occur along a hydrological gradient from wettest to driest communities, including: jurisdictional wetlands, marshlands and herbaceous wetland vegetation, channel bar wetlands, cottonwood-willow forest, mixed broadleaf forests, mesic and xeric shrubby riparian areas, grass/forb plant communities, and agricultural vegetation. Several factors influence the community type:

- Large floods create the substrate for cottonwood willow germination, roots of cottonwood-willow seedlings follow the snowmelt recession limb, and subsequent mid-sized flows support survival of sapling and adult trees.
- Secondary channels are important sites for riparian vegetation recruitment, including wetlands. Groundwater levels are elevated in topographic lows on the floodplain.
- Dense multi-aged riparian forests are maintained by groundwater that fluctuates less than 1 m annually.

Reduced streamflow from CUFA diversion and climate change may negatively influence these flow dynamics and riparian vegetation. Key concerns include:

- decrease in cottonwood/willow establishment;
- decline in overall canopy cover, age-class diversity, and individual tree vigor;
- reduction in the acreage and quality of wetlands; and
- increase in saltcedar and nonnative vegetation.

Historical Overview of Riparian Vegetation in Southwestern Streams

The Gila River headwaters start at over 3,050 m (10,000 ft) in the montane coniferous forest in the Gila Wilderness in southwestern New Mexico. The river is similar to other streams in the Sky Island area of the Southwest in that it flows from high mountainous regions into the desert below and crosses several vegetation zones, thereby providing a variety of habitats for plants and animals. This review will focus on the vegetation of the 35-km (22-mi) floodplain reach of the Gila River in the Cliff-Gila Valley (Figure 1).

Because the flow regime of the Gila River in New Mexico persists in a relatively natural state (i.e., unrestricted by major impoundments or permanent diversions), channel configurations are widely variable and vegetation communities are a diverse mosaic of many communities rather than a long continuum of a single type (Durkin et al. 1996). The vegetation of the floodplain is structured by geology, flood disturbance, and water availability. In addition to these physical processes, plants themselves are recognized as river system engineers as their biomass modifies flows, retains sediment, and creates below-ground biomass (Gurnell 2014). Riparian vegetation in the Cliff-Gila Valley is also influenced by agricultural practices such as grazing, cultivation, and levees.

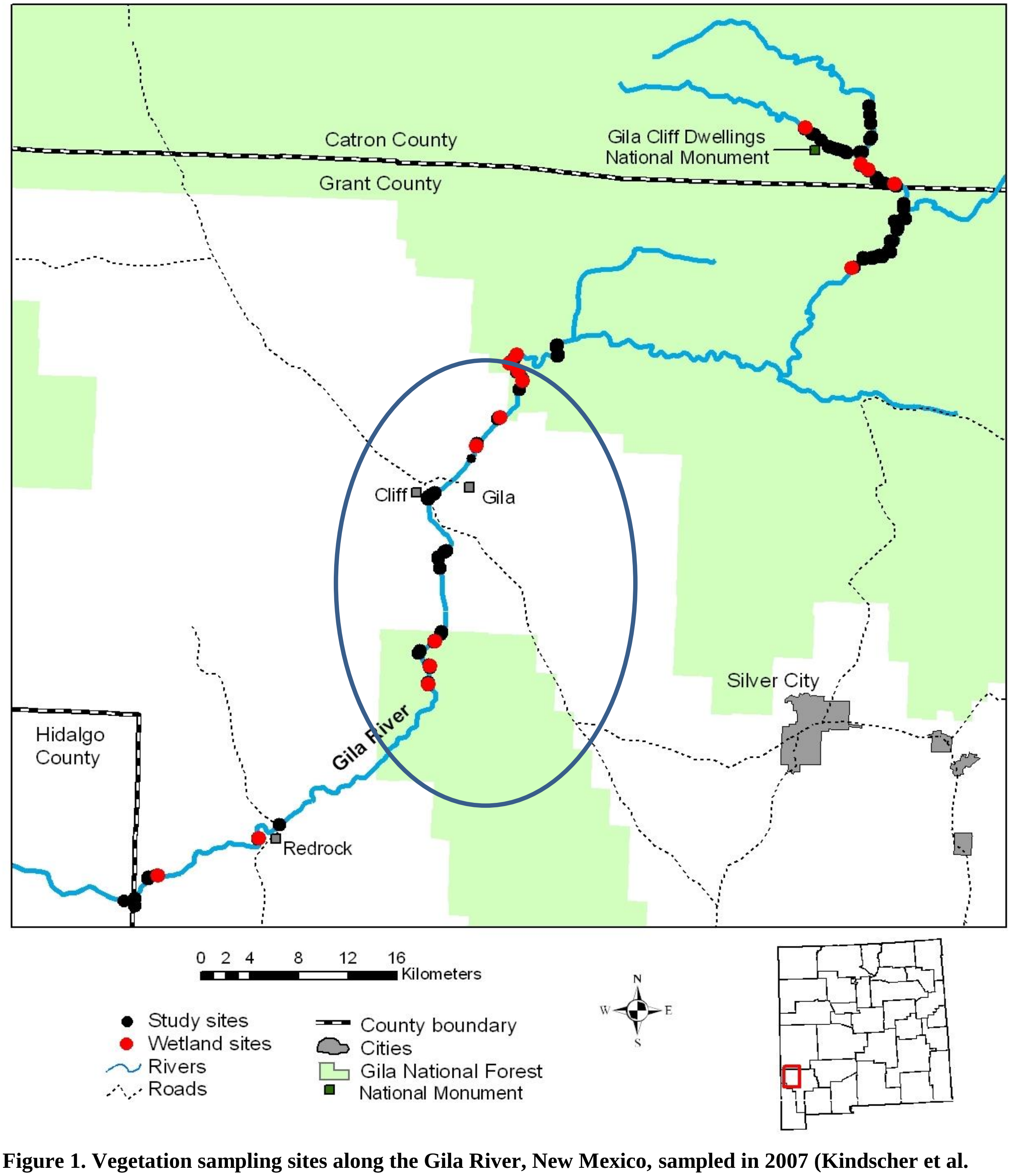

Figure 1. Vegetation sampling sites along the Gila River, New Mexico, sampled in 2007 (Kindscher et al. 2008). Circles designate 0.1 ha plots from which cover for all plant species was recorded and a wetland index was used to calculate where wetland vegetation predominated at the site. The large oval indicates the Cliff-Gila Valley; data from this reach of the river was used for this chapter.

In this dynamic and complex system, the wide floodplain of the Cliff-Gila Valley supports considerably more riparian and wetland vegetation than areas upstream and downstream which are canyon-bound (Kindscher et al. 2010). Riparian forests are dominated by Fremont cottonwood (*Populus fremontii*), Goodding's willow (*Salix goodingii*), seep willow (*Baccharis salicifolia*), and coyote willow (*Salix exigua*), also known as the sandbar or narrowleaf willow (Tables 1 and 2).

Table 1. Plant communities and some dominant species in plant communities along the Gila River, New Mexico, in the Cliff-Gila Valley. Additional species associated with plant communities are listed in the text.

Plant Community	Description
Bare ground / no vegetation	Barren riparian shorelines where located next to the active channel; also used to denote any areas in floodplain devoid of vegetation, between other habitat types
Wetland*	
A. Side and secondary channel ponds or pools	Marshland and herbaceous wetland vegetation adjacent to the active channel and secondary channels. Species include rushes (*Juncus torryii*), cattails (*Typha latifolia*), and rice cutgrass (*Leersia oryzoides*).
B. Ephemeral pools and wetlands	Also called channel bar wetlands. Species include cocklebur (*Xanthium strumarium*), smartweed (*Persicaria maculosa*), and a perennial sedge (*Carex senta*).
Grass/forb	Xeric floodplain grasslands.
Shrub	
A. Mesic riparian	Species: Primarily seep-willow (*Baccharis salicifolia*).
B. Xeric riparian	Species: rabbitbrush (*Hymenoclea monogyra*), desert broom *(Baccharis sarathroides*).
Cottonwood/willow	
A. Gallery	Mature *Salix-Populus* woodland-forest (gallery forest)
B. Pole/sapling	Sapling *Salix-Populus* woodland-forest (young forest). Includes coyote willow (*Salix exigua).*
Other native tree	
Riparian	Native mixed deciduous forest. Species include sycamore (*Platanus wrightii*), alder (*Alnus oblongifolia)*, velvet ash (*Fraxinus velutina),* and Box elder (*Acer negundo)*.
Upland/transition	Arizona walnut (*Juglans major)*, Mesquite (*Prosopis glandulosa)*, hackberry (*Celtis reticulata*), and desert willow (*Chilopsis linearis*).
Nonnative tree	Saltcedar (*Tamarix chinensis*), Russian olive (*Elaeagnus angustifolia*), tree-of-heaven (*Ailanthus altissima*), and Siberian elm (*Ulmus pumila*).
Cultivated	Agricultural field, historical or current. Cover is nonnative or native pasture grass or alfalfa.

*During surveys and within the data, wetland type (secondary channel ponds/pools vs. ephemeral pools/wetlands) was not delineated. Both types were classified as wetlands. Similarly, herbaceous wetlands were classified as wetlands, rather than the grass/forb habitat type.

Floodplain vegetation has varied considerably over time. Soles (2003) calculated the extent of floodplain inhabited by riparian vegetation in the Cliff-Gila Valley during each of six aerial photo dates from 1935 to 1996 using photogrammetry from each aerial photo series. Analyses showed that a pulse of riparian regeneration occurred between 1980 and 1996 and that large floods (12,500 – 35,000 cubic feet per second [cfs]) cleared vegetation through a combination of mechanical reworking of the floodplain and also flood scouring. Abandoned and secondary channels provided ideal nursery sites for riparian establishment (Soles 2003). Groundwater proximity, presence and age of floodplain vegetation, substrate composition, and the relative discharge carried by the main channel, tributaries, and secondary channels during flood events are all important variables influencing conditions in the riparian corridor (Asplund and Gooch 1988; Braatne et al. 1996).

