

Middle Rincon Creek

Water Requirements for Bottomland Vegetation of Middle Rincon Creek and Potential Threats to Water Availability

A Study in Support of an Application for Permit to Appropriate Public Water of Arizona, Instream Flow Maintenance, Middle Reach of Rincon Creek, Saguaro National Park



Mark Briggs
Restoration Ecologist

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An Overview of Middle Rincon Creek's Channel Morphology, Streamflow, Pool System and Bottomland Plant Community Characteristics

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Mark Briggs

Mark Briggs is a restoration ecologist who works on a variety of monitoring, research, and restoration efforts throughout the southwestern United States and Northern Mexico. He has worked on a variety of rivers, including the Santa Cruz River, San Pedro River, Little Colorado River, Colorado River. He is currently with the World Wildlife Fund Chihuahuan Desert Program working on hydrologic issues related to the Rio Grande.

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EXECUTIVE SUMMARY

On December 10, 2002, NPS filed a water-right application with the State of Arizona for instream flow maintenance to preserve and protect the water resources of the reach of Rincon Creek that passes through Saguaro National Park East. NPS requested an annual total volume of 1,210 acre-feet (1,492,513 m³). The overall goal of this study was to characterize middle Rincon Creek's bottomland plant community, hydrology, pool systems, and channel morphology, providing the biophysical context on which to determine water needs for bottomland vegetation as well as identifying potential threats to water availability.

Middle Rincon Creek's bottomland plant community is rich, diverse, and rare. Almost every major low elevation riparian deciduous tree can be found along middle Rincon Creek, including sycamore (*Platanus wrightii*), walnut (*Juglans major*), cottonwood (*Populus fremontii*), willow (*Salix gooddingii*), ash (*Fraxinus velutina*), mesquite (*Prosopis velutina*), netleaf hackberry (*Celtis reticulata*). During wet periods when streamflow persists for extended periods of time, reeds, sedges, rushes establish along the channel bed in dense clusters.

The pools along middle Rincon Creek are important because of their ability to capture and hold water for long periods of time following the cessation of streamflow. In the semi-arid environment of the southwestern U.S., such attributes are critical and provide , sources of moisture for many flora and fauna. Although the distribution and number of pools along middle Rincon Creek will vary over time, it appears that pool morphology is a general characteristic that can be applied to middle Rincon Creek over the long-term.

Results of channel morphologic surveys conducted following a high magnitude, statistically rare flood event in July 2006 revealed that, although that morphologic characteristics of some pools was altered considerably (one pool was removed almost completely), other pools maintained the morphologic traits that allow them to hold surface water for considerable amounts of time following the cessation of streamflow. In other words, middle Rincon Creek's pool system appears not to be a fleeting manifestation of short-term geomorphologic processes that just happened to coincide with the period of study.

Of particular importance for riparian and wetland plant community is the need to maintain the near-surface soil saturation zone at elevations suitable for shallow-rooted riparian and emergent wetland plants. For obligate riparian deciduous plants like cottonwood and willow, this means that the saturated zone of the soil profile cannot drop more than nine feet (two meters) below the soil surface during May and June.

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CHAPTER I. INTRODUCTION

THE WATER RIGHT APPLICATION

On December 10, 2002, the National Park Service filed a water-right application with the Arizona Department of Water Resources (ADWR) for instream flow maintenance to preserve and protect the water resources of the reach of Rincon Creek that passes through Saguaro National Park East (Fig. 1). Henceforth, this reach is referred to as 'middle Rincon Creek' or generally as 'the study reach.'

Saguaro National Park (SAGU) is located in southern Arizona and consists of two parts: an east district and a west district, separated by the burgeoning metropolis of Tucson. The eastern district of the park is known as the Rincon Mountain District (RMD) and was established as a national monument by Presidential Proclamation No. 2032 on March 1, 1933. Middle Rincon Creek is located on land that was added to RMD in 1991 (June 19, 1991, legislation (PL 102-61)), increasing the area managed by RMD by 4,111 acres (1,664 ha) along the southwestern part of its southern boundary. The additional acreage is referred to as the expansion area.

The NPS was established "to conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations." (16 USC 1) Thus the NPS seeks "perpetuate surface waters and groundwaters as integral components of park aquatic and terrestrial ecosystems." Particularly with regard to protecting surface and groundwater, NPS intends to: "consider all available [legal] authorities on a case-by-case basis and will pursue those that are the most appropriate to protect water-related resources in parks." (National Park Service, 2006, p. 50)

An Overview of Middle Rincon Creek's Channel Morphologic, Streamflow, Pool System and Bottomland Plant Community Characteristics

Briggs

11/19/2008

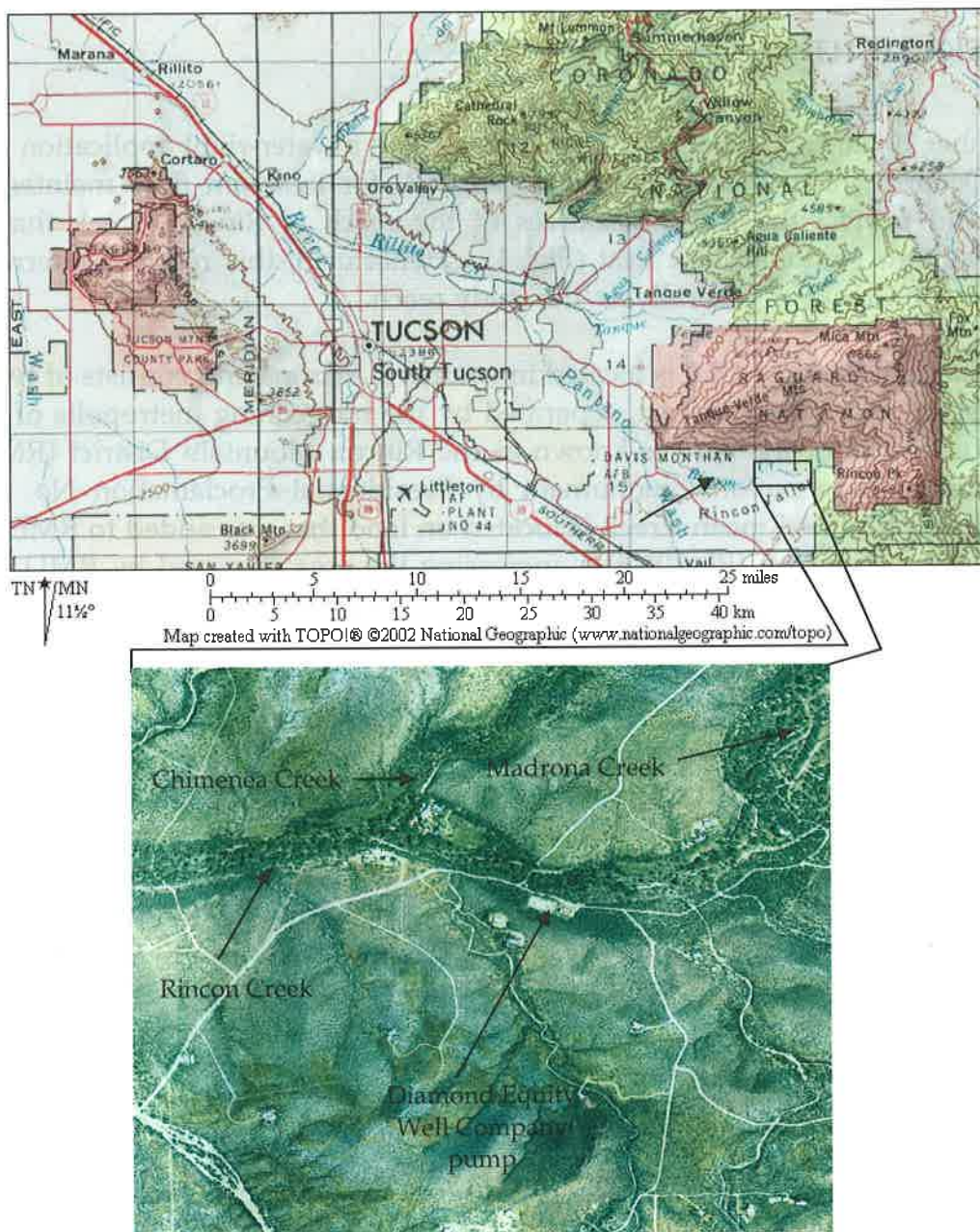


Figure 1. Topography map and aerial photograph showing middle Rincon Creek in the context of the City of Tucson and the protected areas that surround it. Map does not show the Rincon Mountain District Expansion Area, which was included in the Rincon Mountain District in the 1990s and encompasses middle Rincon Creek.

The legislation that provided for the inclusion of the 'expansion area,' noted an outstanding corridor of large Arizona sycamores and cottonwoods (along Rincon Creek) that provide habitat for reptiles, mammals, and birds. Public Law 103-364, dated October 14, 1994), designated the monument as a national park, which signifies the importance Congress placed on preserving and protecting the natural resources of Rincon Creek.

As the National Park Service's mission is to protect and preserve the biologic communities within its boundaries, a main focus of this investigation is to collect and analyze biologic information for describing the relationship between selected biological resources and the quantity of water that these resources need to be viable in the long-term.

OVERALL STUDY OBJECTIVES

The overall goal of this study is to characterize middle Rincon Creek's bottomland plant community, hydrology, pool systems, and channel morphology, to provide the biophysical context on which to determine water requirements for the bottomland plant community as well as identify potential threats to the water availability for the community

Integrity implies an unimpaired condition. A system that is unimpaired is one that has the ability to support and maintain a balanced, integrated, adaptive biological system that has the full range of species, and assemblages, and processes expected for that particular habitat in a given region (Karr 1996). An inherent part of this definition is the concept that an unimpaired system is one where the physical and chemical processes are in place to maintain the system's native biota in the long-term. The great challenge is one of determining when a system goes from being unimpaired to being impaired. In many instances, we simply do not have the knowledge, data, even anecdotal information to adequately describe ecological conditions prior to human impacts.

Middle Rincon Creek likely has already been influenced by a variety of human-related impacts that have affected its biological integrity to some extent (e.g., grazing prior to the establishment of SAGU affecting sediment and water runoff which, in turn, influenced channel morphology). The creek is not impounded, much of the creek's upper watershed is protected from grazing and urbanization, and current groundwater withdrawals are probably not affecting its hydrologic condition.

This study aims to accomplish five specific objectives:

- 1) Characterize the extent and distribution of middle Rincon Creek's bottomland plant associations in context of the morphologic surfaces on which they occur;
- 2) Characterize middle Rincon Creek's channel morphology and develop stage-discharge estimates for selected channel morphologic surfaces of interest;
- 3) Analyze Rincon Creek's long-term hydrologic record characterizing it with regard to annual, monthly, seasonal, and three-day means;
- 4) Characterize middle Rincon Creek's pool system and provide an overview of the flow characteristics required to maintain threshold pool water levels for biota.
- 5) Identify potential threats to the availability of water for bottomland vegetation.

Biological resources selected for inclusion in this investigation are those that are (1) directly dependent on surface water or near-surface groundwater for at least some phase of their life cycle; and (2) sensitive to changes in hydrology (i.e., decreased groundwater elevations, diminished sub-flow, decreased pool elevations, and/or altered frequency or duration of inundation). These include emergent plants (e.g., *Typha*, *Eleocharis*, *Juncus*, *Scirpus*), and deciduous riparian trees (e.g., *Populus fremontii* and *Salix gooddingii*).

MIDDLE RINCON CREEK –AN OVERVIEW

Rincon Creek lies within the Santa Cruz River basin on the eastern fringes of the City of Tucson. The headwaters of Rincon Creek lie in the Rincon Mountains of Saguaro National Park (SAGU) and Coronado National Forest. The stream leaves SAGU and flows through private land before reentering the park in the expansion area. The creek forms part of the southern boundary of the expansion area. The area includes the region underlain by alluvium in the floodplain of the stream. The location of the reach included in the application lies within the NW ¼ of Section 16 and the N½ of Section 17 in T. 15 S., R. 17 E., Gila and Salt River Meridian.

The climate in the Tucson area is classified as semi-arid with an average annual precipitation of about 13 inches a year, which occurs for the most part during the summer monsoon season (July – September) and the winter months December through February. With the exception of a few mountain streams, streamflow in the Santa Cruz River basin is not abundant and typically occurs only during the two “wet” seasons and where groundwater seeps into stream channels or issues from springs.

The reach of Rincon Creek that is the focus of this study is located within the expansion area of Saguaro National Park and is defined as the reach between the confluence of Rincon Creek with Chiminea creek to where Rincon Creek exits SAGU one and one-half miles downstream (Fig. 1). Moving top to bottom along hierarchical levels of channel classification and associated spatial scales, middle Rincon Creek lies within the geomorphic province of the Santa Cruz River basin, reflecting similar hydrologic, erosional, and tectonic processes to lands bounded by this geomorphic province. The Santa Cruz has its headwaters in the high intermontane grasslands of the San Rafael Valley to the east of Patagonia between the Canelo Hills to the east and the Patagonia Mountains to the west. It flows southward into Mexico and turns westward, and reenters the United States just to the east of Nogales. Between Nogales and Tucson the river valley is flanked by the Patagonia and Santa Rita Mountains on the east and the Tumacacori and Sierrita Mountains on the west.

At the catchment scale, middle Rincon Creek lies within the Rincon Creek watershed. At the downstream end of middle Rincon Creek (i.e., downstream end of the study reach), the contributing area of the watershed is approximately 44.8 square miles (116 Km²) (USGS gauge 09485000 Rincon Creek near Tucson, AZ). The valley segment that middle Rincon Creek passes through the pediment of the western flank of the Rincon Mountains..

Much of the Santa Cruz River basin, including Rincon Creek, lies within a transition zone between temperate and tropical latitudes, which contributes to distinct seasonal precipitation and streamflow (Webb and Betancourt 1992). Thus, Rincon Creek is seasonally bimodal, with flow occurring during summer convectional storms and as a result of winter/spring runoff from frontal storms and snowmelt. The mean annual precipitation for the Rincon Creek area is approximately 43 cm. The wettest months occur between July and October, with an average rainfall of 16.2 cm.

Middle Rincon Creek supports one of the few remaining riparian forests in SAGU. Rincon Creek's surface flow, in general, and its riparian resources, in particular, are key factors that led NPS to file the water right application. Riparian areas are characterized by high diversity in both plant and wildlife species, with high endemism (Youngblood et al. (1985); Spear and Mullins (1987); Hubbard (1977)). The riparian and aquatic ecosystems (including wetlands and associated wildlife) depend on the intermittent streamflow of the creek and the occurrence of shallow groundwater.

CHAPTER II. MIDDLE RINCON CREEK'S BOTTOMLAND PLANT COMMUNITY

OVERVIEW AND OBJECTIVE

A brief hike along the middle Rincon Creek channel reveals how unusual this area is botanically. Many low elevation riparian deciduous tree can be found there. Large sycamore (*Platanus wrightii*) and walnut (*Juglans major*) are established in the channel and on floodplain surfaces. Cottonwood (*Populus fremontii*) and willow (*Salix gooddingii*) occur in scattered patches, and ash (*Fraxinus velutina*), mesquite (*Prosopis velutina*), netleaf hackberry (*Celtis reticulata*) dominate throughout. During rainy periods, when channel flow persists for extended periods of time, reeds, sedges, rushes establish and persist until surface moisture dries which, around the fringes of middle Rincon Creek's pools, may be months following the cessation of streamflow.

The riparian plants that are found in the middle Rincon Creek bottomland environment possess numerous morphologic, physiologic, and reproductive adaptations that allow them to establish and survive on so-called 'safe sites.' Safe sites are areas in the bottomland environment that have appropriate conditions for germination (with regard to water and oxygen), offer refuge from herbivores and flooding, and provide other characteristics suitable for survival (at least until the plant is mature enough to propagate), including a soil saturation zone that does not drop below the root zone, particularly during the hot-dry summer months of May and June when the plants count on this near-surface water for their survival.

The combination of intermittent streamflow, water availability at pools, and the rich plant community makes the middle Rincon Creek bottomland environment a very rich habitat for a wide diversity of wildlife species. The bottomland plant community of middle Rincon Creek is comparable in composition and structure to other southwestern rivers (e.g., Rio San Pedro) that have been well-studied for their importance in the arid landscape. The complexity of the vegetation communities in the study area offers abundant and diverse resources including nesting locations, resting areas, and a sheltered travel corridor to other elevations that allows both daily and seasonal migrations. Multiple canopy layers offer important habitat and niches, and cavities present in mature trees and snags are utilized by birds, reptiles, and bats and other small mammals. The herbaceous understory offers additional resources for wildlife that varies in composition with changing seasons. The location of Sonoran Desert scrub communities in close proximity to the riparian corridor further increases its value, because some species such as the rufous-winged sparrow need both habitats in order to survive and flourish.

Wildlife includes both resident and transient populations. Furthermore, the corridor serves to connect neighboring populations and allow gene flow to occur between

adjacent mountain ranges, as well as providing linkages with other major travel corridors such as the upper Pantano Wash. Bats, herpetofauna, and birds have been surveyed along middle Rincon Creek as part of a Park-wide inventory (Powell *et al.*, 2003). Bird surveys of Saguaro National Park expansion area were conducted during late July and early August of 1998 to establish a baseline of avian diversity and populations (Friederici, 1998). This work was followed by a more detailed assessment of middle Rincon Creek bird communities during 2003-2004 (Powell, 2004). Bats were also inventoried to understand their populations at both units of Saguaro National Park and at Gila Cliff Dwellings National Monument. In the RMD, bat inventories took place along Rincon Creek and near Madrona Ranger Station. A general survey of herpetofauna was conducted for the entire expansion area of the Saguaro National Park East during July and August 1998 (Swann *et al.*, 2000).

Middle Rincon Creek's bottomland plant community is the focus of this study. The vegetation surveys conducted and summarized here were carried out to quantify the extent and distribution of middle Rincon Creek's bottomland plant community. Vegetation surveys focused on middle Rincon Creek's in-channel and floodplain plant communities, documenting the cover, density, and diversity of such obligate riparian plants as *Populus fremontii*, *Salix gooddingii*, as well as emergent plants such as *Juncus*, *Carex*, *Eleocharis*, and *Typha*. The focus on these particular plant species is due to (1) the high wildlife habitat values they provide (depending on surrounding biophysical conditions such as persistence of open water, diversity of channel morphologic surface characteristics) and (2) the sensitivity of these species to changes in changes in streamflow and shallow groundwater conditions.

Vegetation surveys were orientated to the morphologic characteristics of the middle Rincon Creek corridor. Vegetation plots were randomly established on like morphologic surfaces (i.e., terrace, floodplain, and in-channel surfaces such as point bars and channel islands) and collected data were grouped and then analyzed based on the surface from which the data collected. In this manner, the collected data - the diversity, demography, density, and percent cover of the plants that occur within the plots - describe not only the entire middle Rincon Creek bottomland environment in general, but how bottomland plant characteristics vary with morphologic surface. Such a channel morphologic orientation to vegetation data collection also allows the results of a stage-discharge model (Chapter 4), which provides estimates of the discharge magnitudes required to inundate channel morphologic surfaces of interest, to also be directly related to the vegetation data.