Table 2. Cover of riparian floodplain habitat mapped by habitat bands during 2012 annual transect surveys.

Habitat type	% of total	Area (m^2)	Area (acres)
Aquatic habitat	2.8%	1,549.2	0.38
None (barren)	7.3%	4,078.9	1.01
Herbaceous wetland/wet meadow	0.5%	261.1	0.06
Grass/forb (upland)	34.4%	19,371.1	4.79
Riparian shrub	2.6%	1,446.7	0.36
Upland shrub	6.3%	3,565.5	0.88
Riparian forest: cottonwood/willow – Pole or sapling	16.6%	9,323.7	2.30
Riparian forest: cottonwood/willow – Gallery, mature	10.2%	5,729.2	1.42
Riparian (mesic) forest: native mixed broadleaf	2.5%	1,389.7	0.34
Transition/upland forest (native)	1.8%	1,009.2	0.25
Nonnative forest	0.2%	92.1	0.02
Cultivated (historical or present)	15.0%	8,413.9	2.08
TOTAL	**100%**	**56,230.4**	**13.90**

Gila River Riparian Vegetation Types

This chapter describes plant community types using two recent data sets from the Cliff-Gila Valley (Soles and Cooper 2013; Kindscher et al. 2008). A diverse mix of riparian forests and shrublands occupy channels and terraces at specific positions and heights across the floodplain (Durkin et al. 1998; Chapter 7, this report). The main vegetation types of the Gila River floodplain are discussed below in order from wetter to drier habitats (Table 1). Habitat sensitivity to streamflow decline follows the same descending order. Plant community types were modeled after work in the Verde River (Stromberg 2008) and San Pedro River (Lite and Stromberg 2005) in Arizona.

Methodology associated with monitoring transects (Appendix 4) surveyed from 2009-2013 is described in Chapter 7 of this report. To evaluate the relationships between topography and floodplain habitat, Soles and Cooper characterized vegetation on line transects within one of 11 habitat types listed in Table 1. This analysis was expanded by overlaying 10-m bands centered on each surveyed transect on georeferenced aerial photography. Habitat types within each band were digitized and ground-truthed. This data is referred to within this chapter as “habitat bands” and is summarized in Table 3. The relationship between habitat type and depths to groundwater was also evaluated using topographic mapping and piezometer data in conjunction with vegetation data collected during the field surveys (Table 4) and is described in Chapter 7 of this report.

Kindscher et al. (2010) studied wetland vegetation along the New Mexico portion of the Gila River; plots were surveyed in 2007. The presence and abundance of plant species from 19 riparian plots in the Cliff-Gila Valley (Figure 1) is included in this chapter. This data is referred to within this chapter as “plot data.” This data set provides additional information on the abundance of specific species (Table 2) and wetland attributes of the Cliff-Gila Valley.

Table 3. Average percent cover and wetland status of species found in 57 plots (1 ha) sampled in riparian areas in July 2007 in the Cliff-Gila reach of the Gila River (Kindscher et al. 2008, 2010). The symbol * designates a nonnative species, OBL = Obligate wetland species, FACW = facultative wetland, FAC = facultative, FAU = facultative upland species, UPL = upland species, and NI = species not included in the wetland species list (USDA NRCS 2013). Number of plots refers to the number of plots within which a species occurred at least once.

Species	Common Name	Wetland Indicator	Avg. % Cover	Number of plots
Populus fremontii	Fremont cottonwood	FACW	20.35%	52
Salix gooddingii	Goodding's willow	FACW	9.06%	42
Baccharis salicifolia	Seep willow	FAC	5.76%	49
Salix exigua	coyote willow	FACW	4.34%	25
Platanus wrightii	Arizona sycamore	FACW	3.13%	25
*Salsola tragus**	Russian-thistle	FACU	3.03%	51
*Melilotus albus**	white sweet-clover	FACU	2.33%	53
Aristida ternipes	Hook threeawn	UPL	2.05%	29
Ericameria nauseosa	rabbitbrush	UPL	1.85%	31
Sporobolus contractus	spike dropseed	UPL	1.81%	24
Acer negundo	boxelder	FACW	1.75%	10
Chenopodium neomexicanum	New Mexico goosefoot	NI	1.49%	31
Artemisia carruthii	Carruth's sagewort	UPL	1.46%	49
*Kochia scoparia**	Mexican fireweed	FAC	1.37%	20
Sporobolus cryptandrus	sand dropseed	FACU	1.25%	29
Conyza canadensis	horseweed	FACU	1.20%	53
Heterotheca subaxillaris	camphorweed	UPL	0.92%	44
Chenopodium berlandieri	pitseed goosefoot	UPL	0.82%	37
Eriogonum wrightii	bastard-sage	NI	0.79%	29
Parthenocissus vitacea	thicket creeper	FACW	0.75%	16
Ambrosia acanthicarpa	bur ragweed	UPL	0.73%	49
Juglans major	Arizona walnut	FAC	0.71%	14

Table 4. Median and standard deviations for depths to water (m) in vegetation communities on four transects from 2009-2012 (Table 8, Chapter 7, this report). Range of values reflects seasonal variation in depth to groundwater. Table organized from least to greatest depth to water.

Habitat type	Depth to water (m)
Herbaceous wetland/wet meadow	0.36–0.75 ± 0.35
Cottonwood/willow – Pole or sapling	0.62–0.95 ± 0.52
Riparian (mesic) shrub	1.13–1.30 ± 0.46
Upland (xeric) shrub	1.30–1.76 ± 0.62
Grass/forb (upland)	1.34-1.61 ± 0.85
Cottonwood/willow – Gallery, mature	1.52–1.78 ± 0.65
Cultivated (historical or present)	3.29–3.68 ± 1.07
Transition/upland forest (native)	5.13-5.38 ± 0.30
Riparian (mesic) forest: native mixed broadleaf	no data
Nonnative forest	no data

Wetlands

For regulatory purposes under the Clean Water Act, wetlands are defined as "those areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions" (Environmental Protection Agency 2013). Vegetation can serve as an indicator of hydrologic and soil conditions of a site. Species richness and abundance can indicate where wetlands occur, even if at the time of observation the area is essentially dry.

In previous work Kindscher et al. (2010) studied wetland vegetation along the New Mexico portion of the Gila River. All plant species found in the Gila River riparian plots were assigned one of five wetland values as defined in the 1987 *Wetlands Delineation Manual* (Environmental Laboratory 1987) and updated with a list from USDA NRCS (2013) Plants database. These categories include: 1) obligate wetland plants; 2) facultative wetland plants; 3) facultative plants; 4) facultative upland plants; and 5) obligate upland plants. These scores were used to calculate average wetland values where OBL = 1, FACW = 2, FAC = 3, FACU = 4, and UPL = 5. More detail on how wetland values were calculated can be found in Kindscher et al. 2010.

For the 19 sites (57 plots) along the river in the Cliff-Gila Valley, 300 plant species were recorded. The riparian area contained forests dominated by cottonwood (*Populus fremontii*) at over 20% of total cover and willow species (*S. goodingii* and *S. exigua*) comprised over 13% of total cover (Table 3). Using the procedure detailed in Kindscher et al. 2010, over 42% of these downstream plots are considered wetlands (Figure 2).

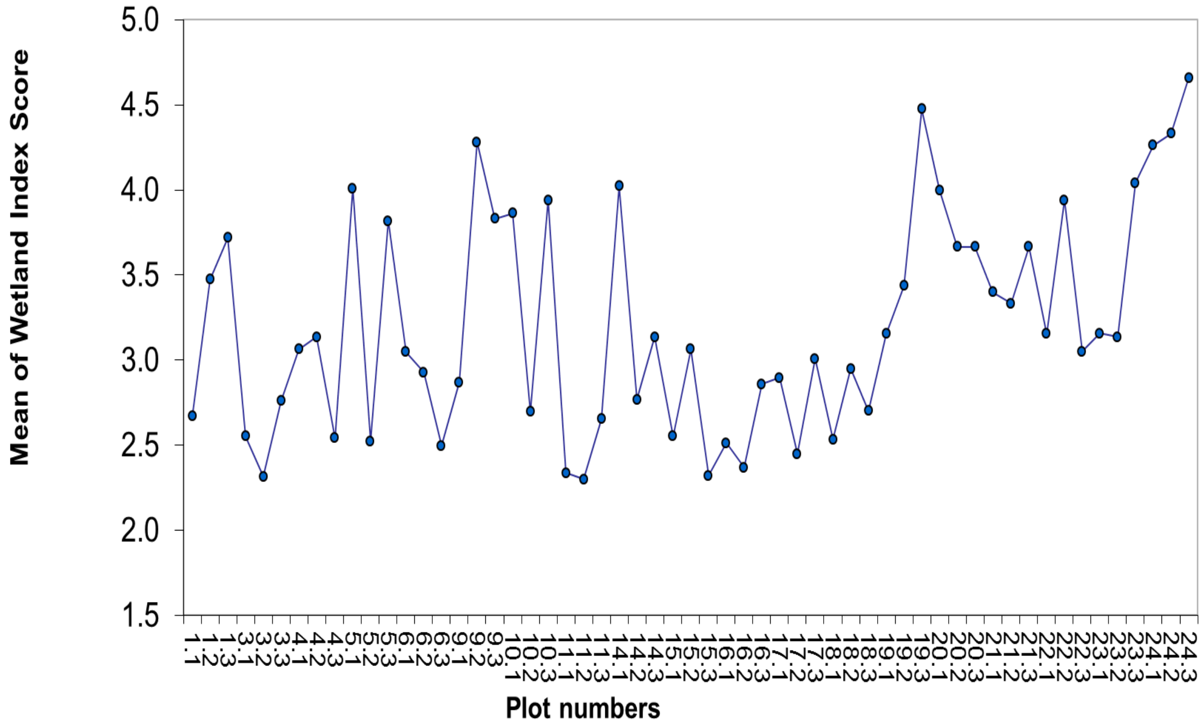

Figure 2. Wetland index scores for 57 sites (all 0.1 ha riparian plots) at 19 sites (3 plots each) along the Gila River in the Cliff-Gila Valley as shown on Figure 1. Scores based on plant cover data collected in 2007, using the wetland index described in the text. Plots with scores below 3.0 have a prevalence of wetland vegetation, and could potentially be classified as regulatory wetlands.

A major driver in the delineation of wetlands is frequency and abundance of obligate wetland species. Categorization of obligate wetland species in the Cliff-Gila Valley shows that they are relatively infrequent. Facultative wetland species - occurring in wetlands 66-99% of the time - include Fremont cottonwood, Goodding's willow, coyote willow, and Arizona sycamore. Because of the dominant cover of these species, over 40% of the plots sampled were classified as wetlands.

Soles and Cooper mapped wetland habitat bands along monitoring transects (Chapter 7, this report), but excluded woody facultative wetland species. Wetlands were identified by obligate and facultative herbaceous species. Similar to Kindscher et al. 2010, wetland habitat was rare, covering only 0.5% of the entire habitat band surveyed. This habitat type had the shallowest depth to groundwater: 0.36-0.75 m.

The two classifications that most accurately describe wetlands in the Cliff-Gila Valley are described below. Because numerous authors within this report refer to wetland habitat, it is valuable to distinguish between these two types.

Marshland or Herbaceous Wetland Vegetation / Obligate Wetlands

Marshlands are the wettest habitat and one of the least common plant communities in the Cliff-Gila Valley. They require a constant source of standing water or soil moisture, and occur in old river channels, depressions in the floodplain where the water table is high, or where seeps or springs occur.

Vegetation in marshlands has roots that extend less than a meter into the soil. These areas are classified as wetlands due to their relatively consistent moist soils that are at times saturated, and the occurrence of wetland obligate plant species. Common species are considered wetland graminoids or emergent herbaceous species and include hardstem bulrush (*Schoenoplectus acutus*), rushes (*Juncus torryii*), cattails (*Typha latifolia*), spikerush (*Eleocharis* spp.) and rice cutgrass (*Leersia oryzoides*). Two large wetlands at the upper end of the Cliff-Gila Valley occur in a historic river channel and are being studied by Jeffery Samson and Dr. Mark Stone at University of New Mexico.

Channel Bar Wetlands / Facultative Wetlands

These wetlands are typically created by scouring during large floods and occur in small discrete bands in off-stream secondary channels or in other depressions where the water table is very high and silt and sand have been deposited over time. In addition, the vegetation often has considerable amounts of annual biomass, comprising the following species: yellow nutsedge (*Cyperus esculentus*), cocklebur (*Xanthium strumarium*), and smartweed (*Persicaria maculosa*). Perennial species, including sedges and notably a large clump-forming sedge (*Carex senta*), also occur here. These areas also serve as nurseries for seedlings of cottonwood, willows, and other species. Because channel bar wetlands typically occur in secondary channels not adjacent to the active channel, vegetation is protected from scouring, although infrequent large floods may reduce vegetative cover.

Historically, beaver played an important role in the Gila in increasing wetland acreage due to their dam building operations (Chapter 13, this report). Further study is needed to determine historic and current acreage of wetlands in the Cliff-Gila Valley. Methodology tested in the Gila and described in Muldavin et al. (2011) would be useful, particularly if expanded to cover a greater portion of the Valley.

Cottonwood-Willow

The most mature communities, such as a Fremont's cottonwood-Arizona sycamore/seepwillow forest, develop on the highest sites such as larger island bars or sidebars. These sites are within the

25-year floodplain, where the force of flows averaging 18,000 cfs can readily remove large trees and destabilize the bars, leading to radical changes in the floodplain landscape.

Cottonwoods and willows are the dominant class of vegetation in the floodplain (Kindscher et al. 2010). From 2012 habitat bands, they occupy 26.8% of total band area (Table 2). The most common species in this vegetation class are Fremont cottonwood (*Populus fremontii*) and Goodding's willow (*Salix gooddingii*), but it includes other cottonwood (*Populus angustifolia*) and willow species (*Salix irrorata*), as well as other riparian and upland tree species. Cottonwood-willow forests in the habitat bands are classified as pole sapling stands and gallery forest (Table 1).

Gallery forests are characterized by large stems and an expansive distinct canopy. Old-growth cottonwoods primarily occur when they are stranded on higher stream banks, or when the meander channel they established on is removed from the greatest intensity of flooding (Durkin et al. 1996).

The youngest community, consisting of cottonwood, willow, and seepwillow, occurs on the lowest bars bordering the main channel or secondary channels (Durkin et al. 1996; Chapter 7, this report). Approximately one-third of this vegetation occurs within 15 m of the main channel, while approximately two-thirds grow greater than 15 m from the river along secondary channels (Chapter 7, this report). In contrast to trees in gallery forests which have typically self-thinned over time, saplings typically grow densely together. Tree crowns are highly variable but are individually much less dense than gallery forests, providing more foliage in the mid-canopy. Developing cottonwood forests are typically within the 2-year floodplain (Durkin et al. 1996).

Riparian Shrub

In places near stream and secondary channels and in full sun where groundwater is high, strands of coyote willow (*Salix exigua*) and/or seepwillow occur. Both mesic species occur extensively in the Cliff-Gila Valley (Kindscher et al. 2008). Seep-willow is a common evergreen shrub (to 4 m) that occurs in bands along the river channel or in cobble. This vegetation type often occurs in very sandy or cobble-strewn deposits. In the habitat bands, coyote willows were included in the cottonwood-willow pole/sapling habitat type, rather than as a riparian shrub habitat type (Table 1). Young cottonwoods and coyote willows typically occur together so it is difficult to map them separately; this habitat band covered 16.6% of the entire area mapped (Table 2).

Seep willows were the primary species included in the riparian shrub category, covering 2.6% of the entire area mapped. However, from plot data, seep-willow ranked third in terms of percent cover, following cottonwood and willow (Table 3).

Grass/Forb

Floodplain grasslands typically occur in areas of full sun with sandy or fine-textured soils. They are found throughout the Cliff-Gila Valley, having the highest percent cover within habitat bands collected along monitoring transects (Table 2). However, the cover within this habitat band is often quite sparse. In terms of habitat bands mapped along monitoring transects, Soles and Cooper (2013) used wetland indicator species to identify herbaceous wetland cover (see above). Therefore, the grass/forb habitat band reflects xeric sites, with greater depths to groundwater than wetland species (Table 4).

The most frequently observed grass species included hook three-awn (*Aristida termipes*—30 plots), barnyard grass (*Echinochloa crus-galli*—28), sand dropseed (*Sporobolus cryptandrus*—28), tall fescus (*Festuca arundinacea*—28), and bermuda grass (*Cynodon dactylon*—28) (Table 2) (Kindscher et al. 2008). Terraces where grass occurs adjacent to the active channel are often composed of Canada wild rye (*Elymus canadensis*), sand dropseed (*Sporobolus cryptandrus*), and spike dropseed (*Sporobolus contractus*) (Kindscher et al. 2008).

Other Native Riparian Trees

This vegetation type is some of the most diverse wooded habitat in both species richness (Table 1) and structure. Deciduous forests are generally located in areas with consistently moist soils that do not experience flood scouring due to their position to the river channel. These protected areas may be distant from the main channel or sit above or adjacent to it. The understory supports numerous native shrubs, such as three-leaf sumac *(Rhus trilobata)* and indigo bush (*Amorpha fruticosa*). In general, these groupings reflect different water needs of these species, although there is overlap in where the species are found.

Mixed deciduous riparian trees often occur in late successional cottonwood-willow forests. Many of these native trees are also found along the earthen irrigation ditches in the Cliff-Gila Valley. Arizona sycamore (*Platanus wrightii*) and alder (*Alnus oblongifolia*) are early-successional trees included in this category. Late-successional trees include box elder (*Acer negundo*) and velvet ash (*Fraxinus velutina*). These two species require moist soils and areas protected from flooding to reach maturity.

Because most of these trees occur in small, isolated stands or as individual trees, their overall cover is quite low on the study transects (Table 2). In addition, if these native riparian trees were beneath an overstory of cottonwood/willow, the habitat bands would have been recorded as cottonwood/willow.

Upland Shrub

Shrubby riparian xeric sites occur on dry terraces or flood-disturbed areas with dry soils or cobbles and where seasonal maximum depth to groundwater is 2-4 m (Leenhouts et al. 2006). Rabbitbrush (*Chrysothamnus naseousus*), burro bush (*Hymenochlea monogyra*), and desert broom (*Baccharis sarathroides*) form in patches or in linear thickets. These species access groundwater by developing deep roots, tolerate low soil moisture, and have the ability to re-sprout after being laid flat by intense flooding. Upland shrubs often co-existed with upland grass/forb cover on terraces and had very similar depths to groundwater (Table 4). Many riparian species commonly found on high terraces of floodplains in arid regions are considered upland species (Durkin et al. 1996; Stromberg et al. 1996).