Measuring and classifying vegetation communities in relation to distinct bottomland geomorphologic surfaces has been used by several researchers, including Harris (1988), Briggs *et al.* (1996), and Hupp and Osterkamp (1996). Such an approach fits well with

the lateral distribution of vascular bottomland plants, which is typically related to well-defined valley and fluvial landforms resulting from distinct hydrogeomorphic processes (Hupp and Osterkamp 1996). Among the fluvial landforms are active channel bars, interfluvial channels, floodplain, and terrace surfaces that differ in position above the wetted channel and experience decreasing flow durations and flood frequencies. With regard to the vascular plant community, earlier serial stages are typically encountered closer to the wetted channel, with more mature individuals further away on higher elevated, less dynamic surfaces (e.g., terraces).

METHODS

Two distinct parts of the middle Rincon Creek bottomland plant community were assessed here: (1) the bottomland plant community established on terrace and floodplain surfaces and (2) the emergent plant community established in the channel. These two parts of the study are separated as the data collection methods employed differed substantially.

Bottomland Plant Community on Terrace and Floodplain Surfaces

The investigation of middle Rincon Creek's bottomland plant community was conducted in four main steps. First, middle Rincon Creek's main channel morphologic surfaces were identified in the field and mapped. Morphologic surfaces of interest included: in-channel (includes thalweg and pools), floodplain, terrace, and surfaces of greater slope that lie between the floodplain and terrace. Second, vegetation plots were established randomly within the area encompassed by each surface of interest. Third, vegetation plots (and transects) were surveyed for plant density, percent cover, and diversity; and, fourth, data were analyzed and interpreted.

Morphologic surfaces of interest and their boundaries were identified in the field and mapped using a GPS Trimble Unit. Identification of these surfaces is based on elevation above the channel bed, soil and vegetation characteristics, geologic boundaries, and abrupt changes in slope. The following definitions and descriptions were used to identify and delineate the morphologic surfaces in the field. Terraces are a valley contained aggradation form composed of unconsolidated material and are generally defined as a long, narrow, relatively level or gently inclined surface bounded along one edge by a steeper ascending slope and along the other by a steeper descending slope. Floodplains are a strip of relatively smooth land bordering a stream composed of sediment carried by the stream. The elevation of the floodplain is about the elevation of the mean annual flood, and therefore only one floodplain level can occur in a limited reach of a stream. For the most part, the transition zone between in-channel surfaces and floodplain surfaces throughout much of the middle Rincon Creek bottomland

environment consists of relatively steep channel banks that rise abruptly from the channel bed. Though narrow and steep, the transition zone encompassed large numbers of riparian deciduous trees and, for purposes of establishing the vegetation plots, transition zone surfaces were ultimately included with floodplain surfaces. Although the morphologic surfaces throughout the entire bottomland were delineated, vegetation plots could not be established in some areas due to land tenure issues.

The collected geospatial data were imported into ArcView and delineated on digital ortho-photo-quad (Fig. 2). The Five foot resolution digital orthoquadrangles (15S17E15 and 15S17E16) of middle Rincon Creek were obtained through Pima County Association of Government (PAG). Using the GPS data, the borders between each of the three surfaces were delineated, polygons were described around the entire surface area of each of the three surfaces, and vegetation plots were randomly distributed within each of the polygons.

The latitude-longitude coordinates for the vegetation plots were randomly selected by using orthoquadrants that were imported into ArcView. To establish plot locations, an overlay grid was generated in ArcView that consisted of 10 x 10 meter polygons that were completely enclosed in the floodplain or terrace surface (Fig. 3). This resulted in 216 cells for the floodplain and 475 on the terrace. These polygons were then numbered and a subset was selected randomly as start points for vegetation plots (each start point corresponding to the right, upstream corner of a 2 * 40 m plot). Each selected start point was described by UTM coordinates, which were entered into a handheld GPS unit that directed investigators to plot locations in the field. The random establishment of vegetation plots was conducted for floodplain and terrace surfaces. A different method was employed to document emergent, in-channel vegetation conditions.



Figure 2. Aerial photograph of middle Rincon Creek showing distribution vegetation plots on terrace and floodplain surfaces.

Ultimately, 18 – 2 x 50 m plots were established on terrace surfaces, and 27 vegetation plots were established on floodplain surfaces, which were expanded to include the aforementioned transition zone. Vegetation data were collected during April and June 2004. The greater number of plots used to quantify middle Rincon Creek's floodplain plant community is due to this community's greater patchiness which, in turn, is due to the higher dynamics associated with this surface relative to terrace surfaces that are inundated much less frequently.

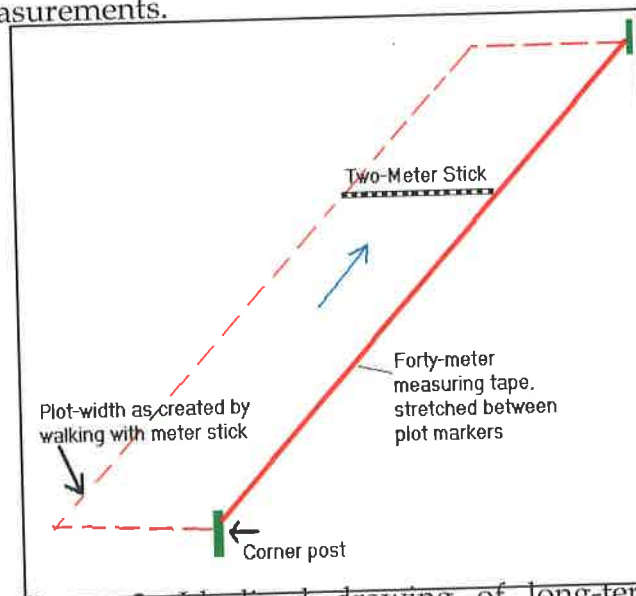
The bearing of the longitudinal axis of the plots is based on the bearing of the creek's channel in the general location of where the plot is being established. Therefore, the plot's bearing changes with location. Once the plot's longitudinal axis was established in the field, both ends of the plots were staked with rebar where such action was permitted. Floodplain plots were not always staked, to avoid the negative aesthetic effect of rebar in the channel bed. The locations of these corners were re-recorded using GPS technology to aid in re-locating the plots in the future as well as in case the monuments are removed or buried during flood events. All geospatial data were recorded in the datum NAD 83.

The methods used to measure the vegetation plots are based on procedures established by the U.S. Bureau of Land Management (Myers 1989), U.S. Forest Service (Platts et al.

1987), and monitoring programs associated with Saguaro National Park, Tucson, Arizona (Briggs et al. 1996). Plots were measured by stretching a measuring tape between the established plot corner posts. This 50-meter line defined one side of the plot. The width of the plot was defined by walking along the tape with a two-meter measuring stick held perpendicularly away from the direction of the channel. Data collected from the plots includes vegetation cover, vegetation density, diameter of the trunks of woody vegetation, and species richness.

The focus of vegetation data collection was on woody species, though several herbaceous species (e.g., *Muhlenbergia* spp., wetland species) were also measured (percent cover and diversity) or described. Both ends of the plots were staked with rebar and photographed. Even though plot coordinates were selected randomly (above) and then used to identify plot location in the field, the two corners along the northern longitudinal axis of each plot were marked again in the field using hand held GPS units. All geospatial data were recorded in the datum NAD 83.

Vegetation cover was measured using the line intercept method that records all vegetation that intercepts the meter tape that defines the east side of the plot (Avery 1975). The tape was stretched between the end posts and the distance that the tape's vertical plane that is intercepted by any plant species was measured and recorded. Multiple canopy layers are measured separately. Percent cover is calculated for all species encountered along the tape measure by dividing its total interception length by the total length of the line (50 m), and then multiplying by 100. Composition of vegetation cover was determined by assessing the relative contributions of species to the overall cover measurements.



Fifty-meter measuring tape stretched between plot corners.

Figure 3. Idealized drawing of long-term monitoring plot.

Density was recorded by walking on the side opposite the channel of the 50-m long tape measure with a two-meter stick, giving a width dimension that creates an 100-square meter plot (1,076 sq. feet). Density was measured by counting all live woody plants rooted (>50 % of total trunk width) within the monitoring plots (Fig. 3). Composition of vegetation density was determined by assessing the relative contributions of measured species to the overall density data.

For shrubs (woody plants that branch near ground level into several main stems) such as lens-scale saltbush (*Atriplex lentiformis*), individual counts are made by considering the multi-stems that intersected the ground as a single entity and then determining if the majority fell inside or outside the vegetation plot. Density is given as number of plants per hectare (pph) by multiplying the number of each species encountered in the 50-m² monitoring plots by 100, which equals the number of plants per hectare (10,000 square meters).

Species lists from each plot describe the vegetation community and species richness. Therefore, as given in the results, species richness is the total number of distinct species found in each plot. All unknown plants encountered during any monitoring event are collected, pressed, and identified using herbaria and reference materials.

In-Channel Emergent Plant Community

Owing to the intermittent flow characteristics of Rincon Creek, the extent and distribution of emergent, wetland plants along Rincon Creek is characterized by tremendous inter- and intra year variation. Nevertheless, emergent species are seen as an important component of middle Rincon Creek's bottomland plant community, providing food and shelter to a variety of wildlife species. Key emergent species include those of the vegetation families *Cyperaceae*, *Typhaceae*, and *Juncaceae*.

The patchy nature of middle Rincon Creek's emergent plant community necessitated using different sampling protocols than those used to sample woody bottomland plants. In contrast to the surveys of middle Rincon Creek's woody bottomland community, which focused on floodplain and terrace surfaces, the survey of the emergent plant community focused on the channel bed. As part of the survey, belt transects orientated perpendicular to the stream channel, were established at regular intervals beginning upstream of the confluence of Chimenea Wash. The belt transects span the entire width of the channel from the edge of floodplain surfaces on channel left to edge of floodplain surfaces on channel right. Emergent species encountered along the belt transect are identified and their cover estimated using a modified Braun-Blanquet scale.

A meter tape positioned longitudinally along the channel axis was used to establish the position of the belt transects. At twenty-meter intervals, a one-meter wide belt transect was created perpendicular to the meter tape. This belt transect varied in length, depending on the width of the channel. All of the emergent species present within the belt transect were recorded and the percent cover was estimated using a modified Braun-Blanquet scale. In this manner, the percentage of available habitat along the belt transect served as the total area and the presence of each emergent species was assigned a relative presence in accordance with the scale. Species represented within the belt transect by few individuals were assigned a rare ("r") status, species with less than five percent cover were assigned a "1," species with 5-25 percent cover a "2," species with 25-50 percent cover a "3," species with 50-75 percent cover were assigned a "4," and species with greater than 75 percent cover were a "5."

Frequency of emergent vegetation was determined by dividing the total number of points occupied by emergent vegetation by the total number of survey points. The percent cover scale and the species list helped to quantify the relative abundances and diversity of the emergent plants present. Specimens of all emergent plants were collected to verify the identity of the species using herbaria and reference materials.

All vegetation data were entered into a database managed by Saguaro National Park. In addition to all collected data, the database contains information about site visits, monitoring personnel, and raw data collected during monitoring events. The database facilitates the analysis of monitoring data by providing the means to perform multiple queries whose results can be easily described statistically. Data are queried in Access and analyzed using descriptive statistics. Data were inputted into ArcView and transposed on to orthquad aerial photographs of the middle Rincon Creek area.

RESULTS

Rincon Creek's bottomland community is described by morphologic surface: channel, floodplain, transition surfaces between channel and floodplain, and terrace. As mentioned previously, plots located on floodplain and transition surfaces were combined such that the vegetation characteristics of two main morphologic surfaces are described: terrace and floodplain (henceforth, floodplain and transition surfaces are combined and called simply floodplain). Although the riparian woodland of middle Rincon Creek differs with regard to the morphologic surface that is being considered, its overall appearance form is a complex mosaic where obligate and non-obligate species overlap and intermix. Nevertheless, the plant community of each surface can be described by its dominant species, with obligate riparian species dominating on the

lower elevated surfaces (channel and floodplain) and non-obligate species dominating higher elevated surfaces (i.e., terrace).

In this sense, the bottomland plant communities of middle Rincon Creek are typical of arid region riparian areas with regard their extent and distribution, with relatively dense, yet narrow patches of obligate riparian vegetation adjacent to the channel and paralleling the watercourse, and non-obligate riparian species becoming increasingly dominant with increasing elevation above the channel bed.

Emergent and aquatic vegetation have established along the middle Rincon Creek channel, particularly in low-lying areas (e.g., reaches dominated by pools) where water accumulates and persists for long periods following the cessation of flow. In-channel wetland species include hydrophytic sedges, rushes, and cattails of the families *Juncaceae*, *Typha*., *Cyperaceae*, and *Poaceae* as well as a variety of wetland forbs. Seven different species were recorded as part of the 2004 in-channel plant surveys. In descending order, the seven most dominant (by percent cover) species are *Juncus buforius*, *Eleocharis montana*, *Cyperus* sp., *Juncus acuminatus*, *Eleocharis* sp., *Typhus domingensis*, and *Cyperus squarrosus*.

Sixteen species were documented on middle Rincon Creek's floodplain surfaces. Floodplain surfaces are dominated by Arizona ash (*Fraxinus velutina*), with other obligate riparian trees as cottonwood (*Populus fremontii*), willow (*Salix gooddingii*), and sycamore (*Platanus wrightii*), having one-third or less the cover (Fig. 4). Dominant floodplain understory species include deer grass (*Muhlenbergia rigens*), seep willow (*Baccharis salicifolia*), and desert broom (*Baccharis sarothroides*). Species such as mesquite (*Prosopis velutina*) and Arizona ash (*Fraxinus velutina*) have a wide distribution on both floodplain and terrace surfaces (Fig. 5).

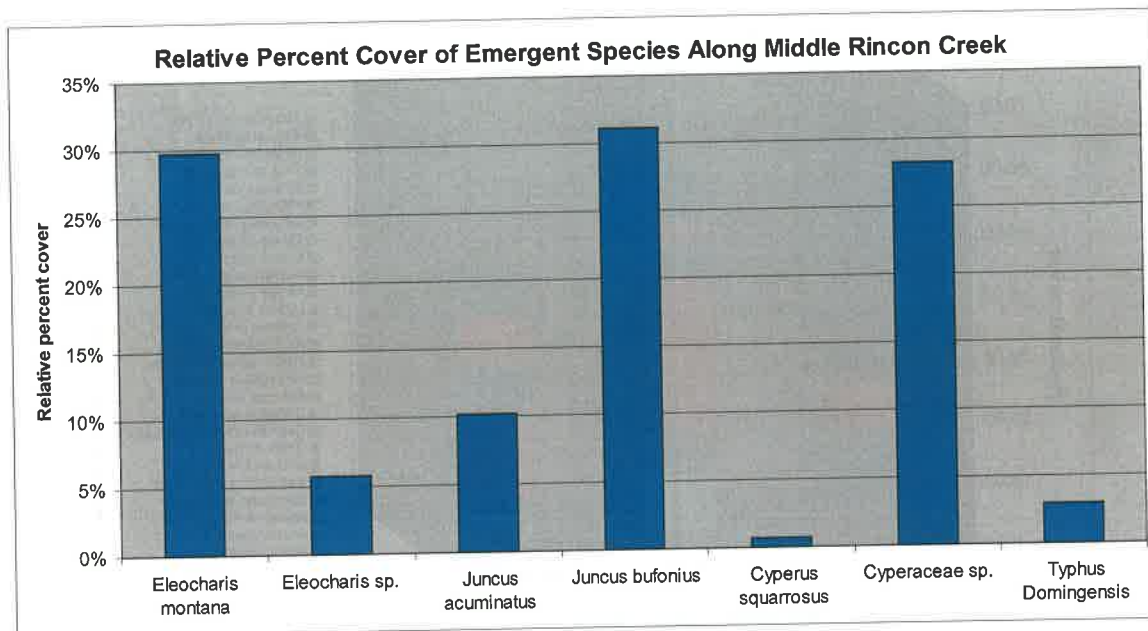


Figure 4. Percent cover of dominant wetland and emergent plants established along middle Rincon Creek's channel (2004 data).

In contrast, middle Rincon Creek's terrace surfaces are dominated by non-obligate riparian species that are adapted to drier conditions. These species include mesquite (*Prosopis velutina*), catclaw (*Acacia greggii*) and whitethorn acacia (*Acacia constricta*), wolfberry (*Lycium andersonii*), netleaf hackberry (*Celtis reticulata*), desert hackberry, desert willow (*Chilopsis linearis*), burrobush (*Hymenoclea monogyra*), graythorn (*Ziziphus obtusifolia*), desert broom (*Baccharis sarothroides*), and four-wing saltbush (*Atriplex canescens*), as well as a variety of grasses and forbs (Fig. 5).

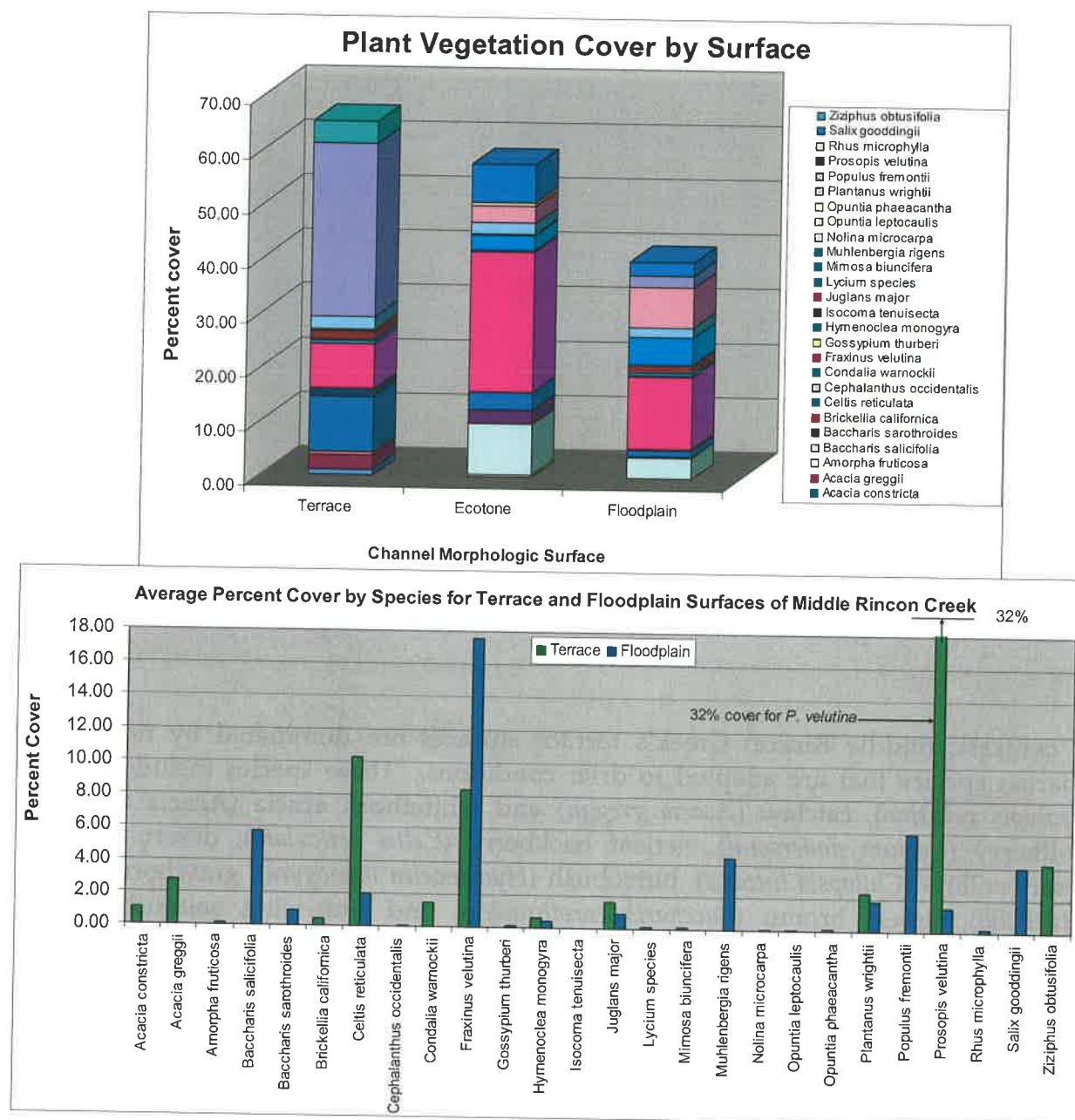


Figure 5. Average percent cover by species on both terrace and floodplain surfaces of middle Rincon Creek.