Other Native Upland Trees

Species grouped in the upland transition woodland include Arizona walnut (*Juglans major*), honey mesquite (*Prosopis glandulosa*), soapberry (*Sapindus saponaria*), netleaf hackberry (*Celtis reticulata*), desert willow (*Chilopsis linearis*), Emory oak (*Quercus emoryi*), and junipers (*Juniperus monosperma* and *Juniperus deppeana*) and occupy the driest sites on the floodplain. These trees, especially desert willow, occur on terraces in the active floodplain but most commonly develop at the edge of the floodplain against the toeslope of adjacent hillsides (Durkin et al. 1996). Flooding is now rare on sites like this (> 100-year return intervals) and also on terraces adjacent to the river out of the active floodplain.

Along monitoring transects, this habitat occurred in only 2% of the habitat band area. One explanation for this very low value is that many of these species occur in the understory of gallery cottonwood forests; in this situation the dominant band would be recorded as mature cottonwood rather than native upland tree. Arizona walnut is a common species in the Valley bottom: it occurred in 26% of the plots sampled by Kindscher et al (2010). Emory oak are typically found on the alluvial fans of drainages in the Cliff-Gila Valley. Some of these species, particularly hackberry, junipers, and mesquite, are also found along irrigation ditches. This is the most mature forest community of the site, and in time the riparian canopy trees will be replaced by facultative upland trees in the sub-canopy, particularly juniper (Durkin et al. 1996). Typically an upland tree and shrub, juniper is also found on the floodplain, although it rarely occurs along study transects.

Exotic and Invasive Species

Woody exotic and invasive species occur throughout the riparian area but their cover is very limited (Table 2). Saltcedar (*Tamarix chinensis*), Russian olive (*Elaeagnus angustifolia*), tree-of-heaven (*Ailanthus altissima*), and Siberian elm (*Ulmus pumila*) all occur in the Cliff-Gila Valley, often as single plants but in some cases as localized stands (e.g., Russian olive downstream of Hwy. 211 bridge). From 2012 10-m habitat bands, nonnative trees occupy less than 0.2% of total band area, which is only .02 of 13.90 acres (Table 2). Saltcedar is currently only a minor component of the vegetation along the Gila River in New Mexico. It only occurred in 5 of 57 plots and had very small percent cover in plots surveyed in 2007 (Kindscher et al. 2008).

In 2007 plot data, the most common exotic species encountered were three annual species: Russian thistle (*Salsola tragus*), sweet clover (*Melilotus alba*), and mullein (*Verbascum thaspus*) (Table 3). Many nonnative annuals are a legacy of a long history of agriculture in the Cliff-Gila Valley.

Cultivated Land

A significant amount of acreage in the Cliff-Gila Valley is associated with current or past agricultural practices, including crops such as alfalfa. Much of the existing acreage within this habitat type is pasture grass or abandoned cropland. Introduced exotic grass species are common throughout the Valley.

Life Histories of Plant Communities and Species

The following discussion focuses on life history characteristics of plant communities and woody species in the Cliff-Gila Valley. They are arranged according to their relative dependence on groundwater.

Cottonwood (*Populus fremontii* and Other *Populus* Species) and Willow (*Salix gooddingii* and Other *Salix* Species)

Cottonwood and willow require a consistent source of groundwater; their distribution is restricted to where this exists. In Arizona they are typically found where the groundwater is within only 1-3 m of the surface (Leenhouts et al. 2006; Stromberg 2008). In addition, the water table beneath these trees is relatively stable and near the ground surface, not varying by more than 2 m (Lite and Stromberg 2005). In the Cliff-Gila Valley, depth to groundwater of cottonwood/willow habitat varied considerably by season and condition (Tables 9 and 10, Chapter 7, this report). When groundwater is not sufficiently high, these species decline along Southwestern streams (Shafroth et al. 1998; Shafroth et al. 2000; Stromberg 2008). Cottonwood trees of all ages and sizes are known to die from severe water stress (Tyree et al. 1994). Another effect of large or sudden drops in groundwater is that as successful recruitment events occur more infrequently, age-class diversity is reduced.

Older stands can tolerate greater depths to groundwater than young stands (Table 4). The depth to groundwater for gallery forests ranges from 1.5-1.8 m (Table 4). Rooting depths in the Cliff-Gila Valley appear to be shallower than for mature stands observed in Arizona (3-5 m (9.8-16.4 ft)) (Braatne et al. 1996; Stromberg 1993).

Young pioneer forests are found in greatest abundance along secondary river channels on the floodplain. Recruitment is most successful in these areas because groundwater is available and these sites are typically protected from scouring (Chapter 7, this report). Cottonwoods and willows often occur in distinct age classes and even-aged heights reflecting they established at the same time. Depth to groundwater is closer (0.62-0.95 m) than for mature trees (Table 4).

The two main irrigation diversions in the upper end of the Cliff-Gila Valley dewater the river immediately downstream, causing large fluctuations in groundwater, particularly on transect 5 (Chapter 7, this report). Consequently, little cottonwood-willow recruitment occurs in this reach along or near the active channel. And over the course of the past decade, older trees have been dying.

Mature cottonwoods and willows flower in the early spring. Cottonwoods produce seeds in March through April. Goodding's willow are very similar, with seed releases beginning slightly later and lasting longer (from late March into June) (Shafroth and Beauchamp 2006).

Seedling establishment is linked to flood disturbance for cottonwood and willow trees (Stromberg 1998; Shafroth et al. 1998). Large floods create bare, disturbed areas. Silt provides a site for short-lived cottonwood and willow seeds to establish in the spring. Roots grow quickly to find moisture in the upper parts of the water table or from the capillary fringe. Root growth of young Fremont cottonwood seedlings is rapid: average growth rate is 4-12 mm (0.16-0.47 inch) per day (Stromberg 1993; Braatne et al. 1996). A growth rate of 13.5 mm (0.5 inch) per day has been observed over a 4-day period (Fenner et al. 1984). Because the upper layers of the moist alluvium dry rapidly with the onset of warmer summer temperatures, rapid root growth is essential to reach depths where a supply of water is available. Fremont cottonwood seedlings die if their roots do not reach seasonal alluvial water tables (Braatne et al. 1996). Successful cottonwood recruitment may occur only once every 5 or 10 years (Stromberg et al. 1997).

The extraordinarily wet spring of 2010 in southwest New Mexico provides an example of conditions conducive to cottonwood recruitment. In the upper portion of the Cliff-Gila Valley, Soles (2013) identified and mapped a band of cottonwood seedlings, 10-35 cm tall, in June and July 2011. Due to their size, seedlings were determined to be at least a year old (Braatne et al. 1996), with recruitment having occurred in 2010. Cottonwood seeds were dispersed between about April 21 and May 25, 2010 (Soles, pers. comm.).

Heavy snowpack in the upper watershed in the winter of 2009-2010 generated one peak event of nearly 8,000 cfs in January 2010, and sustained elevated rates of streamflow (ca. 300-800 cfs) through mid-May 2010. Rates of groundwater recession on each of the three transects from May 1 through mid-June 2010 declined during the period of early seedling establishment. Rates were 8-14 mm per day.

A recruitment box model was established for sites in Arizona (Mahoney and Rood 1998). Based on 2010 groundwater data and observations of seed release, a similar model was created for the Cliff-Gila Valley (Figure 3). An extended period of snowmelt runoff in 2010 elevated groundwater levels and supported cottonwood recruitment throughout the Cliff-Gila Valley.

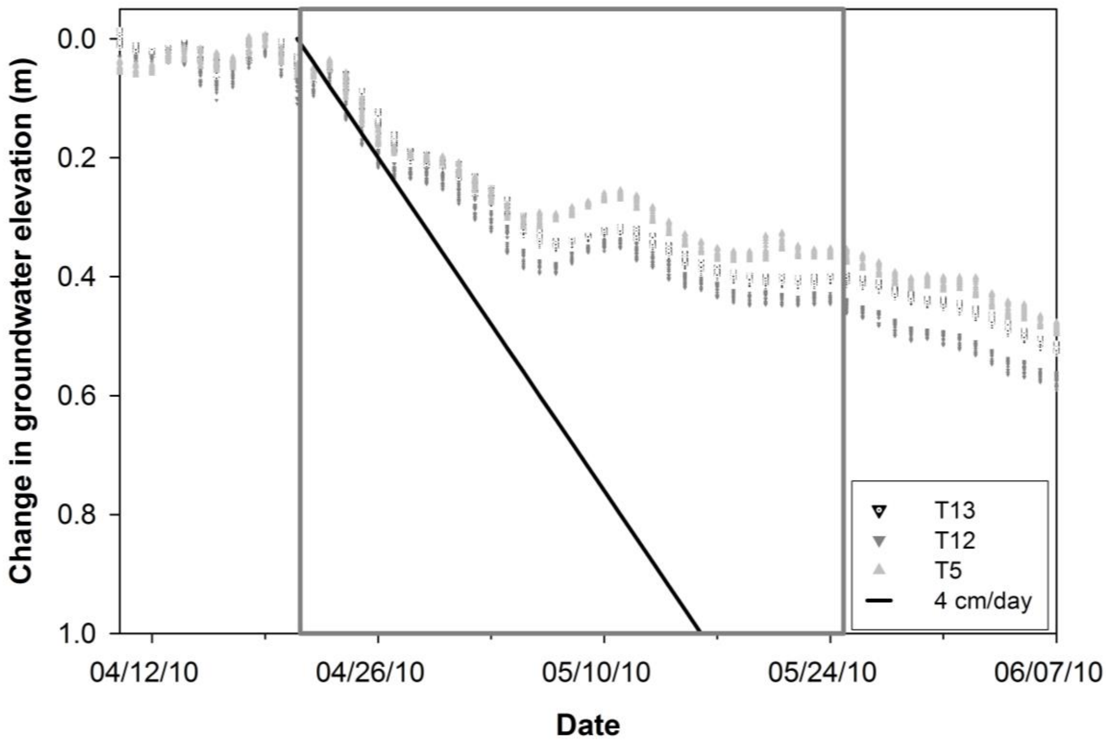

Figure 3. Change in groundwater levels at three transects (T13, T12, T5) during April to early June of 2010. Cottonwood and willow seed dispersal occurred that year April 21-May 25 (within the gray box). The black diagonal line indicates a groundwater recession rate of 4 cm per day.