CHAPTER III. SUMMARY OF LONG-TERM STREAMFLOW DATA

OBJECTIVE

Riparian ecosystems are created, maintained, and eliminated by streamflow, and the solutes and sediments that are carried by flow. In addition to its control on geomorphic processes, the presence and absence of flow in and of itself is an important determinant on riparian habitat. Middle Rincon Creek's bottomland biotic communities are adapted to and reflect the nature of its highly dynamic streamflow characteristics. The intermittent nature of Rincon Creek's streamflow has a greater influence on determining the biotic composition, structure, and function of the creek's aquatic, wetland, and riparian ecosystems as it would if the creek were perennial (Junk et al. 1989; Mitsch and Gosselink 1993).

The most fundamental hydrologic measurement used to characterize stream ecosystems is discharge, which is the volume of water flowing through a cross-section of stream channel per unit time. When combined with slope, the amount of water moving through a channel reach gives an indication of stream power, which is essentially the ability of the stream to perform work, influencing the distribution of suspended sediment, bed material, particulate organic matter, as well as other nutrients. The distribution of these materials has a critical influence on the extent and distribution of biota.

U.S. Geological Survey streamflow gauge (09845000) is located near the lower end of creek's middle reach at 951 m (3,120 ft) above mean sea level. The USGS gauge was installed on October 1, 1952, but was operated as a partial record station between 1975 and 1989. During this period, it was operated as a crest-stage gauge, providing an annual measurement of peak discharge. From 1989, the gauge was operated as a real time gauge.

This streamflow record provides a foundation for assessing Rincon Creek's streamflow characteristics. The emphasis here is to characterize middle Rincon Creek's hydrologic regime using biologically relevant hydrologic parameters that could be influenced by such human impacts as groundwater pumping. The streamflow parameters of interest are those known to have strong influences on stream biota, including:

- Mean discharge by calendar month
- Annual maxima three-day means
- Annual minima three-day means
- Annual maxima seasonal means
- Annual minima seasonal means
- Number of zero-flow days

- Number of annual occurrences of discharge magnitudes exceeding an upper threshold (as defined by channel morphologic surface and estimated by surface area discharge relations)
- Mean duration of upper threshold occurrences

In addition to examining Rincon Creek's hydrologic record to identify relations between streamflow and bottomland biota, another principal aim was to correlate the results of the analysis of streamflow gauge data with stage-discharge relations (estimates obtained from the stage-discharge model discussed later in this report). Of particular importance in this regard is considering the recurrence intervals of the discharge magnitudes required to inundate surfaces of interest.

The study period of 2004 -2006 occurred during an extended period of drought, which had profound effects on streamflow. As a final part of reviewing the hydrologic record of Rincon Creek, streamflow conditions during this time period are compared to average flow conditions as a way of underscoring the profound effects of this recent drought period.

OVERVIEW

Middle Rincon Creek is an intermittent stream that on average experiences flow for long periods of time during the summer monsoon season and the winter storm season. The intermittent nature of Rincon Creek flow, with its inherent variability, makes the quantification of a flow for the long-term viability of its bottomland ecosystem a challenge, particularly as compared to quantifying flow needs for a perennial stream system where base flow characteristics provide a steady foundation for quantifying long-term flow needs.

Although intermittent, the hydrology of Rincon Creek has as much a strong sway in determining the biotic composition, structure, and function of its aquatic, wetland, and riparian ecosystems as it would if the creek were perennial (Junk et al. 1989; Mitsch and Gosselink 1993).

A U.S. Geological Survey streamflow gauge (USGS 09845000) is located near the lower end of creek's middle reach at 951 m (3,120 ft) above mean sea level. The USGS gauge was installed on October 1, 1952, but was operated as a partial record station between 1975 and 1989. During this period, it was operated as a crest-stage gauge, providing an annual measurement of peak discharge. However, for the remainder of the data collection period, the gauge was operated as a real time gauge that provided data for all periods that Rincon Creek experienced flow.

As the analysis of middle Rincon Creek streamflow data is restricted to data collected at one specific point (i.e., the USGS streamflow gauge), defining middle Rincon Creek's hydrologic regime is limited to one temporal and one spatial descriptor. That is, change in flow conditions at the gauge itself. However, within such boundaries lies a vast array of analysis that can be conducted that consider the five fundamental characteristics of hydrologic regimes: magnitude, timing, frequency, duration, and rate of change.

The emphasis here is to characterize middle Rincon Creek's hydrologic regime using biologically relevant hydrologic parameters that could be influenced by human impacts such as groundwater withdrawals. In the future (particularly if withdrawal rates increase substantially), this same group of hydrologic parameters can be reassessed as part of a long-term monitoring program that will evaluate the effect of withdrawals on streamflow (Richter et al. 1996).

Two parameters of streamflow are of particular interest to investigating the ecological characteristics of the middle Rincon Creek ecosystem: average (or, in some cases, median) and variability. Statistics that describe average stream flow, provide insight as to what might be expected during times of average precipitation. Average statistics include considering average annual flow volume, seasonal averages, and monthly averages, as well as shorter time periods such as seven-day and three-day means.

However, when considering average flow statistics, it is critical to keep in mind the dynamic nature of streamflow in arid and semi-arid climates. As is the case with Rincon Creek, streams throughout this part of the western U.S. can experience considerable flow one week and be completely dry the next. Therefore, as part of an analysis of streamflow data, it is critical to convey streamflow variability. In this respect, calculating such parameters as standard deviation around the mean and ranges of flow during a certain time period is also of particular interest.

It is assumed that Rincon Creek's streamflow has not been altered by any human activity, for example, groundwater withdrawals. Given that the withdrawals has thus far been small – particularly when compared to the quantity of pumping that potentially could take place – this assumption is probably sound. An analysis of streamflow data from an area where the human activities have had no measurable effect provides a basis for understanding the streamflow characteristics needed to maintain a bottomland ecosystem in the long-term. The streamflow record would not be as valuable if groundwater withdrawals already were demonstrated to have a large impact on Rincon Creek flow and its bottomland ecosystem.

What the Streamflow Record Tells Us

For the period of record, the mean discharge of Rincon Creek was 6.5 cfs (0.18 cms), with a standard deviation of 6 cfs (0.17 cms). This average discharge equates to an average annual flow volume of 4,814 acre-ft (5,937,976 m³), with a standard deviation of 4,525 acre-ft (5,565,378 m³). The high standard deviation reflects the high-low range of annual flow volumes that have occurred during the period of record. For the period of record, a low annual average flow of 0.1 cfs (0.0028 cms) was recorded during the calendar year of 1996, and high annual average discharge of 29.95 cfs (0.85 cms) during 1993, equating to low total annual volume of 70 acre-ft (86,094 m³) and a high of 21,682 acre-ft (26,667,078 m³), respectively (Fig. 6a).

A summary of Rincon Creek's peak flow history underscores the variability of flow. For the period of record, annual peak discharge also varies considerably for the period of record, with a low of 23 cfs (.65 cms) for WY 2003 and a high of nearly 14,000 cfs (estimated) for WY 2006 (Fig. 6b). Average peak flow for the period of record is 2,016 cfs (57.1 cms) with a standard deviation of 2,703 cfs (76.4 cms).

Based on the long-term record for Rincon Creek, a flow event that occurs on average once every two years has a discharge of 963 cfs (27.3 cms), while a flow with a recurrence interval of 100 years (occurs on average once every 100 years) has a magnitude of 17,600 cfs (498.4 cms) (Fisk et al. 2004) (Tables 1 and 2). A discharge of 0.07 cfs is exceeded 40% of the time, indicating that Rincon Creek is characterized by extensive periods of very low flow and no flow, underscoring the intermittent nature of Rincon Creek's hydrology (Table 3.).

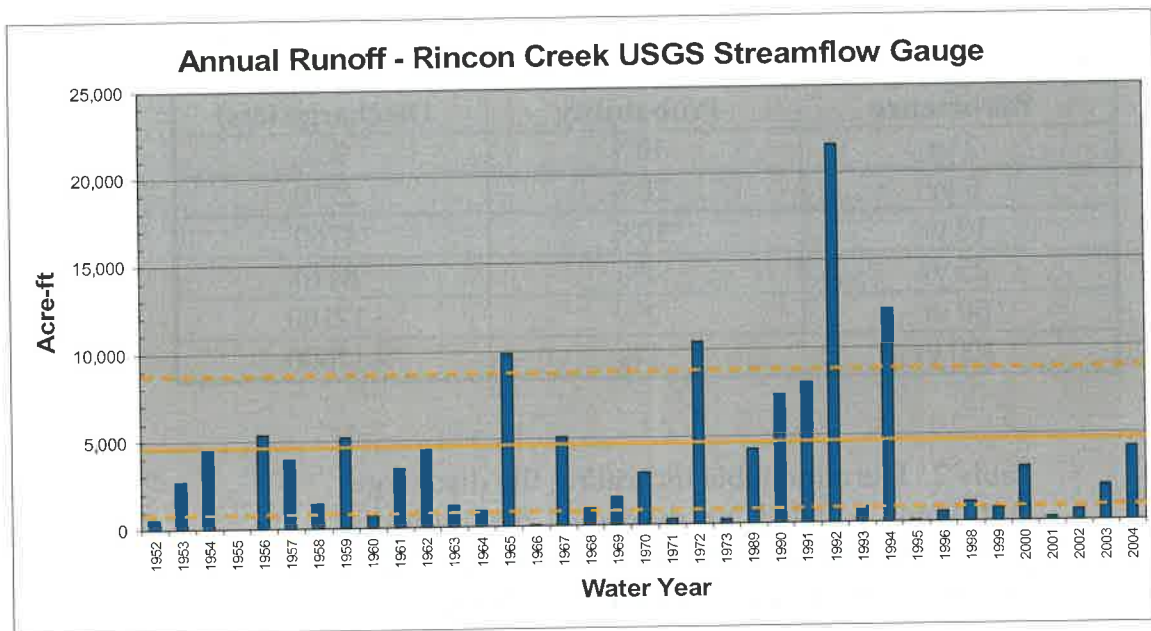


Figure 6a. Total annual runoff since 1952 (missing years 1974-1989) as recorded at the U.S. Geological Survey's Rincon Creek gauge (gauge 09485000).

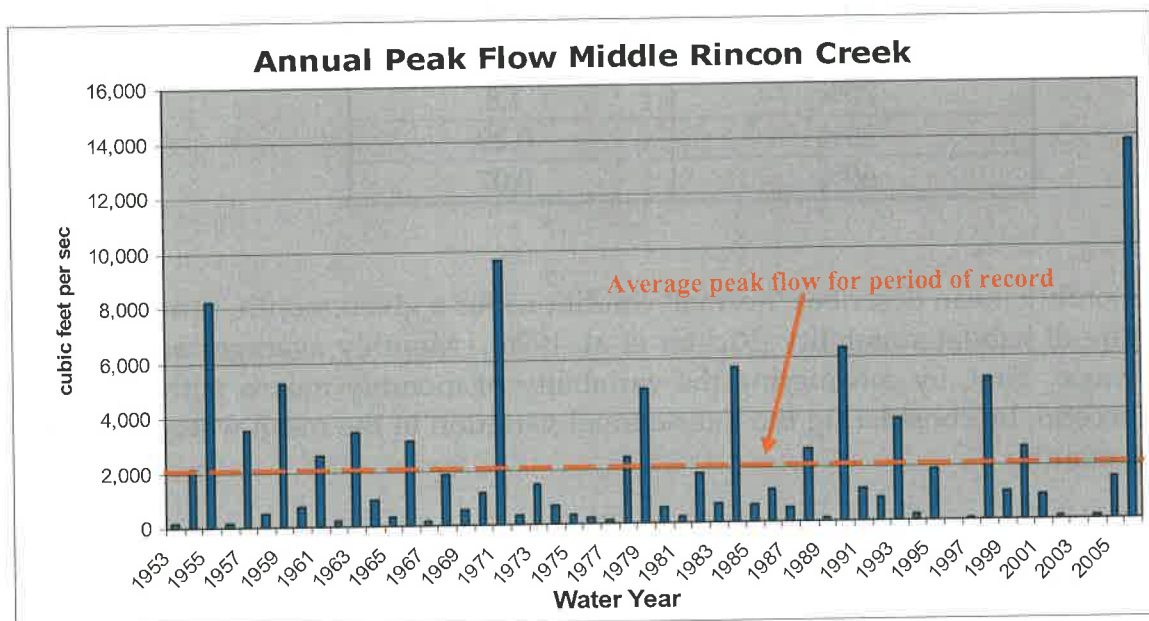


Figure 6b. Annual peak flow as recorded at U.S. Geological Survey gauge for Rincon Creek.

Table 1. Discharge magnitude and probability of instantaneous peak flow based on period of record 1953-96 (source: Fisk et al., 2004).

Recurrence	Probability	Discharge (cfs)
2 yr	50%	963
5 yr	20%	2770
10 yr	10%	4760
25 yr	4%	8410
50 yr	2%	12100
100 yr	1%	17600

Table 2. Duration table indicating the discharges that were equaled or exceeded for indicated percent of time of daily mean flow for period of record '53-'96 (source: Fisk et al., 2004).

Percent of Time	Discharge (cfs)
1%	126
5%	32
10%	12
15%	4.6
20%	1.8
30%	0.29
40%	0.07

The monthly mean describes 'normal' conditions for a given month, providing a general measure of habitat suitability (Richter et al. 1996). Monthly averages are considered in two ways. First, by considering the variability of monthly means within a given year and, second, by considering the inter-annual variation in the mean water condition for a given month.

Monthly means reflect the Sonoran Desert's biseasonal precipitation pattern, with the highest monthly average discharges occurring in the winter rainy season (December through March) and the summer 'monsoon' season (July through August); with very low flow occurring during the months of November, May, and June (Fig. 7). These patterns also vary from year to year, with some years showing little flow in winter, summer, or both seasons.

In general, the hydrograph for Rincon Creek is typical of regions with major flow contributions from mountain catchments, which are typically dominated by spring snowmelt, with peak flows occurring during that time of the year. For Rincon Creek, the highest mean monthly discharge occurs during the months of January, February, and March, with long-term averages of 15 cfs, 14 cfs, and 13 cfs, respectively. Every month of the year has experienced no-flow at least several times during the course of the 38-year streamflow record for Rincon Creek.

During this 38-year period, the month of August experiences the least no-flow occurrences (10.8% of the time) and the month of June experiences the most no-flow occurrences (at 78.9% of the time). Even the relatively wet months of January through March experience no-flow at some point during the period of record (Fig. 7). On the other extreme, many of the months – particularly the wet months of December through March, and August – have experienced wide ranges in the minimum and maximum average monthly discharges, with the month of January having the widest range with a maximum average discharge of 247.1 cfs and a minimum of zero cfs (all months experienced an average discharge of zero several times during the course of the 38-year Rincon Creek record) (Fig. 7).

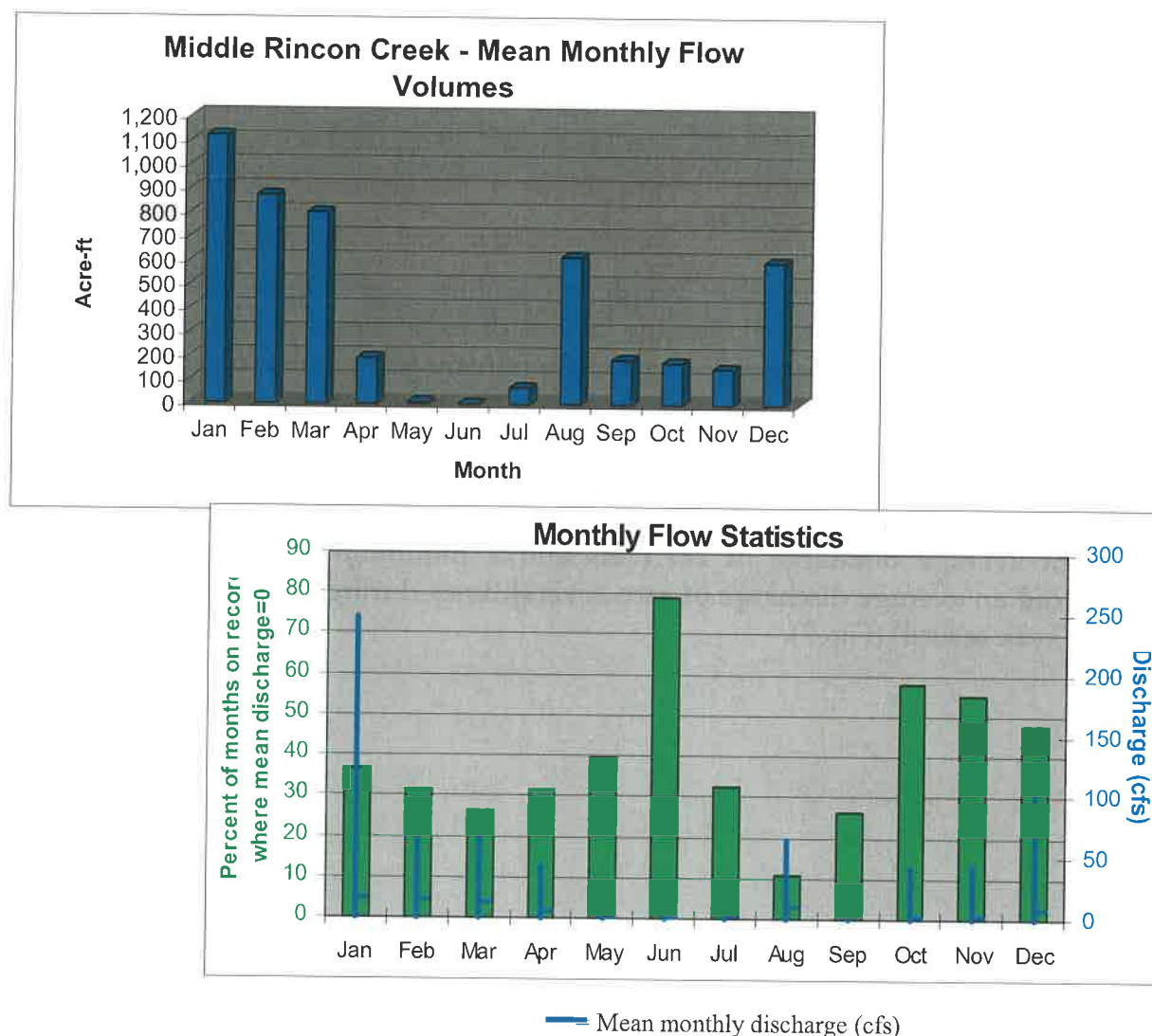


Figure 7. Summary of mean monthly average discharge (dark blue horizontal line) combined with the maximum mean monthly average for period of record (top of vertical blue line) and minimum mean monthly average for period of record (bottom of vertical blue line). The green column indicates the number of months for the period of record where the average monthly streamflow equaled zero (USGS, streamflow gauge Rincon Creek near Tucson, Arizona).

Table 3. Summary of monthly mean, standard deviation, and median of flow recorded at the U.S. Geological Survey Rincon Creek gauge.

Parameter	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec
Monthly Mean (cfs)	15.5	14.4	13.0	4.0	0.18	0.1	1.1	9.3	2.6	2.4	2.1	8.7
Std Deviation around mean	43.0	24.9	19.1	8.1	0.4	0.2	2.8	14.8	5.0	8.2	7.8	23.1
Median (cfs)	0.3	0.8	4.3	0.4	0.0	0.0	0.0	2.0	0.1	0.0	0.0	0.1

Three-Day and Seven-Day Means

Comparing long-term average three-day and seven-day means provides insights into the duration of flow over shorter time periods. A flashy system (e.g., a stream collecting runoff from a small watershed) will typically have large differences between three-day and seven-day means, while a stream characterized by more even flow characteristics (e.g., a perennial stream of a large watershed) will have only small differences. Comparing long-term average three-day and seven-day means by month provides insights as to when the differences between these two parameters are largest, improving our understanding inter-annual variability in streamflow.

For Rincon Creek, the differences between average monthly three-day and seven-day means varied from one month to the next, with the average three-day mean being greater than the seven-day mean for some months and less in others, with seasonality appearing to have little effect (Fig. 8). For example, long-term three-day means for December were larger than the seven-day mean, while the long-term average monthly three-day for January (the winter season) was over one cfs greater than the seven-day mean. Taken together, the analysis of the average monthly three-day and seven-day means indicate that, when Rincon Creek does experience flow, flow tends to last for seven days or longer. Although the ascending limb of individual flow events can be steep (i.e., major change in discharge over a short time period), the descending limb is gradual.

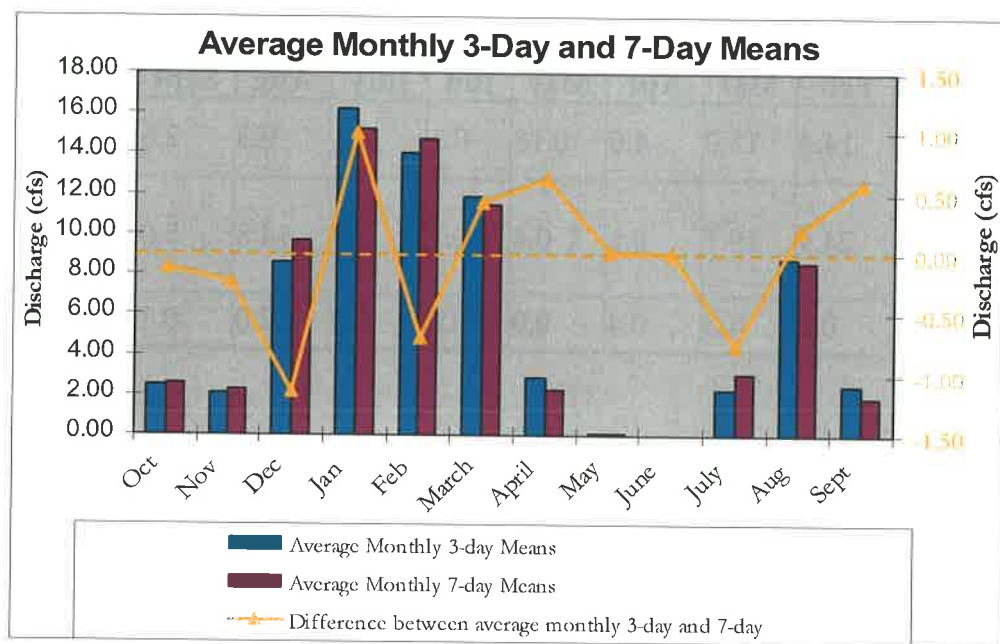


Figure 8. Bar graph summary of Rincon Creek's average monthly three-day and seven-day means, with a line graph overlay describing differences between the average monthly three-day and seven-day means.

Looking at such parameters as high three-day mean is useful for quantifying the discharges that occur over an extended period of time (i.e., in this case, over a period of three-days). Relating such discharges to channel morphology (see chapter on channel morphology) provides insights as to which bottomland surfaces are typically inundated (e.g., once a year) for extended periods of time. From both a physical and biological standpoint, extended inundation of bottomland surfaces that are inundated only once or twice a year (i.e., floodplain surfaces) is critical for a variety of reasons, including saturation of near-channel surfaces, evacuation and deposition of sediment, nutrient cycling, preparation of seedbed, and recharge of shallow groundwater, among other parameters.

For the Rincon Creek streamflow record, annual high three-day spring means vary considerably from low of zero cfs (13 years out of the 38 year record experienced no-flow springs) to high of 209 cfs, which occurred during the spring of 1973; for the 38-year record, the average high spring three-day mean is 36.7 cfs. To propagate riparian deciduous trees, prolonged spring flooding does not need to occur every year. In many southwestern bottomland areas (along streams that have not been impounded), lines of riparian deciduous demographically distinct trees can often be seen running parallel to

the channel, with the lines of trees closest to the channel being the youngest and the lines of trees furthest away typically being the oldest. The age differences between these 'lines' of trees can vary tremendously depending on a variety of factors, including channel morphologic characteristics, flood timing, duration, and magnitude, correlation between seedfall and flooding, weather conditions following flooding (too dry could desiccate floodplain soils threatening establishment of seedlings, too wet and subsequent flooding can remove them through flood scour), among other factors.

Along several reaches of the middle Rincon Creek, the channel is armored (composed of bedrock), restricting the lateral channel movement required for the establishment of these demographically different lines of trees. Nevertheless, there are distinct lines of trees in certain parts of the stream reach, with trees of 30 to 50 years ten to 40 meters (about 40 to 130 feet) away from the channel, younger trees of about 15 years positioned closer, and saplings trees of five years or more establishing on channel banks (see section of this report on bottomland plant communities) (Fig. 9). The bottomland environment on average appears to experience spring flooding of sufficient propagation magnitude every ten to 15 years.

Indeed, the streamflow record does seem to bare out this frequency, with above average high spring three-day means occurring in 1958, 1966, 1973, and several springs during the 1990s (Fig. 10).



Figure 9. Photograph of upper half of the middle Rincon Creek study reach showing some channel incision with young riparian trees (like the Arizona ash on channel left) dominating floodplain surfaces close to the channel.

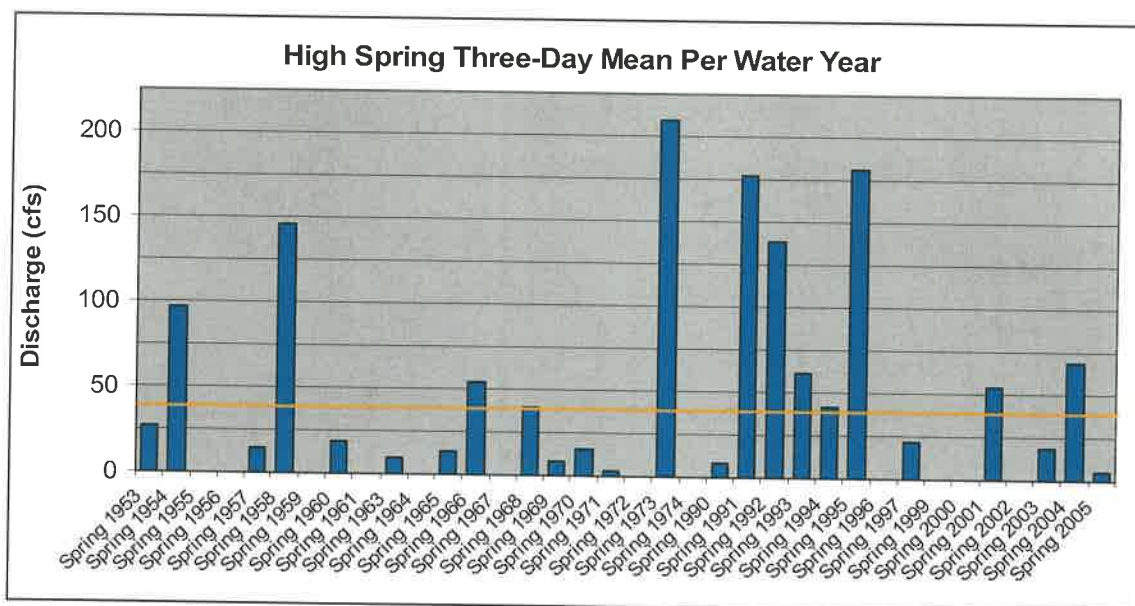


Figure 10. High average three-day mean for years 1953 – 2005 (with gap for years 1975-1990).

The Drought

Although the focus of this chapter is on the long-term streamflow record of Rincon Creek, it is important to note that the three-year period of study (2004-2006) occurred during drought conditions characterized by well-below average precipitation. Of course, drier than normal conditions can have a major impact on bottomland biological resources. Of particular concern in this regard are the studies focusing on middle Rincon Creek's herpetofauna, aquatic invertebrates, and riparian plants, all of these biological factors can respond quickly to changes in water availability by reducing their extent and distribution (either by perishing or, in the case of herpetofauna, moving to wetter environments).

During the 2004 -2006 period, annual precipitation in the Tucson Basin was well below average at 7.62 inches (19.4 cm), 9.58 inches (24.3 cm), and 11.81 inches (30 cm), respectively (National Weather Service Forecast Office, Phoenix, Arizona) (Fig. 11).

Overall, the annual streamflow volume for the 2000-05 period, as recorded at the USGS streamflow gauge, was 14.2% below the long-term average. The effect of this decline becomes more apparent when both the seasons and the number of no-flow days are taken into account. Considering the five year period of 2000-2005, average monthly runoff was considerably less for the months of December through March, which includes the principal months of winter and early spring precipitation, as well as for the months of July and September, which includes the monsoon months (Fig. 12). If it were not for the increase in streamflow, particularly during the months of October and November (due to cyclone and hurricane activity in the Pacific and Gulf of Mexico), drought conditions would probably have been more severe.

The number of no-flow days is a critical parameter to consider with regard to understanding the effect of drought on Rincon Creek streamflow as well as the related effects on middle Rincon Creek's bottomland biotic community. Rincon Creek typically experiences long periods of little or no flow. For example, the long-term percentage of no-flow days for the month of June is over 83%, while March has the smallest percentage of no-flow days at almost 32% (Fig. 13). With the exception of March and April, water years 2000 through 2004 have experienced more no-flow days. For example, flow was not recorded at all for the month of June (i.e., 100% no-flow days) during the 2000-04 period, and all of the months, when precipitation typically occurs (December through March, and July through September), show large increases in no-flow day occurrences during the 2000-04 period as compared to the long-term average.

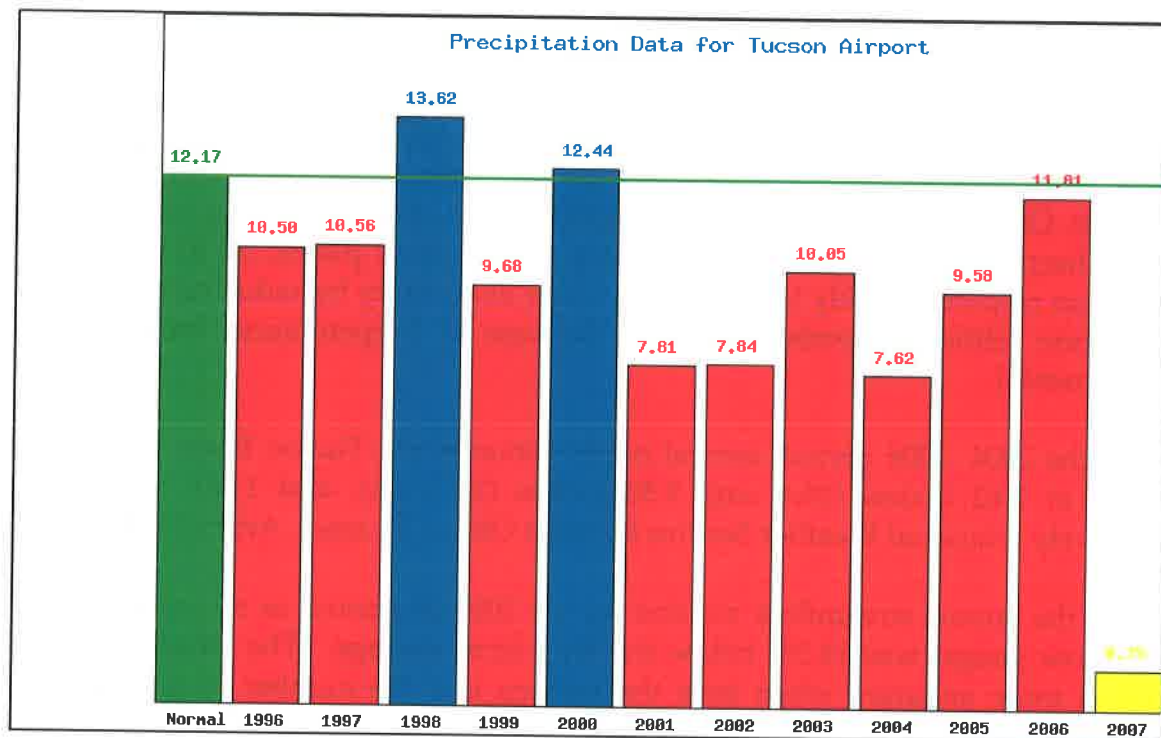


Figure 11. Annual precipitation totals as recorded at Tucson International Airport (source: National Weather Service Forecast Office, Phoenix, Arizona).

Groundwater Decline During Periods of No-Flow

Since December 2004, streamflow in Rincon Creek at Pool A has occurred in two periods. First, continuous flow was recorded from December 30, 2004, through May 24, 2005. Second, continuous flow was recorded from July 27, 2006 and beyond September 30, 2006, which included an estimated 15,000 cfs (450 cms) peak on July 31.

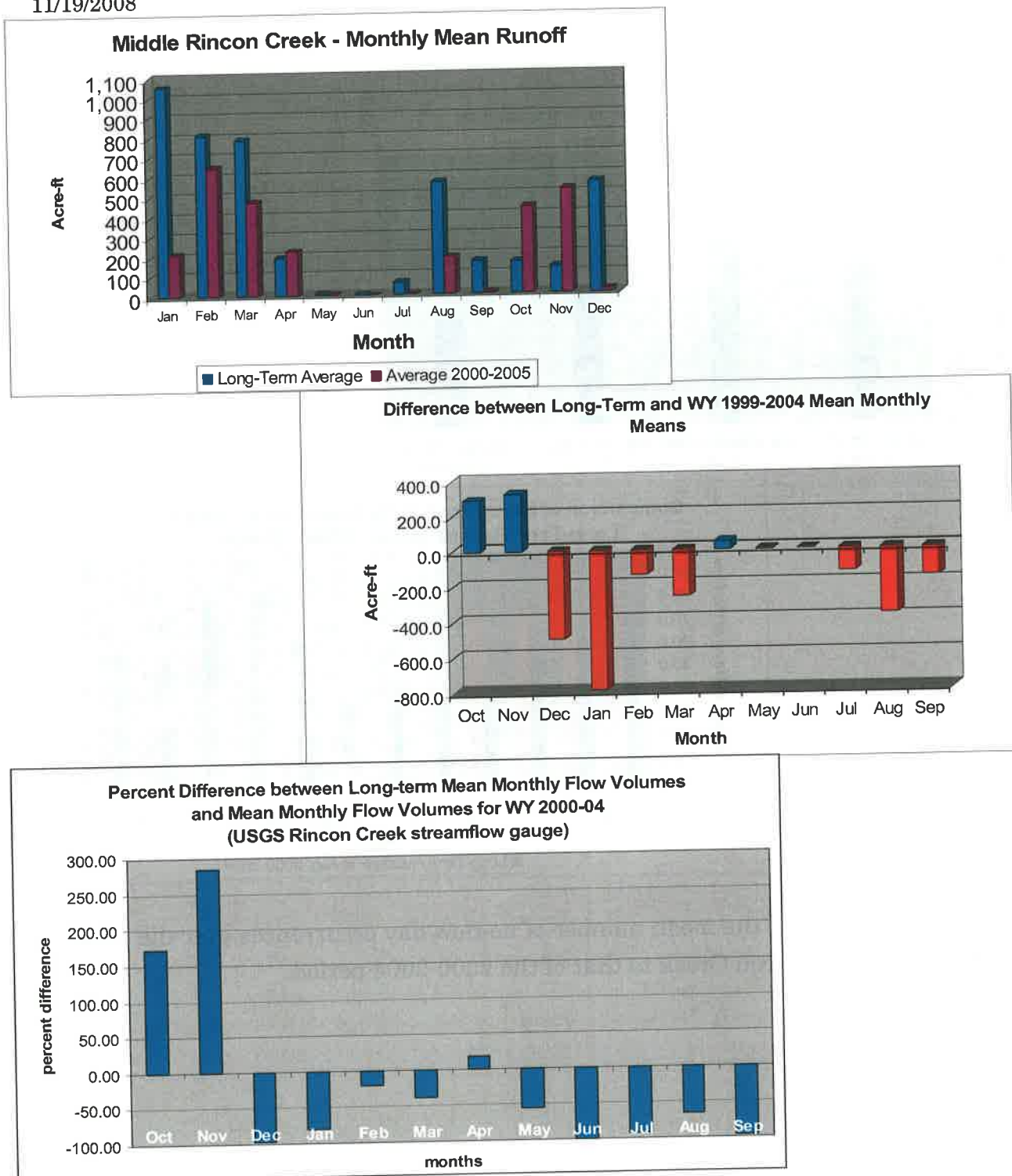


Figure 12. Three bar graphs comparing Rincon Creek streamflow characteristics over the long-term to streamflow conditions during the 2004 – 2006 period: (top to bottom): mean monthly runoff, differences in monthly averages in acre-ft, and percent differences in mean monthly flow volumes.