Steeper declines in groundwater depth led to seedling death as the sites became too dry for survival. Seedlings received the benefit of a few days of flow in the range of 300-600 cfs in early August 2010 and 400-2,500 cfs again in August 2011. As a result of these flows, most of the seedlings persisted through at least early 2013 and were re-located in January-February 2013. However, due to more extreme declines in groundwater levels later in the spring, only a few seedlings remained viable. Seedlings cannot survive rates of decline that exceed 4 cm/day (Mahoney and Rood 1998). During September 2013, major flooding (ca. 30,000 cfs) scoured or buried all of the recruitment sites, underscoring how infrequently seedlings survive through sapling stage. Cottonwood seedlings were not found at these sites in February 2014.

Riparian Shrub

Seep-willow often co-occurs with coyote willow. Both grow from seeds or vegetatively propagate, especially following floods (Stromberg 2008). Seep-willow can produce seeds in the spring or fall (Shafroth and Beauchamp 2006). Coyote willow releases short-lived seeds in the spring.

As facultative wetland species, both shrubs make use of groundwater. On the upper San Pedro River (Leenhouts et al. 2006), these species tend to be found at sites where annual maximum depth to groundwater ranged between 1.0 and 3.5 m, similar to values for the Cliff-Gila Valley (Table 4). Since the groundwater table is high and soils are saturated for 10-14 days during the year, these areas are classified as wetlands (Kindscher et al. 2010).

Other Native Trees - Riparian

Sycamore, alder, and box elder are found within or adjacent to cottonwood and willow stands. These trees may occur as stringers, like alder; in stands, like box elder; or as isolated trees, like sycamore. Depth to groundwater for this habitat band ranges from 1.48-2.19 m.

Sycamore occurs as single trees or small stands on the floodplain (Table 2). Like cottonwood and willow, saplings are frequently located next to secondary channels. Sycamore is most productive when groundwater is less than 2 m below the soil's surface (Stromberg 2001). Along various rivers in Arizona, successful seedling establishment was associated with years that had larger winter floods (Stromberg 2002). Water stress and temperature are significant factors influencing successful germination and initial survival of sycamore, cottonwood and willow seedlings; sycamore had the smallest temperature range for germination and showed the least tolerance for water stress (Siegel and Brock 1990). Water availability has a significant impact on sycamore reproduction and vigor (Stromberg 2001). Water requirements for seedlings were greater than for older trees (Stromberg 2001).

Boxelder (*Acer negundo*) is tolerant of shade and often found in the understory of riparian forests. It requires significant moisture, is deep-rooted, and does not need to be adjacent to perennial water. It produces large amounts of large seeds. The mechanisms of germination and successful reproduction are not well understood.

Other Native Trees – Upland/Transition

Trees within this habitat are probably maintained by tapping groundwater through the sandy soils and accessing moisture from adjacent hill slope (Durkin et al. 1996). Where fine soils accumulate seedling and saplings, roots rely on capillary action for moisture, as well as precipitation. Like hackberry (*Celtis reticulate)*, Arizona walnut (*Juglans major*) tends to occur in floodplain areas far distant from the active channel. They are both deciduous species that can remain dormant in dry spring times and make extensive use of summer precipitation in addition to making use of groundwater. After a wet monsoon season and fall in 2013, numerous walnut and hackberry seedlings germinated beneath the canopy of other trees (Cooper, pers. comm.).

Two juniper species (*Juniperus monosperma* and *J. deppeana*) occur rather commonly in the riparian areas. They do not depend on groundwater and so make use of drier sites. In fact, *Juniperus monosperma* is more drought tolerant than saltcedar (Whiteman 2006). Birds spread their seeds by eating the fleshy pulp. Junipers are abundant throughout the Gila watershed due to lack of fire historically and tolerance of grazing.

Upland Shrub

Rabbitbrush (*Ericameria nauseosa)* is common on floodplain terraces (Table 2). It often forms thickets that have grasses and other forbs between clumps. It establishes by seeds produced in late fall or vegetatively propagates. Rabbitbrush is a facultative phreatophyte and can tolerate lower groundwater depths and go dormant during dry spells. Along the San Pedro River in Arizona it is often found where the groundwater is 2-4 m deep (Leenhouts et al. 2006).

Nonnative Trees

Monocultures of saltcedar (*Tamarix*) can develop in floodplains, particularly in altered hydrosystems throughout the Southwest. Along the San Pedro River in Arizona, saltcedar increased as streamflows became more intermittent and groundwater deepened and became more variable (Lite and Stromberg 2005). When surface flow was reduced to less than 75% of the year on the San Pedro, saltcedar became co-dominant with cottonwood (Lite and Stromberg 2005). Saltcedar is a facultative phreatophyte with deeper rooting ability than native species. It is often found where depth to groundwater is at least 1-1.5 m (3-5 ft) (Leenhouts et al. 2006). Unlike cottonwoods and willows, it can produce seeds continuously throughout much of the growing season (Shafroth and Beauchamp 2006).

Hydrologic Influences on Riparian Plant Diversity

Interactions between surface water, groundwater, and riparian systems support the Cliff-Gila Valley's biodiversity. Specifically, riparian vegetation patterns are closely linked to groundwater levels, and the mosaic of vegetation shapes the floodplain topography. Periodic large floods re-work the floodplain and support nutrient cycling, both of which are important to life stages of plants. Mid-size floods sustain riparian vegetation. Relationships between flows and habitat are described in greater detail in Chapter 14 of this report.

Groundwater availability and soil type are also major determinants of vegetation type and diversity (Muldavin 2011). Moist soils are essential for germination and establishment of riparian trees. In the San Pedro River in Arizona, cottonwood-willow forests had high density and high age-class diversity where the mean depth to groundwater was less than 3 m (10 ft) and did not vary seasonally or annually by more than 1 m (Lite and Stromberg 2005). These same depth-to-groundwater values are generally reported along other desert rivers in the Southwest (Stromberg et al. 1991; Shafroth et al. 1998; Shafroth et al. 2000; Horton et al. 2001), including the Cliff-Gila Valley (Table 4).

Riparian tree vigor declines in response to groundwater decline (Stromberg et al. 2004). Dry periods shape riparian vegetation, determining which species survive as seedlings, juveniles, and adults. Annual species are abundant in the floodplain of the Cliff-Gila Valley (Kindsher et al. 2008); many are dependent upon rainfall for establishment and survival.

Patterns of secondary channels that flow through the floodplain in the Cliff-Gila Valley create extreme topographic complexity and diversity. Vegetation communities across the floodplain alternate between wetland, riparian, and xeric species. Numerous habitat bands occur within small distances, creating a high proportion of ecotones relative to total floodplain area. Riparian species establish in the lower topographic areas, while vegetation on higher elevations relative to the active channel tends to be xeric species like upland shrubs, grasses, and forbs.

Impacts of CUFA Diversion

Reduced flow in Arizona streams has been studied extensively; with well-documented impacts to the active channel, secondary or abandoned channels, wetlands, floodplain forests, and floodplain terraces (Stromberg et al. 2005; Stromberg et al. 2007; Stromberg et al. 2010). When floodplain inundation is reduced by diversion, cover of obligate and facultative wetland species is reduced (Stromberg et al. 2005).

Reduction in Cottonwood Recruitment and Growth

Flooding events and extended periods of time with moist soil are essential for establishment of cottonwoods (*Populus* spp.) and other wetland-dependent species (Lytle and Merritt 2004; Shafroth et al. 2000). If the water table is significantly reduced by additional diversion or climate change, many wetland species, including trees, may not germinate or survive.

If CUFA diversion occurs, 14,000 acre-feet of water per year on average could be diverted. Changes to the hydrograph by the proposed diversion are described in Chapter 5 of this report. Diverting small to moderate flows will reduce median floodplain inundation frequency by 10% (Chapter 6, this report), with most pronounced reductions in the late winter/early spring. Consequently, the number of riparian recruitment events is also predicted to decrease (Chapter 6, this report).

Loss of Wetland Plant Communities

Reduction of flows in the 400-4,000 cfs category will considerably diminish the amount of groundwater supporting marshlands (Chapter 7, this report). Obligate wetland species, such as cattails (*Typha latifolia*) and spikerush (*Eleocharis* spp.), may be replaced by grasses and other non-wetland species that can tolerate drier conditions. On the San Pedro River in Arizona in areas where there was a lower water table, native herbaceous and graminoid wetland species were replaced with the exotic species Bermuda grass (*Cynodon dactylon*) and white sweetclover (*Melilotus alba*) (Stromberg et al. 2005). Both of these species are present along the Gila River, and thus the potential exists for these problematic exotic species to become more dominant.

Invasive Species Colonization

Saltcedar is a woody species that would likely increase in cover in the Cliff-Gila Valley if the natural hydrograph changes. Finally, there could be a cascade of other impacts on overall plant growth if stress due to water limitation occurs. Drier conditions decrease rates of leaf decomposition and nutrient cycling (Chapter 2, this report).