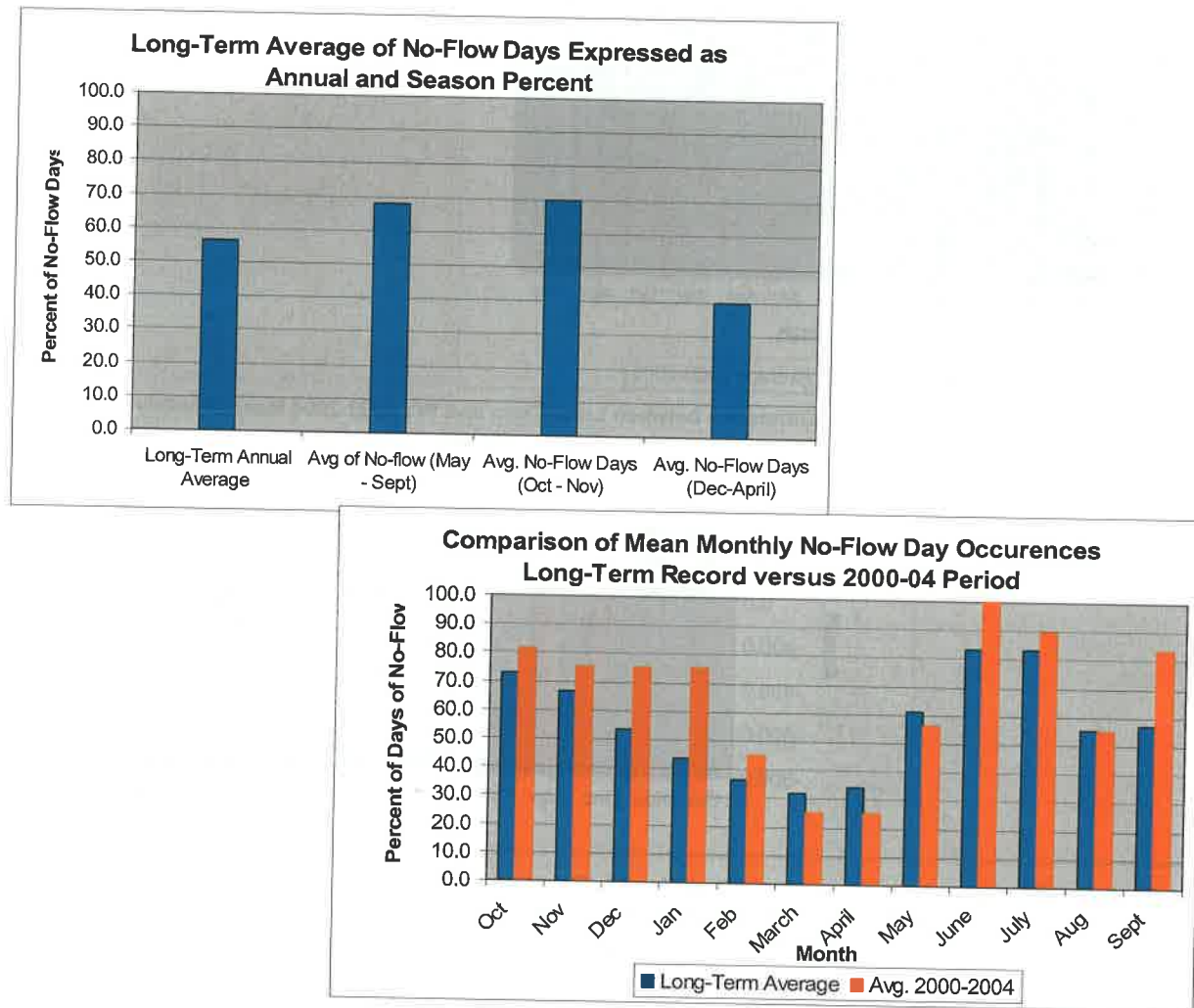


Figure 13. Comparison of the mean number of no-flow day occurrences over the entire streamflow record for Rincon Creek to that of the 2000-2004 period.

The rise and fall of ground-water levels in the monitoring wells correlates strongly with occurrences of streamflow and no-flow periods. Ground-water levels are described here as depth below the land surface, so that they can be easily correlated to threshold depths required for riparian deciduous species. From the May 11, 2005, depth to water in well RC-1 gradually fell from 4.69 feet (1.43 m) to 8.83 feet (2.69 m) on September 30, 2005, when the well went "dry." (The stream had quit flowing on May 25, 2005.) This equates to an average daily decline of the water surface elevation in well RC-1 of 0.032 feet (.010 m).

Shallow groundwater elevations respond much more dramatically to increases in surface flow than to decreases, particularly as measured in the RC-1 monitoring well, which is the closest to the channel of all the monitoring wells. During the strong monsoonal activity that took place during July 2006, water surface elevation rose from July 28 through July 30, 2006, the water level in well RC-1 rose from 4.99 ft (1.52 m) to 2.08 ft (0.63 m) below land surface, just before the statistically rare flood that took place on July 31st. Streamflow during this three-day period increased from 0.70 (.02 cms) to 350 (9.91 cms).

First, the connection between streamflow and shallow is direct. When streamflow occurs after a prolonged dry period, the effect on shallow groundwater elevations is almost instantaneous. Although abnormally dry period is far from ideal for the objectives of this investigation the dry situation did verified that groundwater levels do indeed fall below threshold levels for many riparian plants.

For well RC-2, groundwater elevations slowly declined from June 4, 2005, before going dry on February 1, 2006 (a period of 242 days). On June 4th, depth to water in RC-2 was 6.73 ft (2.05 m) below land surface, and on February 1, 2006 the well was dry at a depth of 11.94 ft (3.64 m) below the land surface. This amounts to an average daily decline of the shallow groundwater levels of 0.022 ft (.007 m) per day. There had been no flow at Pool A since May 25, 2005.

Considering the results during this time period for both the RC-1 and RC-2 wells, the conclusion is that shallow groundwater in the middle Rincon Creek system declines somewhere between 0.022 feet (.007 m) to 0.032 (.010 m) feet per day during times of little to no flow.

The period of August 6, 2006 to September 31, 2006 was selected as the next focus for making correlations between shallow groundwater and streamflow, because this was a period of relatively normal flow, although it occurred immediately after the record flood of July 31, 2006, which peaked at over 15,000 cfs (450 cms). The high magnitude and statistically rare characteristics of the July 31st event is not conducive for developing

correlations between what should be considered as normal or 'average' flow needed to maintain shallow groundwater levels at identified threshold levels. Nevertheless, the flows that followed July 31, 2006 provide an opportunity to see what flow characteristics may be needed to maintain groundwater levels after they have risen to elevations higher than threshold levels for riparian plants.

During the August 6, 2006 through September 30, 2006 period, discharge at Pool A decreased from 29.0 cfs (.82 cms) to 0.49 cfs (.014 cms). For RC-1, groundwater levels declined from a depth of 3.33 feet (1.01 m) to 4.12 feet (1.26 m) over the course of the 55-day period. This amounts to a decline of 0.014 feet (.004 m) per day. During the same period for RC-2, the level of shallow groundwater declined 4.33 feet (1.32 m) below the land surface on August 6th to 5.58 feet (1.70 m) by September 30th. The rate of decline was 0.023 ft (.007 m) per day. Although average daily discharge during this time period was large at least as compared to average daily flow the preceding summer), shallow groundwater declines occurred. Even with some flowing water in the stream, water levels in the wells continued to decline, probably because of evapotranspiration and seepage.

Nevertheless, given the amount of water that had just passed through the system, such drop in groundwater elevations may be expected. That is, the high magnitude flow event of July 31st inundated and saturated all of middle Rincon Creek's bottomland environment that there was really no where to go be down. Only subsequent flows of magnitudes capable of at least inundating terrace surfaces would have been able to maintain groundwater levels at the abnormally high elevations that were recorded just following the peak flow of July 31st.

The period of August 24, 2006 to September 30, 2006 was also analyzed because it occurred (1) three weeks after the July 31st flood and therefore may not be as compromised by the residual effects of the flood, and (2) just prior to a several smaller magnitude flow events that provide an additional opportunity to correlate shallow groundwater elevation to more usual flow events. During this time period, average discharge was 1.56 cfs (.047 cms). For well RC-1, groundwater elevations declined from 3.77 feet (1.15 m) to 4.12 feet (1.26 m), amounting to an average daily drop in groundwater depths of 0.009 feet (.003 m) over the course of the 37-day period. During the same period, the elevation of shallow groundwater as measured in the RC-2 well declined from a depth of 9.85 feet (3.00 m) to 10.67 feet (3.25 m). The rate of decline was 0.022 feet (.007 m).

CONCLUSION

For the period of record, the mean discharge of Rincon Creek is 6.5 cfs (0.18 cms), with a standard deviation of 6.0 cfs (0.17 cms). This average discharge equates to an average annual flow volume of 4,814 acre-ft (5,937,976 m³), with a standard deviation of 4,525 acre-ft (5,565,378 m³). The high standard deviation reflects the high-low range of annual flow volumes that have occurred during the period of record. Based on the long-term record for Rincon Creek, a flow event that occurs on average once every two years has a discharge of 963 cfs (28.9 cms), while a flow with a recurrence interval of 100 years (occurs on average once every 100 years) has a magnitude of 17,600 cfs (528 cms).

A discharge of 0.07 cfs is exceeded 40% of the time, indicating that for the majority of time, the streamflow of Rincon Creek is characterized by long low-flow and no-flow periods. The highest mean monthly discharge occurs during the months of January, February, and March, with long-term averages of 15 cfs (.45 cms), 14 cfs (.42cms), and 13 cfs (.39 cms), respectively. Every month of the year experienced no-flow at least several times during the course of the 38-year streamflow record for Rincon Creek.

From both a physical and biological standpoint, extended inundation of floodplain surfaces is critical, allowing the saturation of near-channel surfaces, evacuation and deposition of sediment, nutrient cycling, preparation of seedbed, and recharge of shallow groundwater. All of these factors play a critical role in determining riparian form and function. The role that long-term flows play in maintaining shallow groundwater levels is of particular importance as nearly year-round access to water is a characteristic need common to many riparian plants.

With reference to propagation, high annual three-day means are singled out as being particularly important. Along middle Rincon Creek, it appears that the bottomland environment experiences flooding of sufficient magnitude to promote propagation of native riparian trees every ten to 15 years, which means that such flow events occurred almost four times during the course of the Rincon Creek flow record.

During the 2004 -2006 period, annual precipitation in the Tucson Basin was well below average, seriously affecting streamflow conditions. Overall, the annual streamflow volume for the 2000-05 period, as recorded at the USGS streamflow gauge, was 14.2% below the long-term average, and long periods of low flow or no flow conditions occurred. Throughout the 2000 – 2004 period, streamflow did not occur at all for the month of June (i.e., 100% no-flow days). During this same period, the typically wet months of December – March and July – September included increases in no-flow day occurrences as compared to the long-term average. The lack of streamflow and decline in overall surface water availability affected middle Rincon Creek's bottomland biota.

The drought affected wetland and riparian plants greatly (in particularly, seedlings and saplings, and wetland emergent plants). The effects perhaps were more serious to this area's herpetofauna and aquatic invertebrates. As similar biologic studies have not been conducted during times of average precipitation, differences in extent and distribution are surmised. Nonetheless, as the results are the biologic studies are reviewed, it is critical that the dry conditions during this period should be kept in mind. That is, the population of middle Rincon Creek's aquatic invertebrates, herpetofauna, emergent wetland plants, and riparian plants would likely be greater during periods of average or above-average precipitation.

CHAPTER IV. CHANNEL MORPHOLOGY AND DEVELOPING A STAGE-DISCHARGE MODEL

OBJECTIVE

This chapter has three objectives. First, the channel morphology of middle Rincon Creek will be described and the results of channel cross-section and longitude surveys will be summarized. Second, the collected channel morphology survey data will be used as a foundation for a stage-discharge model that will provide estimates of minimum discharge magnitudes required to inundate selected channel morphologic surfaces (e.g., terrace, floodplain, in-channel). These surfaces offer physical conditions suitable for the propagation and establishment of many native riparian species. Developing estimates of discharge magnitudes required to inundate them provides critical information for the determining water needs of the bottomland vegetation. The third objective of this chapter is to discuss channel morphologic change following the July 2006 flood event, looking at selected resurveyed cross-sections and pools.

OVERVIEW OF CHANNEL MORPHOLOGY

Middle Rincon Creek just downstream of the confluence with Chimenea Creek is a low-gradient (slope of 0.0067), slightly meandering, moderately entrenched channel with broad well-developed floodplains (stream type 'C' in the parlance of Rosgen classification). Its passage along the pediment of the Rincon Mountains consists of moderate step-pool sequences defined by boulders and cobbles that form the steps separating pools containing finer material. The step-pool sequences themselves are separated by alluvial dominated reaches that in some parts are moderately confined by bedrock outcrops, are characterized by less roughness, and lack tumbling flow. These relatively smooth flowing reaches are dominated by sand and silt and can be described generally as dune-ripple reaches that exhibit a succession of mobile bed forms with increasing flow depth and velocity.

In addition to boulders and cobbles, the morphologic expression of the middle Rincon Creek channel includes other materials, such as large woody debris and bedrock outcrops that force local flow convergence, divergence, and sediment retention. Of particular interest for the study, Pool B (following the July 2006 flood) and pool C (prior to the July 2006 flood), are/were strongly affected by large trees whose trunk and root systems establish and maintain pool morphology. The location and importance of these pools to aquatic and semi-aquatic biota are discussed in Chapter V.

Although such relatively large magnitude discharges probably will not be affected by pumping (even larger than the withdrawals occurring presently), they are considered essential to the long-term viability of middle Rincon Creek's riparian plant community,

given the strong connection between the process domain of flooding and bottomland plant community characteristics. The bottomland plant community type (its composition, extent, and distribution) is determined by a host of geomorphic characteristics and contrasting flow-driven disturbance frequencies and intensities (Hupp 1982; Hupp and Osterkamp 1996). An essential adaptation strategy of riparian plants is dispersing seed during the seasonal retreat of floodwaters when recently inundated (and potentially scoured and therefore free of competing vegetation) near-channel surfaces offer conditions ideal for successful germination and colonization. Characterizing middle Rincon Creek's channel morphology is therefore an important ingredient to understanding the streamflow conditions required to maintaining the bottomland plant community in the long-term.

In addition to the importance of providing an overall characterization of middle Rincon Creek's channel conditions, the cross-channel and longitudinal surveys also provide a understanding of the size and form of middle Rincon Creek's alluvial-dominated reaches. For alluvial channels, channel size and form is generally indicative of the water conveyed through it, and its shape is largely the result of the sediment transported along it by the stream (Hedman and Kastner 1977; Hedman and Osterkamp 1982). Therefore, measuring channel geometry features along alluvial-dominated channel reaches over time provides the data needed to assess overall channel stability, as indicated by changes in channel gradient, channel width, width-depth ratios, alluvial material, etc. Setting up the cross-section surveys in a manner that can be easily repeated (where the exact same cross-section is surveyed) in the future was a critical part of identifying cross-section locations and developing survey methods. Indeed, setting up the cross-sections with an eye toward future monitoring was already helpful in assessing channel morphologic change following the large flood event of July 2006.

In addition to monitoring and improving our overall understanding of channel morphologic characteristics, surveying channel cross-sections and longitudinal profile are essential ingredients to developing the stage-discharge model. Of particular importance in this regard is developing estimates of bankfull estimates of discharges capable of inundating at least a portion of middle Rincon Creek's active floodplain.

In the spring, flood disturbances play an important role in the initial establishment of riparian vegetation (Hupp and Osterkamp 1985; Reichenbacher 1984; Campbell and Green 1986; Everitt 1968). Following high flow events, sites are produced that are suitable for riparian seed germination (White 1979), if sufficient water is available (Fenner et al. 1984; Reichenbacher 1984). In short, flooding often produces a seedbed with the environmental characteristics required for the propagation of many riparian species. For example, moist, sparsely vegetated mineral soils or alluvium with little or no post-germination flooding provide ideal conditions for germination and

establishment of cottonwoods and willows (Stromberg et al. 1991). Summer flooding, particularly during the hot dry months of May and June, is important with regard to wetting floodplain soils and recharging shallow groundwater during the time of year when evapotranspiration rates are at their highest and soil moisture becomes less available.

Given the importance of flooding in the life cycles of riparian deciduous trees, attention needs to be given to determining if overbank flow is vulnerable to groundwater withdrawals. In this regard, it is probably safe to assume that flows of sufficient magnitude to inundate large parts of the middle Rincon Creek bottomland environment are simply too large to be affected by just about any withdrawal scenario. With regard to the propagation and maintenance of riparian deciduous trees, flows of magnitudes that are just barely overbank may not be as important as higher magnitude flows that inundate large parts of the bottomland system. Nonetheless, the former flows are important to the propagation and maintenance of riparian zones and, due to their smaller magnitude, potentially could be affected by withdrawals.

Decline of groundwater levels caused by withdrawals is blamed, at least in part, for loss of deciduous riparian communities along the Verde River in central Arizona (McNatt et al. 1980). And, increased groundwater withdrawals in within Santa Cruz basin, Arizona is at least partly to blame for the loss of cottonwood stands along the Santa Cruz River (Stromberg et al. 1993). Even non-deciduous bottomland communities (communities comprised of deep-rooted plants that are typically less vulnerable to groundwater decline) are affected. For example, the mesquite bosques that formerly occurred in parts of Casa Grande Ruins National Monument, Arizona and along the Tanque Verde River in Tucson, Arizona have been affected by increased withdrawals that have lowered groundwater levels (Judd et al. 1971; Stromberg et al. 1992).

Discharges capable of inundating large parts of middle Rincon Creek's floodplain will probably not be affected by groundwater withdrawals and will probably continue to occur at natural levels and frequencies, even if the withdrawals in the Rincon Valley greatly increase in the future. That is, at the time the flood event passes through the Rincon Creek system, the volume of water associated with the flood event overrides the volume of water being removed from the system by the withdrawals. However, overbank flow is important to the long-term viability of middle Rincon Creek's riparian plant community.

The objective of developing the stage-discharge model is to estimate overbank discharge magnitudes for several selected cross-sections, providing a general assessment of the flow discharges required to inundate middle Rincon Creek's floodplain surfaces. Although greater in magnitude than in-channel flows, it is important to note that the

focus here is on flows capable of inundating middle Rincon Creek's floodplain surfaces, which are nowhere near the magnitudes of discharges capable of inundating the creek's entire bottomland environment.

METHODS

The three objectives were realized by:

- Surveying channel cross sections at selected locations;
- Surveying the longitudinal profile of the entire middle Rincon Creek reach;
- Developing a stage-discharge model for the cross-sections that were surveyed and use the model to estimate discharge magnitudes required to inundate selected near-channel surfaces;
- Resurveying selected channel cross-sections to understand how middle Rincon Creek's channel morphologic conditions have changed as a result of the very large flood event that occurred at the end of July 2006 (after the channel was originally surveyed); and
- Summarizing how the results of the above pertain to determining water needs for bottomland vegetation.

Survey Methods

Surveys of (1) the longitudinal profile of the middle Rincon Creek channel and (2) channel cross-sections were conducted. Surveys were initiated at the point where Rincon Creek Ranch road crosses Rincon Creek (cross-section 1) and ended with cross-section 7 positioned just upstream of where Rincon Creek exits Saguaro National Park East (Fig. 14). Transects are numbered sequentially in the downstream direction. Ultimately, one longitudinal profile and seven cross-channel surveys were conducted. Surveys were conducted during two main periods: Spring of 2005 and Fall of 2007 (to assess morphologic change following the July 2006 flooding). As noted previously, channel cross-sections as well as the longitudinal profile were conducted to both satisfy data needs for developing a stage-discharge model as well as part of a long-term monitoring program.

The number and position of cross-channel transects are based on morphologic and vegetation characteristics, and are coordinated to support surveys of vegetation, herpetofauna, and aquatic invertebrates. Where occupied, transects run perpendicular to the channel, encompassing as much of the active bottomland environment as possible (transect distance may be limited by issues of access, channel morphologic characteristics, overall width of the bottomland plant community, and land use activities

(e.g., roads, pastures, etc.). Moving from channel left to channel right, cross-channel transects often encounter – though not always – terrace, floodplain, and in-channel features such as channel bars, point bars, channel islands, and thalweg. In addition to the cross-channel transects, a detailed longitudinal profile of the middle reach of Rincon Creek reach was surveyed.

All channel morphologic surveys were conducted using a Leica total station and a prism rod. For the channel cross-sections, a tape is stretched across the channel in-between two established metal stakes (monuments) that were installed on the left and right sides of the channel. The tape measure is not used for measuring distance (the total station measures distance accurately by bouncing an infrared signal off of the prism rod), but only as a guide for the surveyor to follow. The length of the cross-channel transect varies from one monitoring station to the next depending on characteristics of channel morphology, the overall width of the active bottomland environment at the point of measurement, land ownership, amongst other factors.

Data collection procedures and location of transect lines for measuring cross-sectional profiles followed methods described in Hedman and Kastner (1977), Hedman and Osterkamp (1982), Gordon et al. (1992), Harrelson et al. (1994), and Briggs et al. (2002). Cross-channel transect placement is determined by a variety of natural and human-related characteristics, including:

- Access,
- Location of tributaries (as a general rule, survey transects are not placed immediately upstream or downstream of tributaries to avoid measuring channel morphologic characteristics that may be affected by tributary flows, rather than mainstem flow),
- Roads or other localized disturbances – surveys should not be conducted near localized disturbances (particularly those that are human related) as such measurements may provide misleading information about the overall characteristics of the reach;
- Channel biophysical characteristics - channel pattern, morphologic complexity, bottomland plant community characteristics;
- Channel morphologic homogeneity – as the objective is to characterize the middle Rincon Creek's channel morphology by surveying a select number of cross-channel transects, it is critical to survey locations that are representative, avoiding reaches that have been affected by local and comparatively unique perturbations (e.g., road crossing, flood control structures, etc.).

Cross-section elevations are referenced to a datum and transect end points are positioned on surfaces outside the influence of the active channel. As such, the channel

An Overview of Middle Rincon Creek's Channel Morphologic, Streamflow, Pool System and Bottomland Plant Community Characteristics

Briggs

11/19/2008

cross-sections encompass the active floodplain surfaces and as much of the surrounding terrace surfaces as possible. As defined for the purposes of this study, active floodplain surfaces correspond loosely to that portion of the bottomland environment that is below the bankfull level. As defined by Hedman and Osterkamp (1982), the bankfull reference level is the active floodplain and is the stage at which overbank flow occurs. For intermittent streams, the bankfull level approximates the stage of a flood with a recurrence interval between 1.5 to three years (Hedman and Osterkamp 1982). Within the cross-channel area encompassed by the bankfull reference point are channel features that are subject to change by prevailing discharges, including the thalweg, depositional bars, and flood plain.

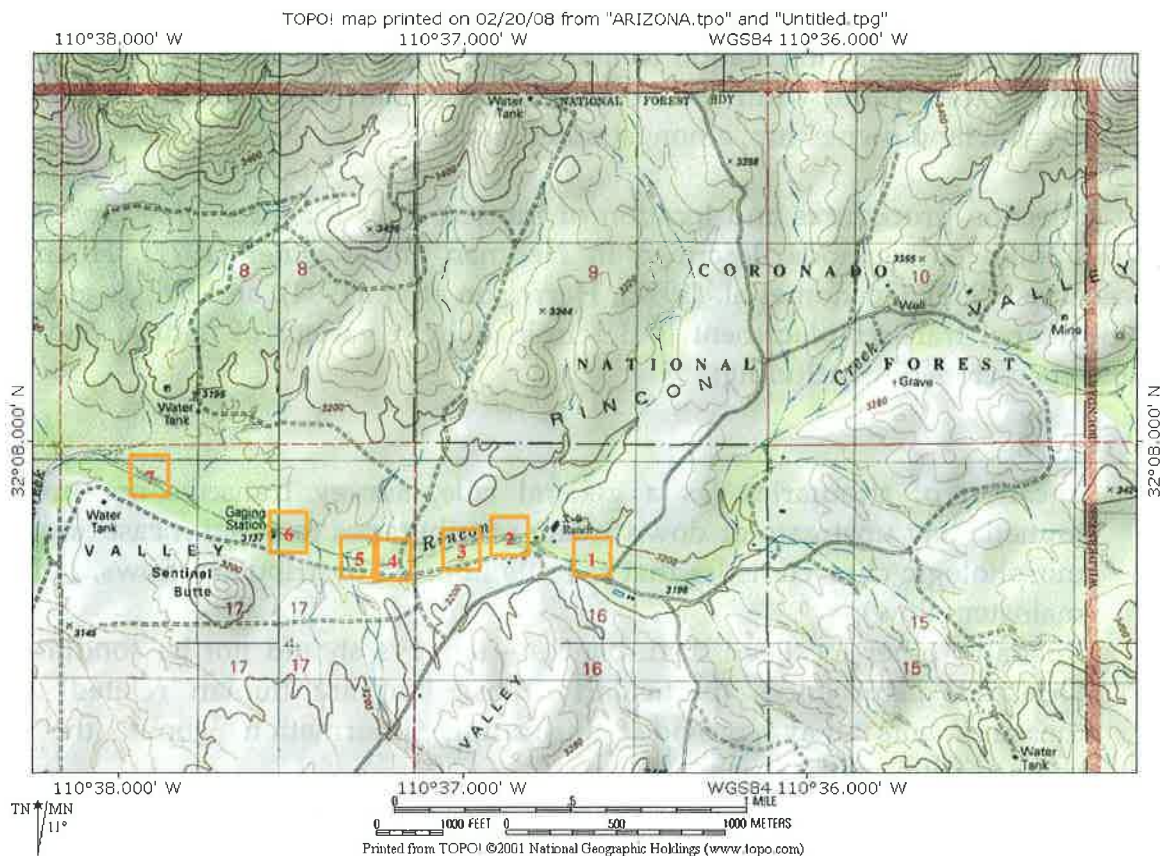


Figure 14. Topographic map of middle Rincon Creek with locations of cross-section transects (orange boxes).

Longitudinal profile surveys were conducted along the thalweg of the river, beginning at the point where Rincon Creek Ranch Road crosses over Rincon Creek about one-third of a mile upstream of the confluence with Chimenea Creek. For both channel cross-sections and the longitudinal profile, individual survey readings were recorded in areas

where larger changes in gradient were observed. In this manner, relatively numerous survey points are recorded in areas with larger topographic variability, and only a few survey readings are required in areas where the gradient is relatively constant. For cross-channel surveys, elevation readings are taken at numerous locations along each transect, including larger breaks of slope in the channel, the active flood plain, bankfull elevations, and stream terraces.

To ensure relocation of transects for future inventories, endpoint monuments were installed at both ends of each channel cross-section, and their locations determined with a Global Positioning System (GPS) receiver. The GPS coordinates of each transect monument are included in the database that will be developed as part of the monitoring program. Photographs of the channel at each of the study sites were also taken. Both longitudinal and cross-channel survey data were analyzed using software programs Foresight, Surfer, and Excel.

For the resurvey of channel morphologic conditions to assess changes following the July 2006 flooding, only cross-sections two, three, and four selected were resurveyed because they were located along the upper half of middle Rincon Creek, where three of the four pools are located

Changes in morphology are assessed by evaluating changes in cross-channel area under a constant elevation datum between the two survey years (2005 and 2007). Cross-section area was determined by selecting an elevation datum and then calculating the area underneath it. An overall increase in cross-section area indicates degradation, or a general evacuation of sediment from the surveyed reach during the time period between the two surveys. A decrease in cross-section area indicates aggradation. Subtle changes in cross-section area may indicate a channel reach that is relatively stable (sediment moving into the reach generally equals sediment leaving), whereas major changes (whether degradation or aggradation) may indicate a channel reach that is unstable and is responding to local and/or watershed scale disturbances.

Stage-Discharge Model

Stage-discharge model was developed to estimate discharge magnitudes required to inundate morphologic surfaces of interest. Of particular interest was developing an estimate of the discharge magnitude for overbank flow to occur along at least some of the parts of the middle Rincon Creek reach where cross-channel surveys were conducted. Estimated discharges of interest are then related to the long-term streamflow record for Rincon Creek to estimate their frequency.

The stage discharge model was developed in two principal steps. First, channel morphology surveys were conducted of selected channel cross-sections in the manner

described above. Second, high flow marks from several major events that took place along middle Rincon Creek during the study period were surveyed as part of the calibration phase in the model's construction. The time that the high flow was marked was 'matched' to discharge at the US Geological Survey streamflow gauge for that time period. After flow had dissipated, the high flow marks were surveyed in at each of the cross-sections, thereby providing model development with several water surface elevations and known discharges for these elevations (given loss or gain between point of measurement and USGS gauge). Third, morphologic survey results, surveyed known elevations and discharges from selected flow events were used to build the HEC-RAS stage-discharge model.

HEC-RAS v3.1.1 was used for the modeling, all units are metric, and the model was run in subcritical mode. The boundary condition at the downstream cross section was normal flow with a slope of $S=0.00673$. The model was calibrated using five different flow events that occurred along Rincon Creek during 2005. Discharges for the five flow events were measured at the U.S. Geological Service streamflow gauge. Flow stages were marked along cross-channel transects as distance from left monument to the point where flow was occurring. The time was noted at the time of measurement and then correlated to discharge as measured at that time at the U.S. Geological Survey streamflow gauge (gauge 09485000, Rincon Creek, near Tucson, Arizona).

Assessing Channel Morphologic Change

Of the seven cross-sections surveyed as part of baseline conditions, cross-sections two, three, and four were selected to be resurveyed following the high magnitude flooding of July 2006. Changes in channel cross-section area are portrayed graphically and quantified by the change in cross-section area under a consistent elevation datum (i.e., a datum whose elevation did not change between the two survey periods) (Fig. 15). The location of elevation datums were selected graphically (using graphs produced as part of the cross-channel surveys), and cross-section area is calculated using a spreadsheet with embedded equations for calculating area between successive survey points.

The criteria used to establish the elevation datum include change in slope across the channel, ease of identification (both in the field as well as graphically), and how well they can be identified graphically from one time period to the next. The elevation datum used for the resurveyed transects corresponds to a high, stable point that was not greatly morphologically affected by the July 2006 flow. In some cases, the elevation datum was the left monument. However, for cross-channel transects characterized by larger topographic variation between the left monument and thalweg, a point was selected between the monument and thalweg that was well above the channel bed.

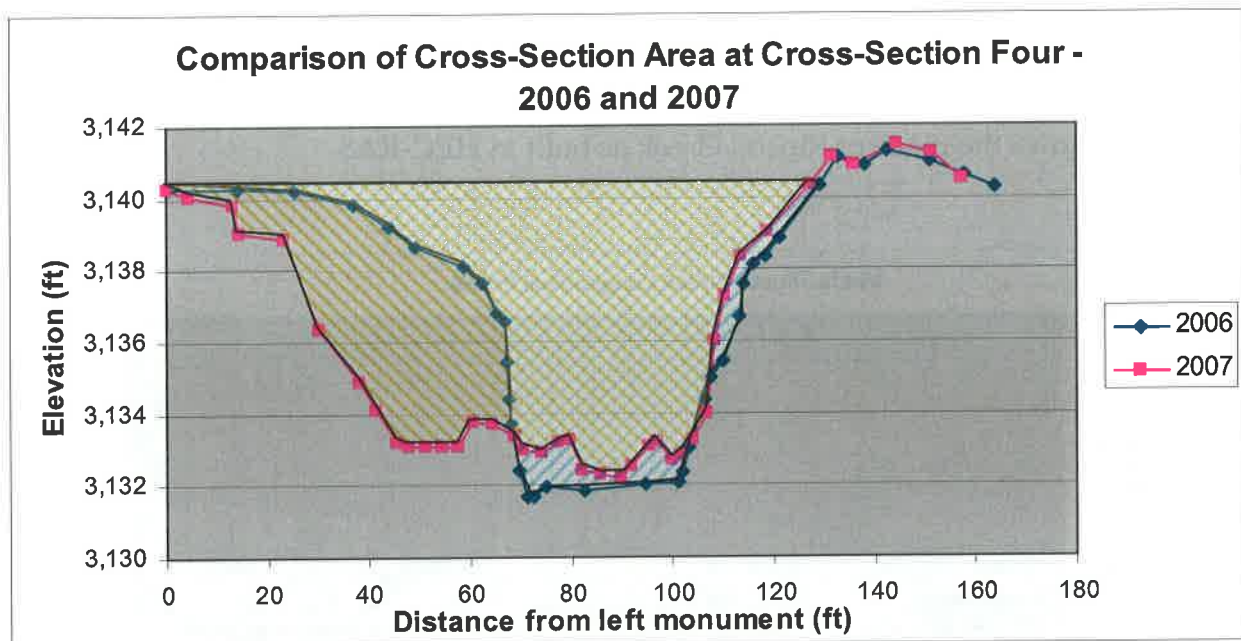


Figure 15. Idealized example of cross-section area calculated at middle Rincon Creek cross-section four for 2006 (diagonal lines moving top left to bottom right) and 2007 (diagonal lines moving top right to bottom left). Checkered patterns indicate overlap between 2006 and 2007 cross-section areas.

Regardless, of the exact location of the elevation datum used to calculate channel cross-section area, changes in cross-section area under the high elevation datum relate to changes throughout the active bottomland environment (e.g., aggradation and/or degradation of terrace, floodplain, channel, point bars, and all the remaining surfaces of the active bottomland environment.). That is, change in channel cross-section area from one time period to the next does not in-and-of-itself identify which surfaces aggraded or degraded, but only identifies a general trend across the entire bottomland surface. However, combining changes in channel cross-section area with graphic results of the two different survey periods can help to identify the channel morphologic surfaces that were affected most by the July 2006 flood.

RESULTS

Stage-Discharge Model

Based on site reconnaissance, the roughness coefficients used in the model were estimated at $n=0.06$, for in-channel surfaces, and $n=0.125$ for active floodplain surfaces.

These values were later changed during the calibration exercise (see below) to 0.04 for in-channel and 0.09 for active floodplain surfaces. The distance between transects in the model was estimated from aerial photography and the longitudinal profile (Fig. 16). Figure 17 shows the reach of Rincon Creek as built in HEC-RAS.

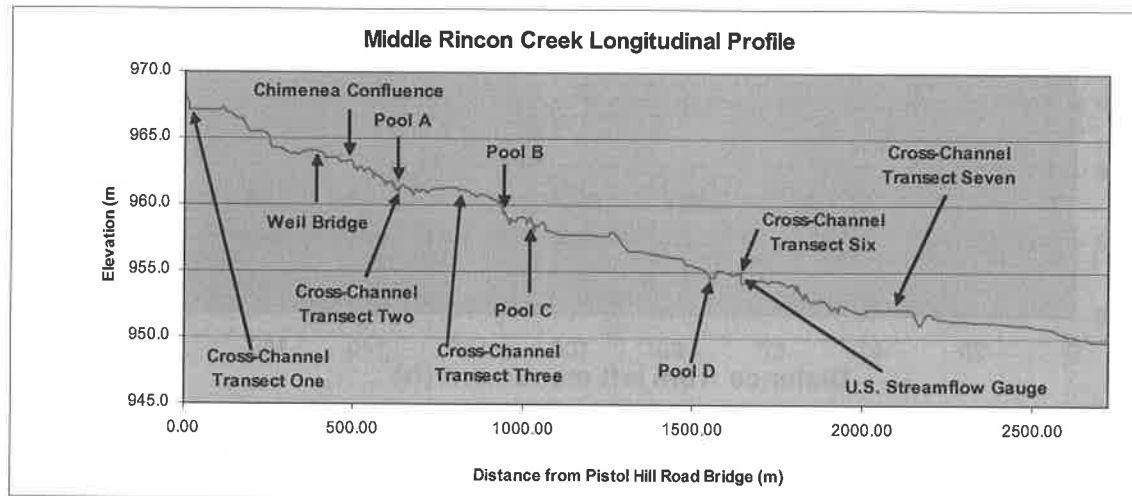


Figure 16. Graph showing results of longitudinal profile with locations of cross-channel transects and pools A – D indicated.

The five discharge events that were used to calibrate the model occurred during the winter season of 2004-2005 were of magnitudes 0.11, 0.82, 4.05, 4.31, and 42.76 m³/s (4.1, 29, 143, 152, 1510 cfs). Discharge estimates were taken from the USGS gage no. 09485000, "Rincon Creek near Tucson, Arizona." The high magnitude flow event that occurred during July 2006 was not used in the calibration as its peak had to be estimated (the flood damaged the USGS gage preventing direct measurement), and the estimation of the event's peak discharge was still being determined after the model was developed.

The Manning's n values of the model were systematically adjusted until the predicted water-surface values closely matched the observed values. HEC-RAS (ver. 3.1.3) was used for modeling. The model was run in subcritical mode and the Manning's n roughness values were consistent with the calibrated values determined by Magirl (2005): n=0.04 in the channel and n=0.09 on the overbanks. These values were kept consistent for all transects.

In general, the predicted water-surface elevation closely matches the observed values (Table 4). The exception to this generalization is the poor low-flow prediction that occurred at Transect Four (-0.61 m) (- 2 ft). Ignoring this error, the resulting standard

deviation error is 0.17 (including the error, the standard deviation is 0.22). With a 95% confidence, prediction accuracy is within 0.45 m (1.48 ft).

Table 4 shows the predicted discharge values for each cross section and each measured mark. Predicted discharge for the low-water marks at each cross section ranged between 0.25 cms (8.8 cfs) and 8.2 cms (290 cfs), though the 8.2 cms (290 cfs) is clearly an outlier. Discharge estimates for the high-water marks ranged from 19 to 53 m³/s (671 cfs to 1,872 cfs). Figure 17 gives a profile view of the water surface for the entire reach for the modeled discharges. Figures 18-24 provide cross-section views of modeled results at all of the cross-sections.

Table 4. HEC-RAS results of water-surface elevation predictions at each transect for each of five modeled flows (elevations used here were adjusted after the cross-channel transect monuments were surveyed in using a base station. Updated elevations for cross-sections are used henceforth).