A more comprehensive discussion of changes to riparian habitat with CUFA diversion and climate change is found in Chapter 15, this report.

Changes in Ecosystem Functions and Services

Riparian areas provide many ecosystem functions and services that can benefit both humans and wildlife, including reducing the scouring effects of flooding, capturing sediments and nutrients, and creating habitats for other organisms (Stromberg 2008). The role of shading and evapotranspiration as a service to humans can be understood more fully when one encounters the impacts of large trees dying, where shading is reduced and less moisture is available in the local environment. Graphically, a house in a cottonwood forest is much cooler in the summer than one surrounded by no trees or dead trees. In Arizona, residents will pay more to live near a densely vegetated river bank (Bark-Hodgins et al. 2006). In addition, Soles (2003) documented that dense bands of multi-aged vegetation absorb flood energy and resist scouring (more so than levees). CUFA diversion and climate change could reduce the future ecosystem functions and services of the Gila River in the Cliff-Gila Valley.

Research Needs

Riparian Vegetation

A primary limitation for understanding riparian vegetation patterns in the Cliff-Gila Valley is the absence of a high resolution vegetation map linked to elevation data such as LiDAR imagery. People have assessed overall vegetation cover and changes in cover over time, but we are unable to characterize the species and structural diversity that exists in the riparian corridor in the Cliff-Gila Valley.

For many riparian tree species, the specific hydrological conditions, within a year and over the course of years, necessary for recruitment and survival are not known. Studies that reconstruct recruitment history by tree coring and relate this history to hydrological conditions will assist in identifying the hydrological requirements for establishment of these species. Diversion and climate change will alter the timing and shape of the snowmelt recession limb, a critical period of time for cottonwood recruitment. In addition, the summer low-flow period will be longer or drier, a period that reduces survivorship of riparian vegetation. With better data on the hydrological requirements for establishment and survival of tree species, we could better understand potential impacts.

Wetlands

Wetland mapping for the Cliff-Gila Valley is inadequate. The techniques of Muldavin et al. (2011) would be a useful model for this work. The basic question of how many hectares of wetlands occur in the Gila River is not known. Data indicate that there are quite a few areas with wetland vegetation, although not all wetland boundaries correspond to plant community boundaries. Because wetland vegetation integrates both wetland hydrology and soils, it is assumed that many of these areas could be defined as regulatory wetlands. How is the composition and abundance of wetland plant communities related to surface water levels?

Flora

A complete flora of the Cliff-Gila Valleyis needed. While there has been some documentation of plant species (Kindscher et al. 2008, Muldavin et al. 2000), a complete flora by river reach and for specific habitats has not been completed. Questions include: Which species are rare in the area? Which plant species are truly obligated to the wettest habitats and are at most risk due to dewatering of the riparian area? What is the current abundance of salt cedar and other exotic species?

A comprehensive description of research needs related to riparian vegetation is found in Appendix 13, which integrates information gaps identified by participants at the January 2014 workshop and within this chapter.

Acknowledgments

There have been many people who have helped make this manuscript a better piece of work. First there was data collection along the Gila River in 2008 that was used to look at specifically at this stream reach. Those who helped with that data collection who worked for the Kansas Biological Survey include: Hillary Loring, Quinn Long, Jennifer Moody-Weis, Gianna Short, Bernadette Kuhn, Maggie Riggs, and Sarah March; in addition Rachel Craft has provide help in data management and tables and Michael Houts for creating our map. The New Mexico Department of Game and Fish is thanked for funding that original fieldwork. State Wildlife Grant T-46 provided funding for the habitat band data. This manuscript also greatly benefited from reviews, edits and workshop comments from Ellen Soles, Dave Gori, Hira Walker, Martha Cooper, and Mary Harner.

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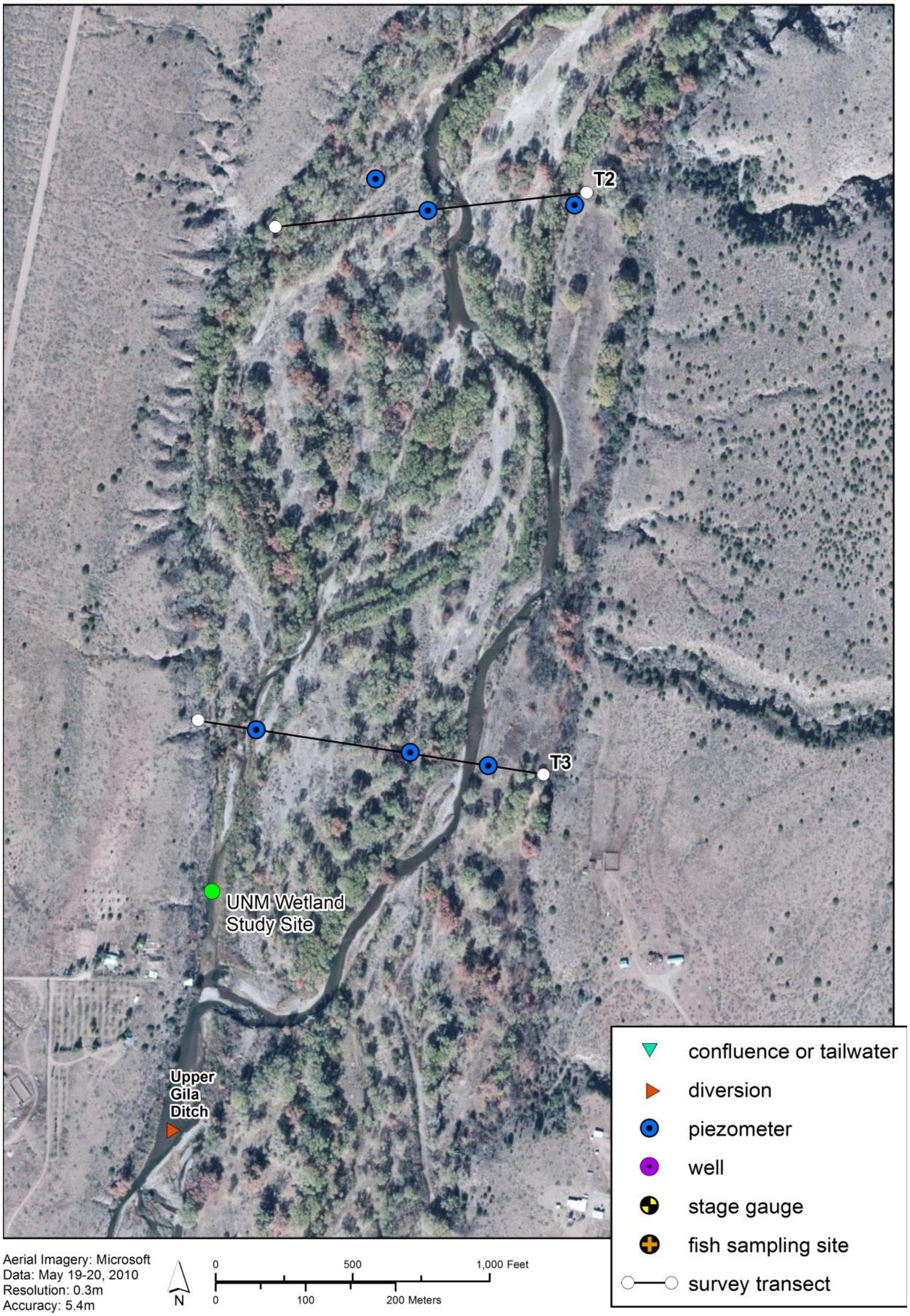
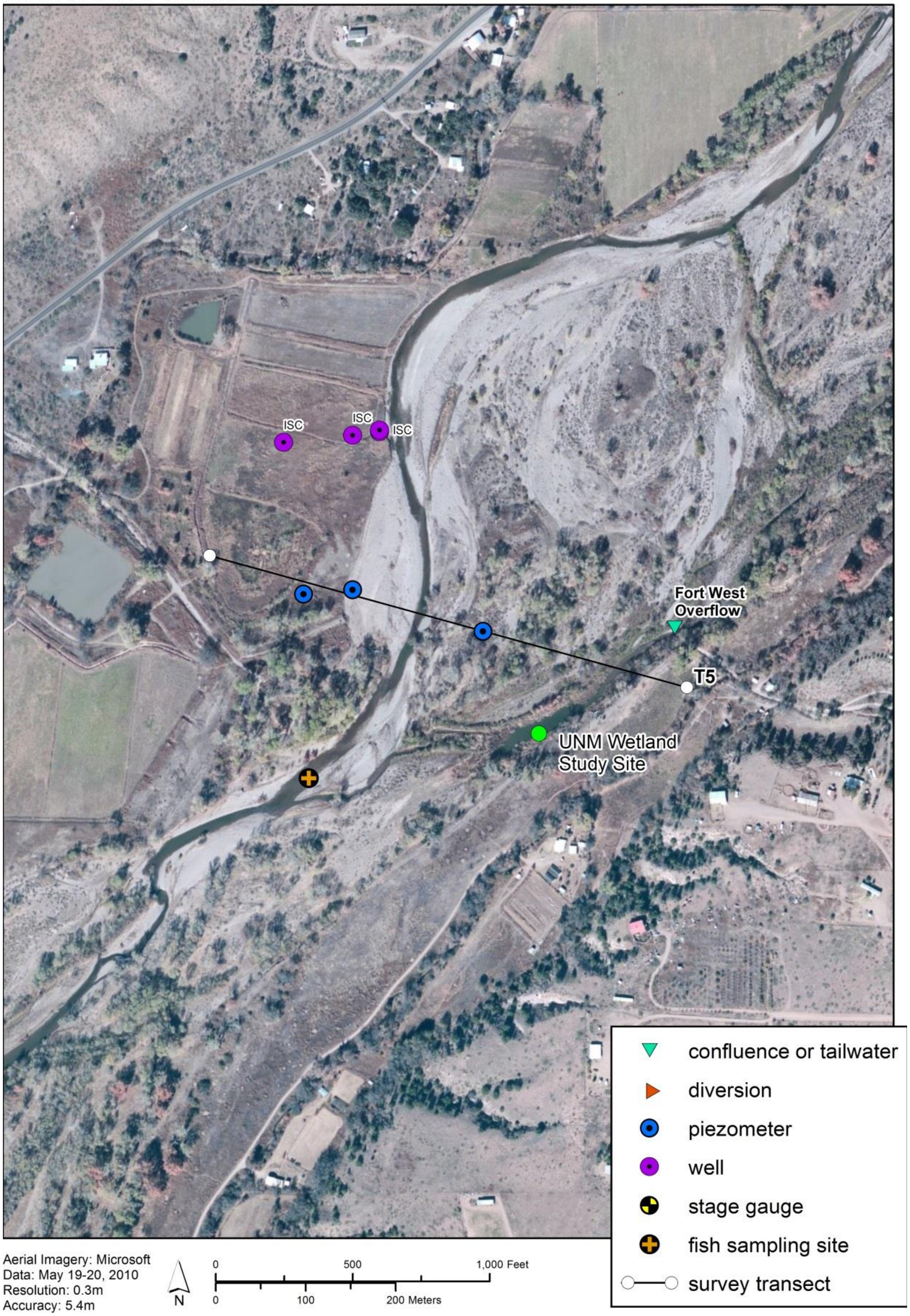
Appendix 4. Overview of Study Reaches and Monitoring Transects, Groundwater and Surface Water Interactions in the Cliff-Gila Valley.

Subreach 1: Transects 2 & 3

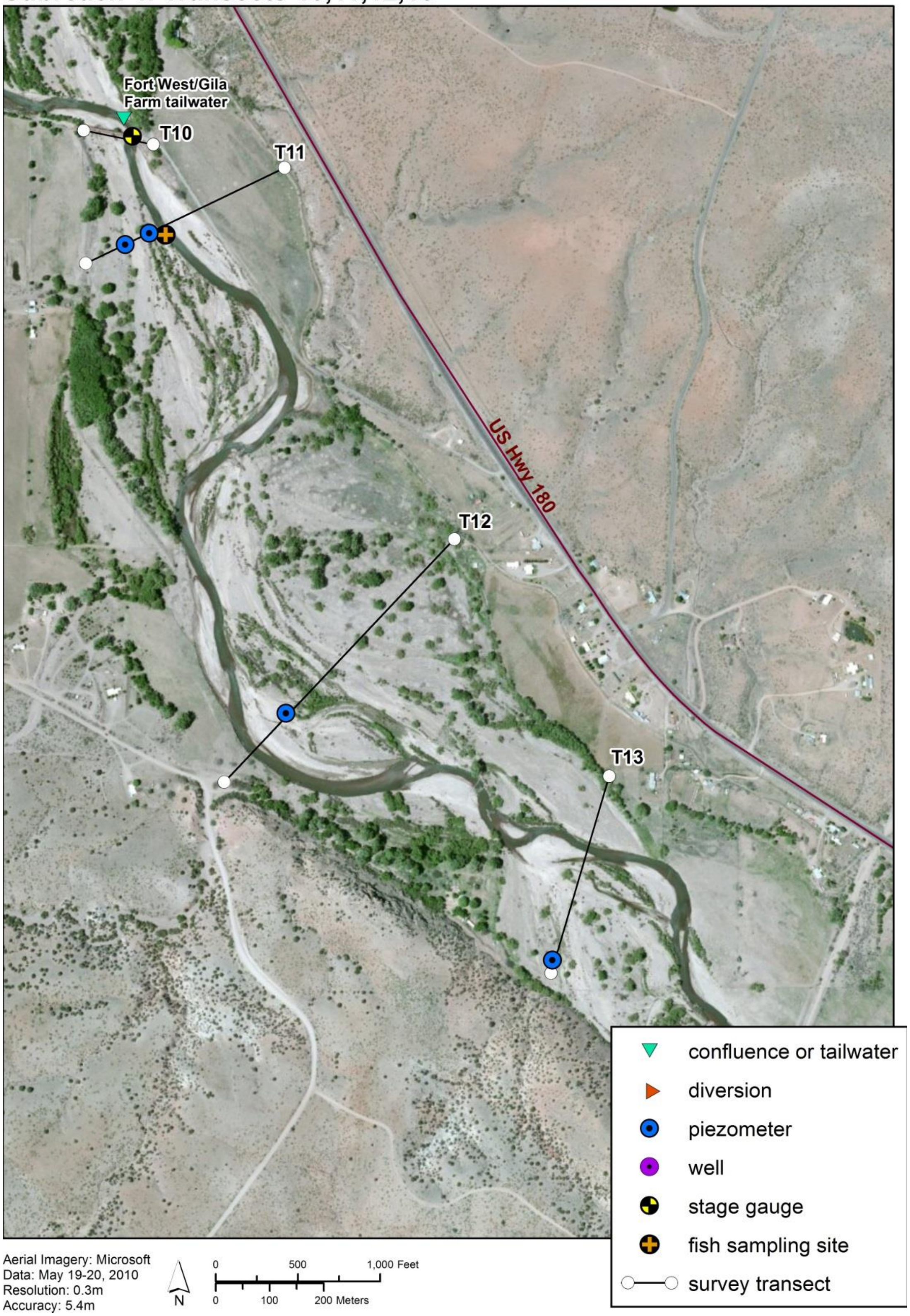


Subreach 2: Transect 5



Subreach 3: Transect 6

Subreach 4: Transects 10,11,12,13



Subreach 5: Transects 14

Appendix 13. Research Needs Identified by Workshop Participants

The following research needs were identified by participants during scheduled breakout sessions at the Silver City Workshop, January 8-9, 2014. During these sessions, participants were tasked with identifying and discussing flow-ecology relationships and the projected impacts of the CUFA diversion on the Gila River ecosystem (Chapters 14 and 15, this report). Participants felt that future studies to address critical knowledge gaps would assist in refining the streamflow needs of aquatic and riparian species and further assessing the impacts of diversion and climate change on them. Many of these studies will build on and expand ongoing research efforts in upper Gila River. The following research needs are summarized by taxonomic group: riparian vegetation; aquatic invertebrates, fish, amphibians, and reptiles; and birds and mammals. Participants did not attempt to prioritize these information needs so the numbered lists below do not represent relative priority.

Riparian Vegetation

1. The absence of a high resolution vegetation map linked to elevation data such as LiDAR imagery is a primary limitation for understanding riparian vegetation patterns in the Cliff-Gila valley. Studies have assessed overall vegetation cover and changes in cover over time, but we are unable to characterize the species composition and structural diversity that exists in the riparian corridor in the Cliff-Gila Valley. In addition, high-resolution LiDAR imagery obtained at low streamflow (< 30 cfs) is needed to better understand dynamics associated with inundation of secondary channels.
2. The majority of riparian vegetation in the Cliff-Gila Valley is found along secondary channels (Chapter 7, this report). Workshop participants wanted to know more about how flows in these channels affect groundwater and support survival of native species. The group also discussed the importance of the first short duration flow event during the monsoon or fall-winter for groundwater recharge.
3. Cottonwood regeneration is episodic in the Cliff-Gila Valley, with a widespread recruitment event estimated to occur every 5-15 years. Individual recruitment events that are much smaller in scale may occur more frequently. Timing and duration of seed release in the Cliff-Gila Valley has only occasionally been recorded; cottonwoods usually start releasing seeds before willows. The length and conditions under which seeds remain viable is unknown. In some cases, cottonwood and willow seedlings may be seen sprouting in August, as long as the seeds remain dry prior to this. This is not thought to be a major route for cottonwood/willow recruitment because monsoonal sprouting individuals may lack sufficiently deep roots to access groundwater. In addition, cottonwoods and willows reproduce asexually, in particular narrow leaf cottonwood. The relative proportion of sexual vs. asexual propagation is unknown.
4. The age structure of cottonwoods in the Cliff-Gila Valley is not known, although it would be possible to re-construct the history of recruitment events by coring trees. Without these data, the age structure of riparian forest can only be understood by size classes. Large floods, followed by extended snowmelt run off flows, support cottonwood recruitment, but the timing of these events and how they influence germination and survival is unknown. Cottonwoods are typically able to sustain up to 4 cm of groundwater retreat per day (Mahoney and Rood 1991). For good plant development, is one good year required for success or is it more variable? More information is needed.
5. Anecdotally, 2010 was a big recruitment year for cottonwood in the Cliff-Gila Valley; we could look at the hydrograph to better understand conditions favorable for recruitment. It would also be possible to assess how the CUFA diversion might have altered flows and recruitment patterns. Similarly, if the history of recruitment events is known (by coring trees), investigating hydrologic

conditions in recruitment years and up to 3 years after would assist in identifying the hydrological requirements for cottonwood germination and establishment in the Valley.