River Station	Discharge (m3/s)	Min Channel Elevation (m)	Predicted Water-surface Elevation (m)	Actual Obs Water-surface Elevation (m)	Difference (predicted - observed)
Transect One	0.12	963.49	963.57		
Transect One	0.82	963.49	963.66		
Transect One	4.05	963.49	963.87		
Transect One	4.31	963.49	963.88		
Transect One	42.76	963.49	964.85		
Transect Two	0.12	957.42	957.8	957.91	-0.11
Transect Two	0.82	957.42	958.11	958.07	0.04
Transect Two	4.05	957.42	958.69		
Transect Two	4.31	957.42	958.72	958.6	0.12
Transect Two	42.76	957.42	959.73	959.36	0.37
Transect Three	0.12	957.49	957.57	957.52	0.05
Transect Three	0.82	957.49	957.71	957.84	-0.13
Transect Three	4.05	957.49	957.92		
Transect Three	4.31	957.49	957.93	958.05	-0.12
Transect Three	42.76	957.49	958.62	958.45	0.17
Transect Four	0.12	954.87	955.01	955.62	-0.61
Transect Four	0.82	954.87	955.13	954.97	0.16
Transect Four	4.05	954.87	955.38		
Transect Four	4.31	954.87	955.4	955.64	-0.24
Transect Four	42.76	954.87	956.54	956.65	-0.11
Transect Five	0.12	953	953.14	953.08	0.06
Transect Five	0.82	953	953.26	953.08	0.18
Transect Five	4.05	953	953.52	953.29	0.23
Transect Five	4.31	953	953.54		

Transect Five	42.76	953	954.66	954.5	0.16
Transect Six	0.12	950.98	951.17	951.28	-0.11
Transect Six	0.82	950.98	951.3	951.57	-0.27
Transect Six	4.05	950.98	951.51	951.62	-0.11
Transect Six	4.31	950.98	951.52		
Transect Six	42.76	950.98	952.38	952.23	0.15
Transect Seven	0.12	948.01	948.12		
Transect Seven	0.82	948.01	948.26	average	-0.01
Transect Seven	4.05	948.01	948.49	max	0.31
Transect Seven	4.31	948.01	948.5	min	-0.61
Transect Seven	42.76	948.01	949.47	stdev	0.21

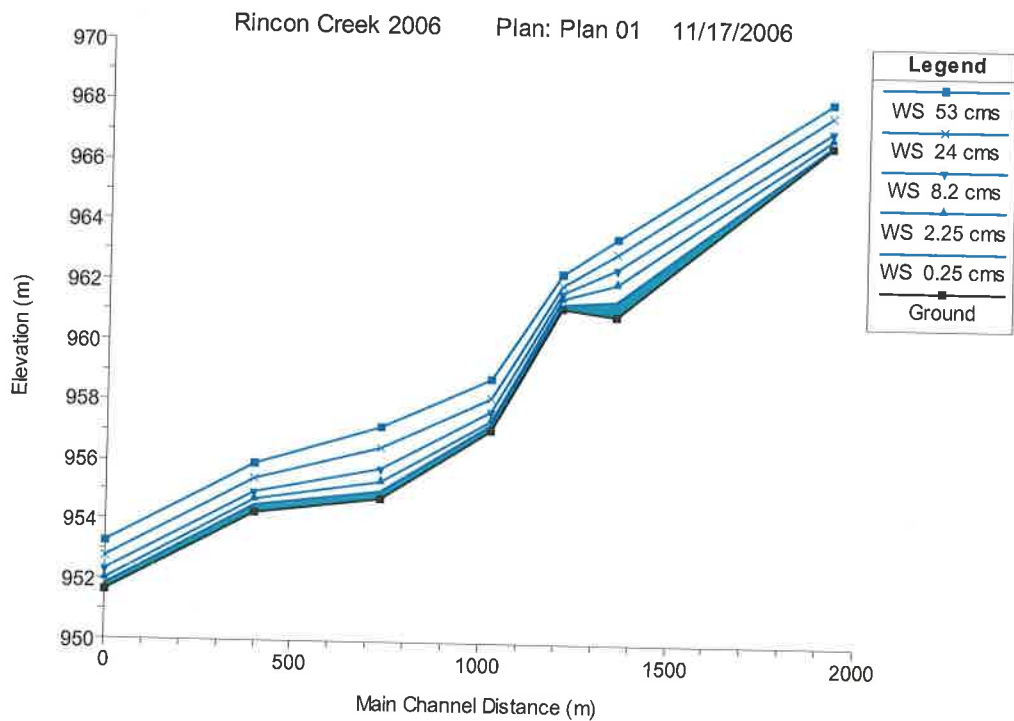


Figure 17. Longitudinal profile of the model showing flow values spanning the range of predicted discharges. Transect One is at the uppermost part of reach. Note the deep pool at Transect Two and the faster, more pinched flow at Transect Three.

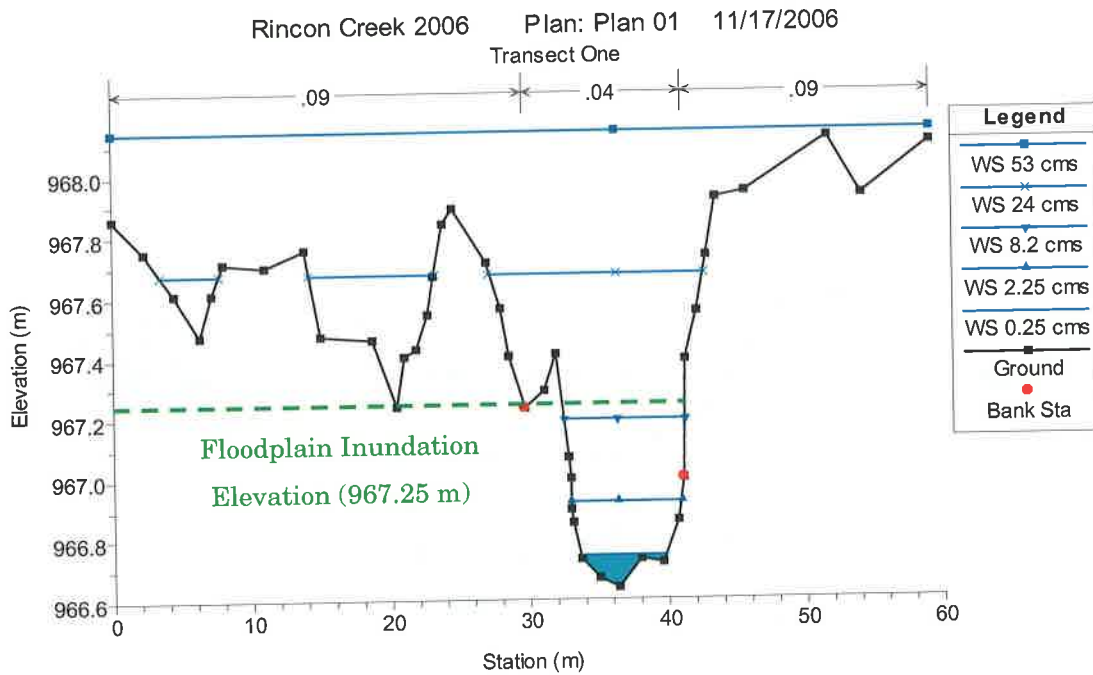


Figure 18. Graphic portrayal of model results at cross section one showing water surface elevations for the range of modeled discharges.

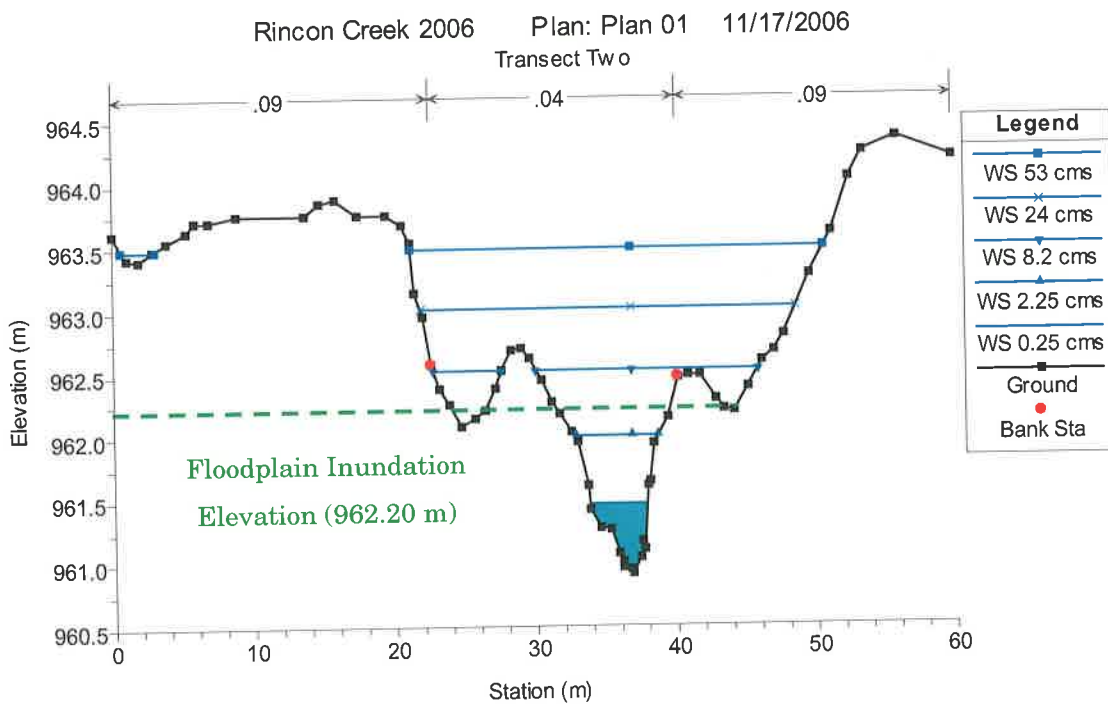


Figure 19. Graphic portrayal of model results at cross section two showing water surface elevations for the range of modeled discharges.

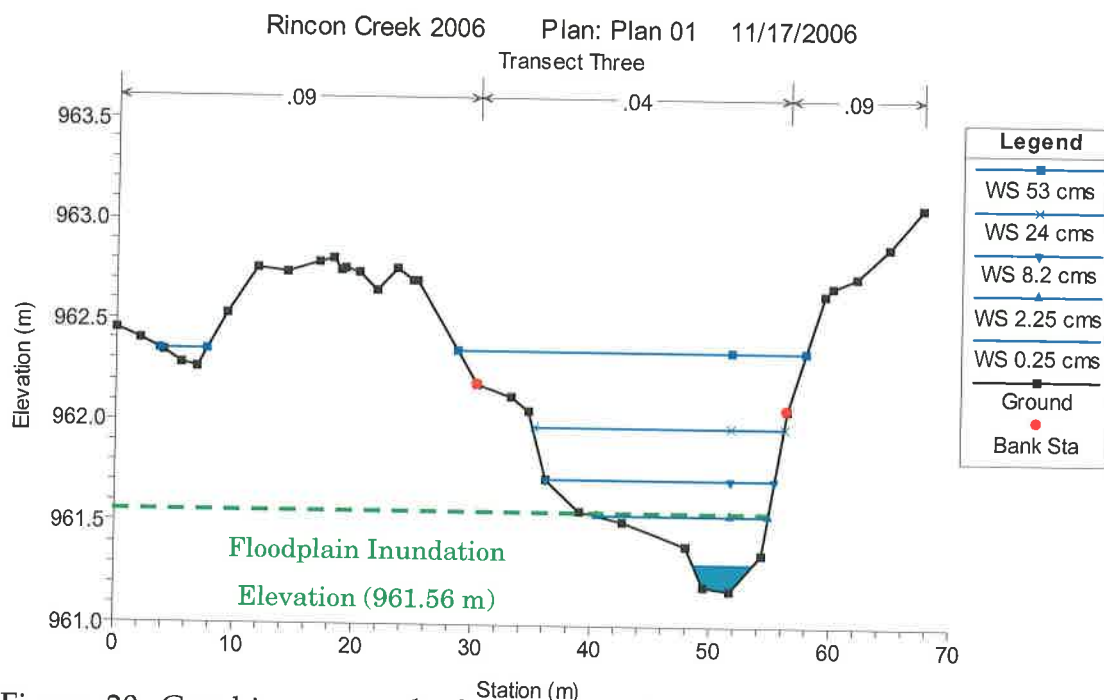


Figure 20. Graphic portrayal of model results at cross section three showing water surface elevations for the range of modeled discharges.

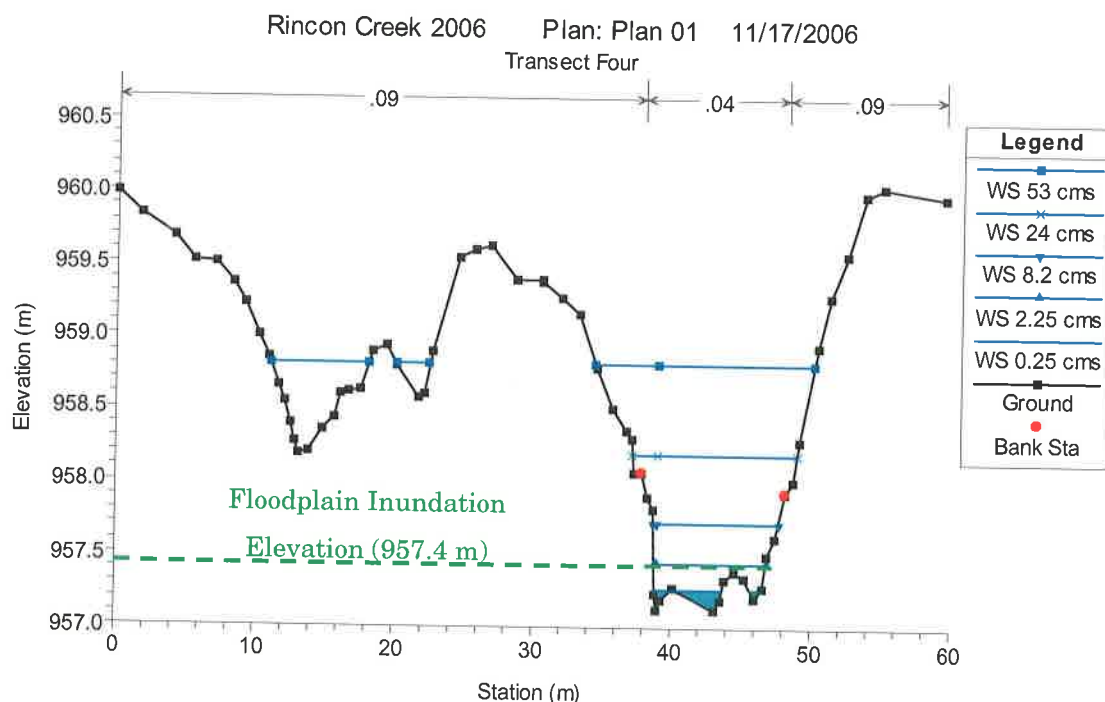


Figure 21. Graphic portrayal of model results at cross section four showing water surface elevations for the range of modeled discharges.

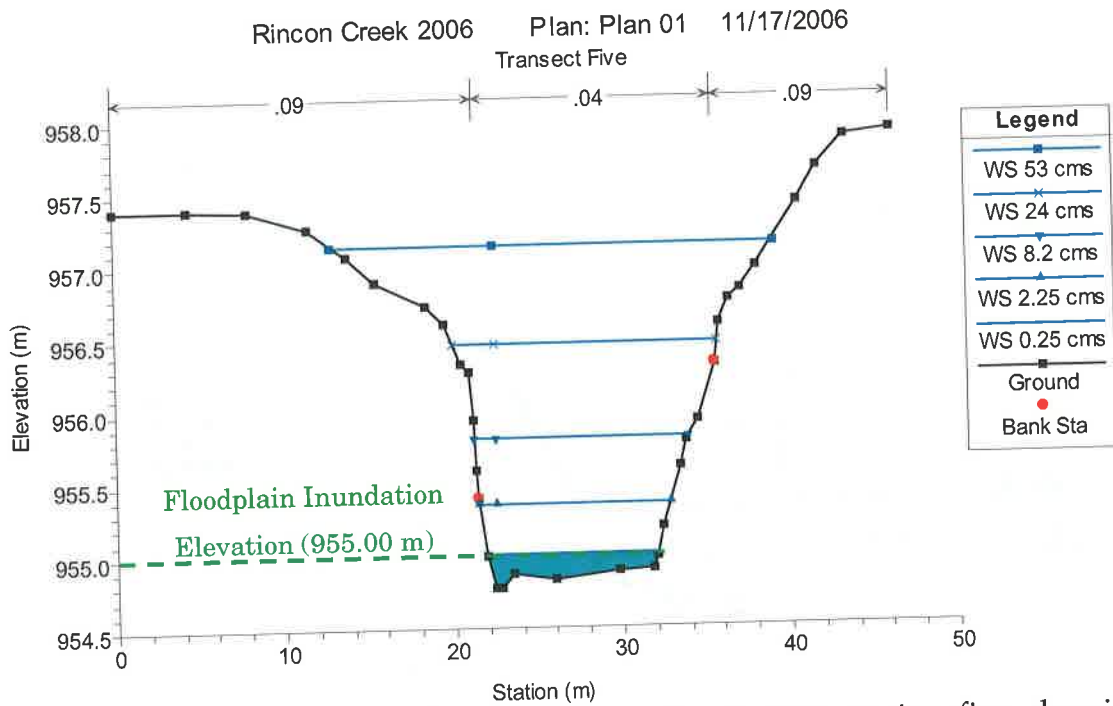


Figure 22. Graphic portrayal of model results at cross section five showing water surface elevations for the range of modeled discharges.

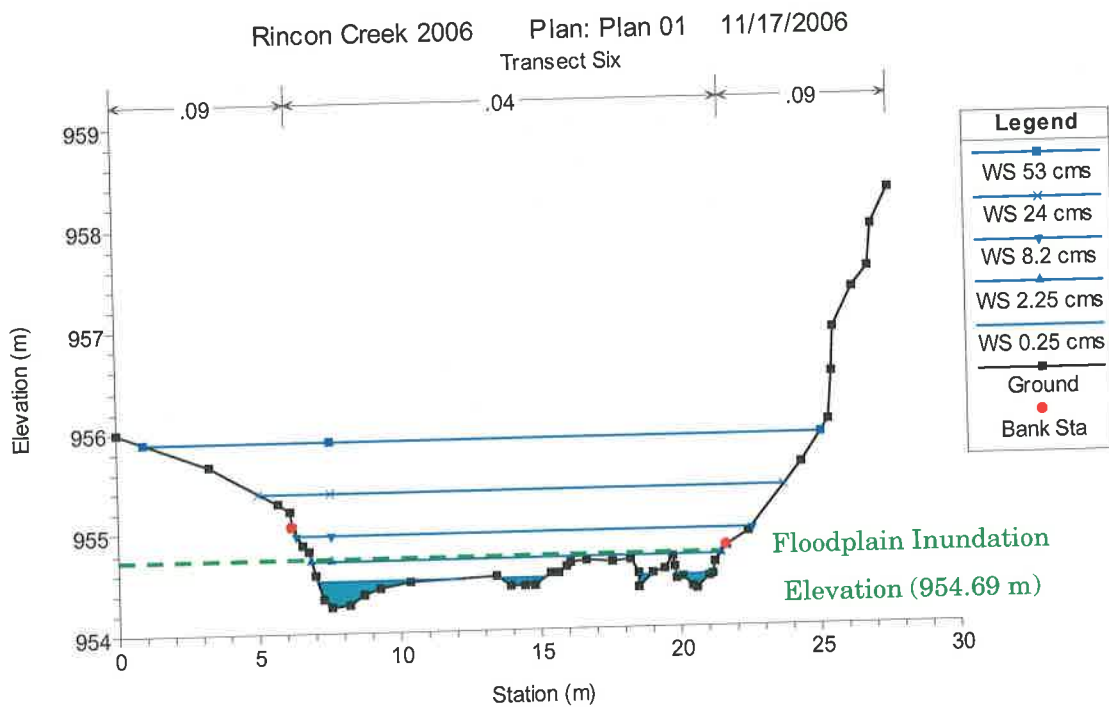


Figure 23. Graphic portrayal of model results at cross section six showing water surface elevations for the range of modeled discharges.

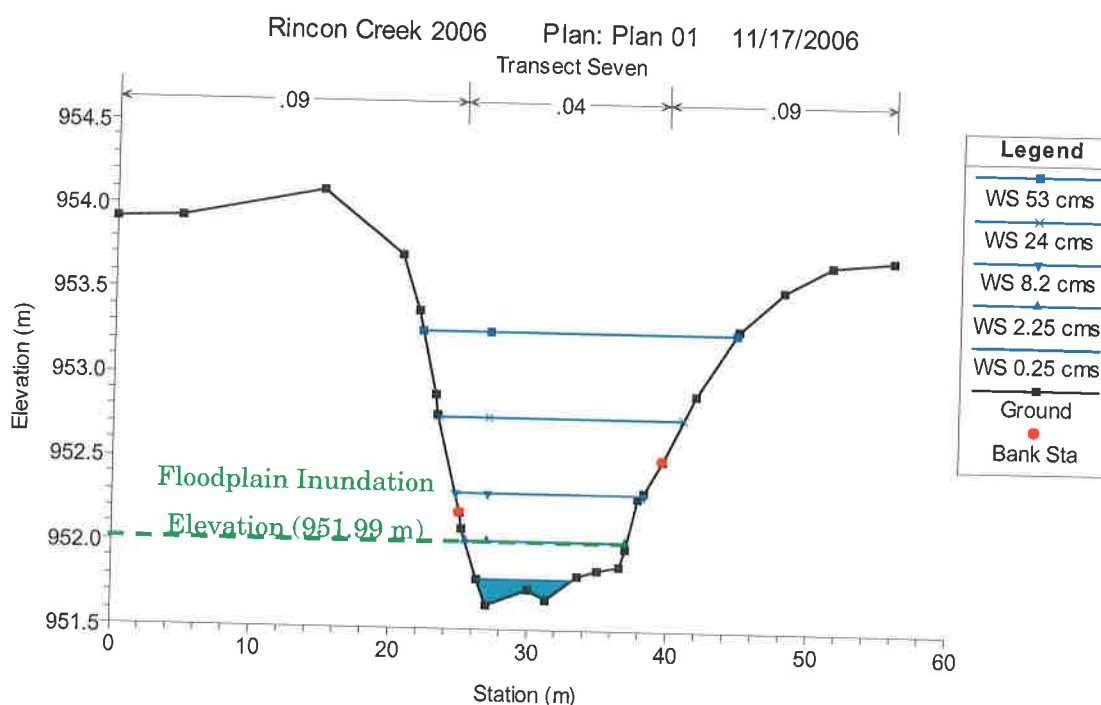


Figure 24. Graphic portrayal of model results at cross section seven showing water surface elevations for the range of modeled discharges.