6. For many riparian tree species, we do not know the specific hydrological conditions, within a year and over the course of years, necessary for recruitment and survival.
7. The group discussed sycamore communities. Sediment/substrate requirements for sycamore recruitment are poorly understood; they seem to need scouring floods and cobble to regenerate. Older sycamores may be found on high terraces. Later successional species typically germinate beneath the canopy of mature cottonwoods, but how often successful recruitment occurs and what hydrological conditions are necessary for recruitment are not known. Again, studies that reconstruct recruitment history by tree coring and relate this history to hydrological conditions will assist in identifying the hydrological requirements for establishment of these species.
8. Late successional riparian forests composed of walnut, ash, hackberry, box elder are found throughout the Cliff-Gila Valley, in the floodplain, on terraces, and along irrigation ditches. Floodplain edges are more likely to include these species than nearer to the main channel. Groundwater relationships for these species have not been described, except in terms of their elevation relative to the river channel. For example, walnuts typically are 5.5 m from groundwater (Chapter 7, this report). Are walnuts able to germinate and establish 5.5m from groundwater, or has sediment accumulated during the life of the walnut? If so, walnut probably requires shallower groundwater levels for establishment.
9. The group discussed Julie Stromberg's work on the San Pedro River on flow and groundwater conditions that favor saltcedar success (Stromberg 1998; Stromberg et al. 1996; Lite and Stromberg 2005). Would these relationships be similar for the Gila and what effect would elevation differences between the two sites have on salt cedar invasion and success? How might altered flows and associated changes in groundwater levels affect invasive woody species such saltcedar, juniper, and tree of heaven in the Cliff-Gila Valley?
10. Herbaceous wetlands, characterized by sedges and cattails, are typically within 30-50 cm of groundwater. They often hold fine sediments, even clay. Further study is needed to determine current and historic acreage and location of wetlands in the Cliff-Gila Valley. In addition, the extent and location of floodplain grassland habitat has not been mapped.
11. Riparian tree death is poorly understood. The spatial distribution and timing of large die-off events are not well documented, nor have they been related to changes in the depth-to-groundwater or to the degree of physiological stress that individual trees experience. Field and experimental studies to better understand the factors that contribute to large die-off events are needed.
12. There are a lot of unknowns about how riparian vegetation (e.g., quality, composition, and quantity) interacts with both the aquatic and terrestrial food webs in the Cliff-Gila Valley. For example, variation in plant tissue chemistry, like carbon to nitrogen ratios, can have cascading effects on the quality of that plant matter for consumers, including insects that are key prey for birds, mammals, amphibians, and reptiles. The quality of that organic matter also exerts strong controls on its decomposition rates, which, in turn, influences nutrient release to soil and water. A study is needed to investigate how the quality, composition and quality of riparian vegetation affects nutrient cycling in aquatic and terrestrial habitats, including the abundance and composition of consumer species and their effects on higher trophic levels.

Aquatic Invertebrates, Fish, Amphibians, and Reptiles

1. Large floods can reduce the density of bullfrogs in off-channel and main channel aquatic habitats. However, systematic observations of this phenomenon have not been made in the Cliff-Gila Valley or in other Southwest streams. A study is needed to quantify the effects of flood

magnitude, duration, and seasonality on bullfrog densities in different aquatic habitats in the Valley.

2. Knowledge of the distribution, abundance, and diversity of aquatic invertebrates is limited for the Cliff-Gila Valley. The New Mexico Environment Department sampled four sites in the Valley sporadically between 1987 and 2007as part of the Benthic Macroinvertebrate & Bioassessment Program; invertebrates were identified to the family level. The relatively small number of samples and variability in when sampling occurred preclude any spatial or temporal analyses of community structure. A detailed, multi-year study is needed to characterize the abundance, seasonality and diversity of aquatic invertebrate species in main channel and off-channel habitats. In addition, an understanding of how streamflow magnitude, duration, frequency, and seasonality affect lentic and lotic invertebrate communities in the Valley is needed.
3. Peak flows during the snowmelt-runoff period and the ensuing recession limb are important for cleansing cobble substrates in riffles that loach minnow use for spawning and as larval (nursery) habitat. However, the incipient motion conditions and sheer stress needed to mobilize silt and fine sediments from these habitats, and how these physical parameters are related to flow magnitude, are not quantitatively known for the Valley. With LiDAR imagery obtained at low streamflow levels (20 cfs), these incipient motion conditions can be modeled through an extension of the SRH-2D hydrodynamic model developed for this project (Chapter 6, this report). The model can also be used to estimate the incipient motion conditions and flows needed to cleanse ash and wildfire debris from these habitats. Finally, the physical characteristics (e.g. depth, water velocity) of habitats used for spawning and by larvae, juvenile and adult loach minnow are known (Chapter 10, this report). With this information, the expanded SRH-2D model can be used to estimate the amount of available habitat for each loach minnow life-stage as a function of streamflow magnitude. Similar analyses by life-stage can be performed for spikedace and other native fish in the Cliff-Gila Valley, together providing critical information on how altered flows due to diversion may affect the distribution and abundance of habitats required by native fish.
4. Native fish species spawn in the spring following peak snowmelt flows but may spawn a second time during the monsoon-early fall period. Little is known about this secondary spawning including the influence of monsoon flood pulses (e.g., magnitude and duration of flows) in triggering spawning; which species are capable of secondary spawning and to what extent, and the predictability of secondary spawning given the appropriate streamflow cues.
5. Water temperature is known to be an important determinant of feeding rates, growth, and survivorship of larval native fish. However, the effect of rapid changes in water temperature on larval fish rearing that would result from abrupt streamflow declines due to CUFA diversion is not known. Better data on the relationship between air and water temperatures as a function of streamflow volume are needed for the Cliff-Gila Valley as well as quantitative site-specific information on how changes in water temperature affect larval fish rearing and invertebrate populations.
6. Genetic data indicate that native fish disperse up and downstream (Chapter 10, this report), however, when and how far different native and nonnative species move during dispersal is not known.
7. Alluvial groundwater inflow into the main channel influences surface water temperature because groundwater is typically cooler than surface water. A study is needed to better understand how these hyporheic flows affect temperature heterogeneity across aquatic habitats in the main channel and how native and non-native fish respond behaviorally to this heterogeneity.
8. Little is known about how native and nonnative fish use off-channel aquatic habitats in the Cliff-Gila Valley and the extent of this habitat over time. A quantitative study is needed to investigate how native fish by life stage use off-channel aquatic habitats and how reduced inundation and

shrinking of off-channel habitats affect them; similar studies are needed for amphibians and aquatic invertebrates in the Valley to quantitatively assess the impacts of reduced inundation (and hydroperiod) on these off-channel biotic communities.

Birds and Mammals

1. It is not known whether there is a frequency of large floods that when exceeded results in a long-term loss of cover or structural diversity of riparian vegetation. A related uncertainty is whether there is a minimum stem density or cover of herbaceous and woody riparian vegetation needed to withstand the scouring effects of large floods. A study is needed to quantify how flood magnitude and frequency affects the survival of riparian vegetation as a function of species composition, size (i.e. stem diameter), stem density, and patch size. Field observations from recent Gila River flood events may provide some information relevant to this study.
2. It is not known whether birds and mammals require minimum vegetation patch sizes, below which the patch becomes unsuitable as habitat. A study is needed to quantify minimum vegetation patch size requirements for selected birds and mammals in the Cliff-Gila Valley.
3. It is not known how the distribution and abundance of birds and mammals by life stage are related to variation in groundwater depth, temperature, humidity levels, and soil moisture in riparian habitats in the Valley. A study is needed to evaluate these relationships for selected bird and mammal species.
4. Flow alteration affects the seasonal availability of aquatic and terrestrial invertebrates (i.e. abundances, composition, and distribution). However, participants felt that additional discussion was needed on how flow alteration under Scenario 1 (CUFA diversion with 150 cfs minimum bypass) would affect the seasonal interactions between aquatic and terrestrial invertebrates and birds and mammals. These interactions are complex and would likely affect the survivorship, reproductive success, and population dynamics of bird and mammal species differentially.
5. Dam-building by beaver in the Cliff-Gila Valley has decreased over the last 120+ years. It is not known how the reduced abundance of beaver dams impacts hydrology in the Valley. A multi-river comparative study is needed to better understand the factors (e.g., ecological, geomorphological, and hydrological) that contribute to dam-building behavior by beaver and how changes in behavior may affect hydrology in the Valley.
6. It is not known what role the riparian corridor in the upper Gila River and Cliff-Gila Valley plays as a source or sink habitat for bird and mammal populations regionally. It is suggested that a study be conducted to determine the relative importance of these areas to regional populations for selected bird and mammal species.
7. Low streamflow periods can cause stress for some bird and mammals. It is not known, however, whether foraging success of some birds and mammals increase because food resources (e.g., aquatic invertebrates) become concentrated as the areal extent of surface water decreases. A study is needed evaluate the impacts to birds and mammals from decreases in areal extent of surface water.
8. It is not know to what extent streamflows can be altered and still maintain the vigor of the riparian forest mosaic, upon which migratory bird populations depend. A study is needed to quantify how streamflow variation and changes in groundwater levels affect vigor of riparian forest mosaic.
9. It is not known how intermittent or perennial reaches of the Gila River correspond to biodiversity (species richness). Also, it is not known how seasonal shifts correspond to biodiversity. It is suggested that a study be conducted to evaluate whether and how streamflow and seasonal shifts impact biodiversity in the Cliff-Gila Valley.

10. Both the CUFA diversion and climate change have the potential to dramatically alter the streamflow regime of the Gila River. These changes will likely result in earlier, diminished snowmelt runoff, longer low-streamflow periods and perhaps greater monsoon streamflows. Species endemic to the Cliff-Gila Valley have evolved under the previous flow-regime, which include multi-decadal scale fluctuations in precipitation. It is not known how projected changes to the Gila River's streamflow regime will impact life cycles of key species, especially with respect to shifts in streamflow timing relative to species life stages. A study is needed to evaluate the potential impact to species' life stages in the Cliff-Gila Valley from projected changes in streamflow timing.

References

Full citations for references cited in this Appendix can be found in Chapters 7 and 8, this report.