At each cross-section, the elevation was marked in the field at the point where the majority of floodplain surfaces would be inundated. This 'floodplain inundation elevation' is indicated graphically at each of the channel cross-section graphs. Using the results of the HEC-RAS model, discharge estimates were developed for both the floodplain inundation and terrace inundation elevations (Table 5).

The low-flow inundation estimate provides an estimate of discharge needed to cover at least some of middle Rincon Creek's floodplain surfaces. Prolonged inundation of floodplain surfaces is particularly critical for riparian deciduous plants during the spring when these species typically produce vast quantities of seed. To propagate successfully, these plant species require moist surfaces of freshly deposited alluvium. For their long-term establishment, the channel morphologic surfaces on which the seeds fall need to be intermittent between terrace surfaces, which are higher above the channel bed and may be too dry for deciduous riparian plants, and surfaces that are so close in elevation to the channel bed and therefore vulnerable to flood scour by minor and frequently occurring flow events. Inundation of floodplain surfaces is also critical during the summer, providing near-surface water and augmenting shallow groundwater levels during the hottest and driest time of the year when soil moisture is less available.

Based on model results and considering all of the transects, the average discharge required to inundate low-flow (floodplain surfaces) is 2.63 cms (92.88 cfs). If the low-flow discharge estimate for transect one is removed from the average (as it is considered an outlier), the average becomes 1.7 cms (60.03 cfs) (Table 5).

Table 5. Predicted discharge at each cross section in Rincon Creek for measured low-flow and high-flow water.

Transect	Low-flow water mark	Predicted Discharge m³/s (cfs)	High-flow water mark	Predicted Discharge m³/s (cfs)
One	967.20	8.2 (290)	967.80	30 (1,059)
Two	962.00	2.25 (79.5)	963.50	53 (1,872)
Three	961.56	2.5 (88.3)	962.26	44 (1,554)
Four	957.40	1.5 (53)	958.19	24 (848)
Five	955.00	0.25 (8.83)	-	-
Six	954.69	1.8 (63.6)	955.28	19 (671)
Seven	951.99	1.9 (67.1)	-	-
Avg low-flow inundation dischg: transects 1-7 cms (cfs)				2.63 (92.9)
Avg low-flow inundation dischg: transects 2-7 cms (cfs)				1.7 (60.03)
Avg high-flow inundation dischg: transects 1-4, 6 cms (cfs)				34 (1,200.7)

Assessing Channel Morphologic Change Following the July 2006 Flood Event

During the course of this investigation, drought conditions dominated, resulting in below average flow and long periods where the creek was dry throughout its entire length. However, during the last days of July 2006, atmospheric conditions aligned to generate heavy rainfall - precipitation frequency for many Pima County Flood Control gages exceeded a 100-year return period - that produced record floods in the Tucson area, particularly in the Santa Catalina Mountains and Rincon Mountains (Fig. 25). The largest flooding occurred after midnight and into the early morning hours on July 29th and July 31, 2006 (McGuire and Cordova 2007).

Estimated peak discharge at Rincon Creek during this time period was over 14,000 cfs (396 cms), which correlates to a statistical recurrence interval of 100 years (with precipitation frequencies of many Pima County gauges exceeding a 100-yr return period) (McGuire and Cordova 2007). Although flow receded quickly from its peak, flow of sufficient magnitude to inundate large portions of the Rincon Creek bottomland environment persisted for several days following flood crest. Field reconnaissance immediately following flooding revealed redistribution of sediment, changes in thalweg

alignment, excavation of cobbles and boulders, and removal of large organic obstacles that, prior to the flood event, had played a role in altering flow and channel form. Of particular interest in this regard were the boulders and the large sycamore tree that dominated and affected hydraulics at Pools B and C.

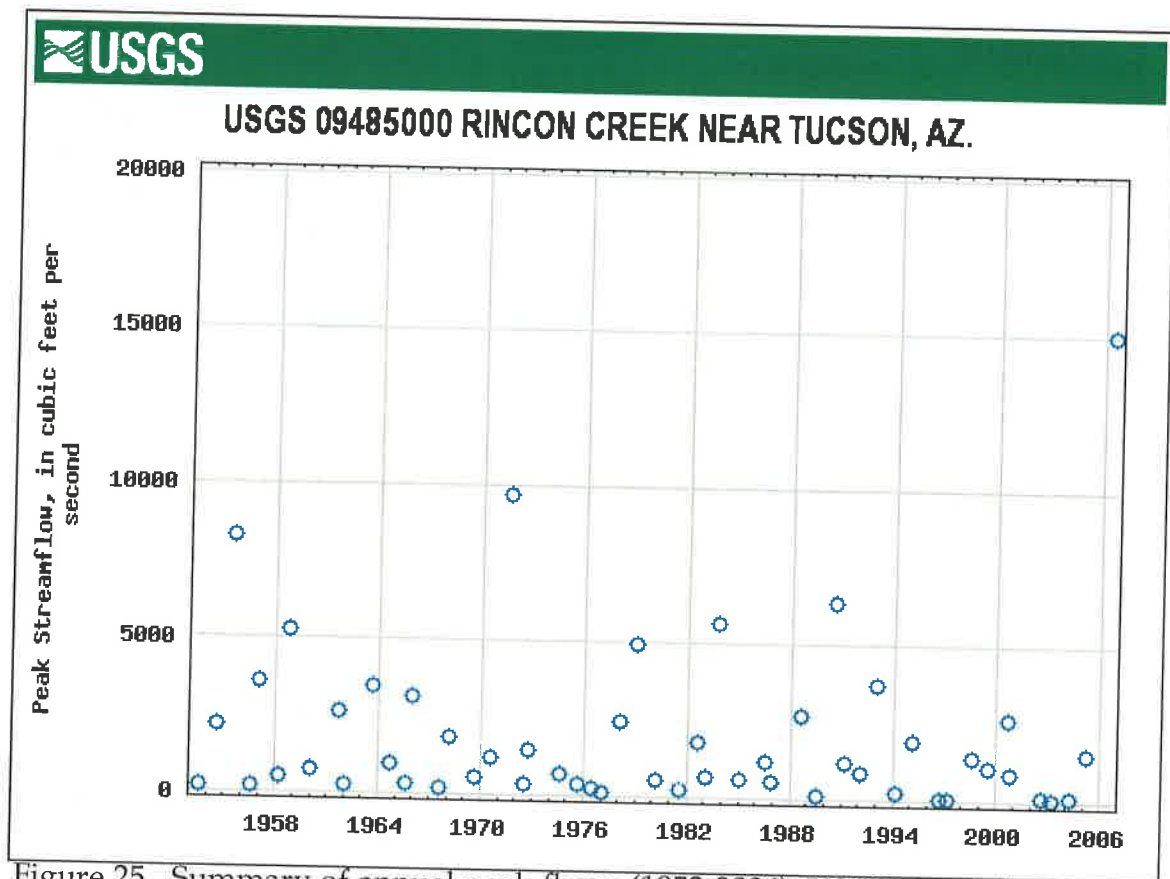


Figure 25. Summary of annual peak flows (1952-2006), USGS streamflow gauge, Rincon Creek near Tucson, Arizona.

Although parts of middle Rincon Creek channel bed are dominated by bedrock, still a large portion of middle Rincon Creek channel bed is alluvial dominated and, therefore, alters its form and geometry to flows. As with alluvial rivers all over the world, the alluvial dominated portions of middle Rincon Creek adjust as a result of changes in sediment and runoff. Lateral shifting of the channel, changes in channel geometry and gradient, and other morphologic change can abruptly occur during large flow events. Although base flow conditions can also produce channel morphologic change over time,

the occurrence of overbank flooding provides a convenient time for re-doing channel morphology surveys.

Channel cross-sections two, three, and four as well as Pool B were resurveyed after the July 2006 flood events to assess how the floods affected channel morphologic conditions. As additional survey data are collected in the future – describing both longitudinal and cross-section geometry – a channel morphology monitoring program would be able to describe trends in channel morphologic change with greater confidence. As it stands now, the channel morphologic monitoring program is young and is based on the results of only two surveys over a two-year period, providing only limited insights as to channel morphologic change that occurred as a result of the July flooding (see Appendix for graph results). The the second survey was not conducted until December 2007 and thereby reflects channel morphologic changes that occurred due to the July 2006 flooding as well as flow events that occurred between July 2006 and December 2007.

As the location of both elevation datums vary from one transect to the next, it is not the overall cross-sectional area under the datum that is of interest, but percent changes in area under the same elevation datum from one survey time period to the next. A positive percent change in cross-section area indicates an increase in channel cross-section area between the two survey periods (i.e., cross-section area 2007 > cross-section area 2005), while a decrease in channel cross-section area indicates a reduction in cross-section area (i.e., cross-section area 2005 > cross-section area 2007).

During the course of the monitoring period, percent change in channel cross-section increased – indicating evacuation of alluvium – in transect two, Pool B, and transect four (Fig. 26 and Table 6). Transect three experienced an overall decrease in percent cross-section area, which indicates overall aggradation. The channel cross-sectional area of Pool B changed most (increasing by almost 106%). The morphologic characteristics of Pool B prior to the flooding of 2006 were narrow (just over 10 ft wide at the pool's longitudinal center) and armored by large boulders that created cascading, turbulent flow even during low flow discharges. The removal of the pool's large boulders have the potential of creating large differences in morphologic survey results.

At Pool B, the July high flow event moved the boulders downstream a considerable distance, thereby removing a flow impediment that had contributed to the pool's formation and maintenance. However, the July flow also eroded the pool's right bank, excavating sediment from the roots of a large Arizona ash (*Fraxinus velutina*) that fell across the channel, producing similar hydraulic characteristics to that produced by the removed boulder (e.g., cascading, turbulent flow) (Fig. 27 and Appendix).

Table 6. Summary of change in cross-sectional area under established elevation datums at transects two, three, four, and pool B.

Transect No.	Cross-Channel Area (m ²) Under Designated Elevation Datum		Percent change since initial survey
	2005	2007	
Transect Two	92.90	97.18	4.61
Transect Three	74.76	70.23	-6.05
Pool B	8.41	17.29	105.69
Transect Four	41.20	57.36	39.23
Average	54.31	60.52	35.87

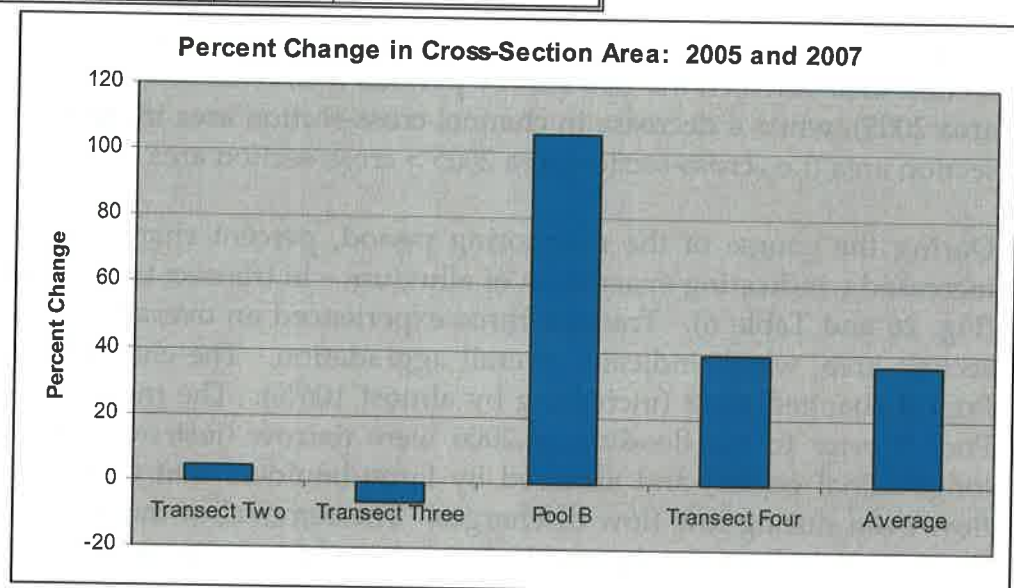


Figure 26. Bar graph summarizing percent change in cross-section area between the 2005 and 2007 surveys.

At Pool C, the roots and trunk of a sycamore stabilized of the pool's left bank morphology and forced flow to channel right which, during high flow events, produced turbulent flow that continually excavated alluvium on the right side of the channel, which formed and maintained the pool. The sycamore's removal allowed the channel to

straighten which, along with deposition that occurred during the descending limb of the July flood hydrograph, essentially removed Pool C. However, subsequent low flows appear to have excavated some of the alluvium deposited during the July flood, reestablishing some shallow pool characteristics (See Appendix).

At Pool C, the roots and trunk of a the sycamore stabilized and allowed persistence led to the formation and maintenance of the pool. The sycamore's removal allowed the channel to straighten which, along with deposition that occurred during the descending limb of the July flood hydrograph, essentially removed

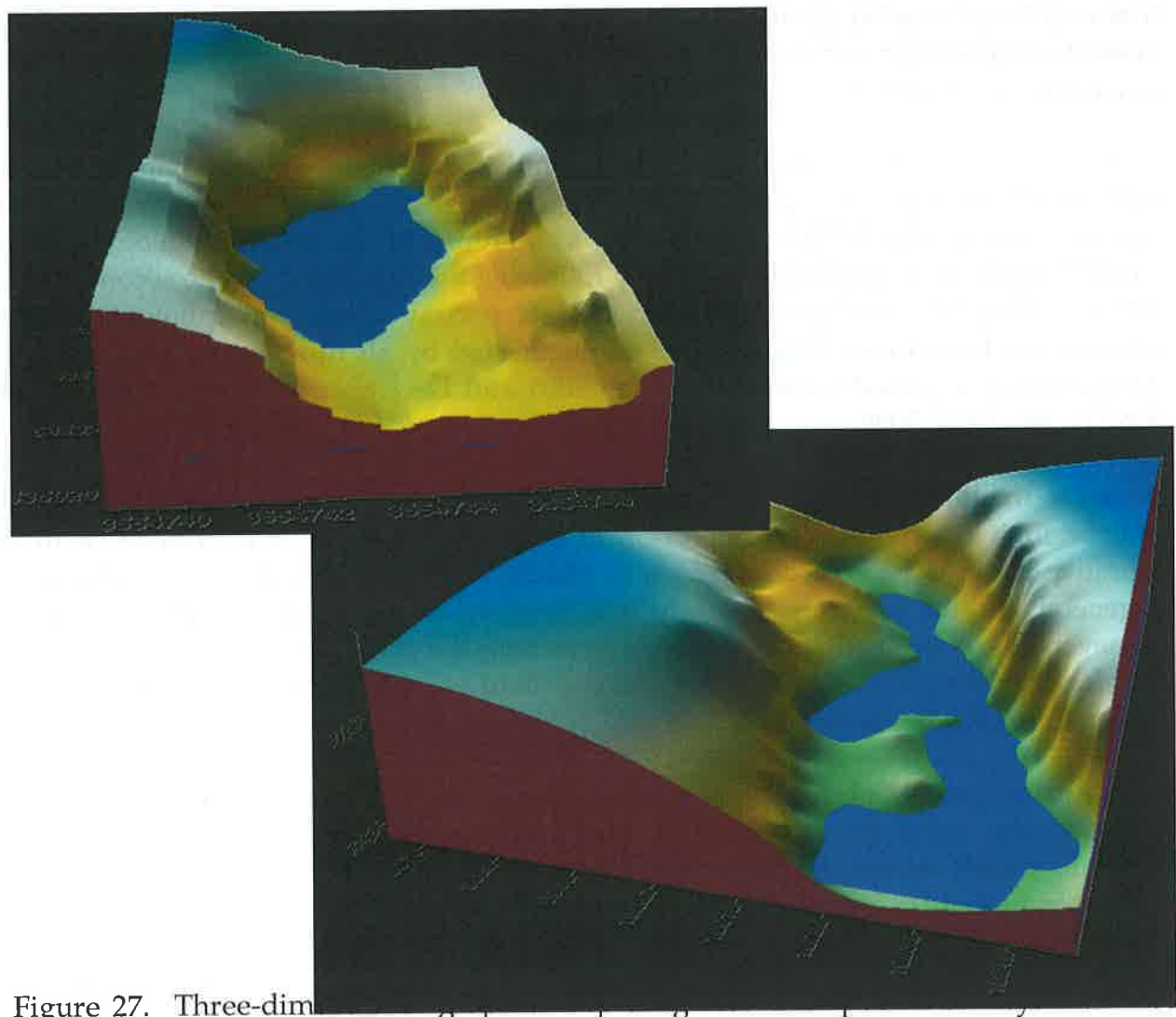


Figure 27. Three-dimensional perspective view of the channel cross-section in 2006 (top) and 2007 (bottom). Perspective is looking downstream. Water surface elevation for both graphics is at 3,145.52 ft (958.75 m). Note changes on channel left where some of the larger boulders were pushed downstream by the July 2006 floods.

CONCLUSION

During the three-year period of study, middle Rincon Creek experienced below than average streamflow as a result of drought conditions that affected much of the southwestern U.S. Despite the persisting drought conditions, the Tucson Basin was affected by a series of convectional storms during late July 2006 that led to extensive flooding in many parts of the basin. As a result of these storms, Rincon Creek experienced a large floods that culminated in a high magnitude flow, statistically rare flow event that crested at over 14,000 cfs (396 cms). The collection of pre-July 2006 channel morphologic survey data provided a baseline to which post-July 2006 survey data could be compared.

One of the objectives of the morphologic studies described in this chapter was to understand the extent of channel morphologic change that occurred as a result of the extreme flooding of July 2006. Ideally, the second round of channel morphology surveys should have been conducted immediately following the July 2006. As the second round did not take place until late 2007, survey data portray channel morphologic change between the two survey time periods as manifested by all flow events that occurred during the time period between the May 2005 and December 2007 surveys, with the flood event of July 2006.

Owing to the highly dynamic nature of streamflow in the semi-arid southwestern U.S. and the limited database (a comparison of only two surveys), it is difficult to draw definitive conclusions regarding trends in middle Rincon Creek's channel morphology, in general, and the impacts of the July 2006 flooding, in particular. Nevertheless, there are several conclusions that can be made from both the collected survey data as well as anecdotal information collected from several field reconnaissance trips along middle Rincon Creek following July 2006.

Field reconnaissance observations made immediately following the July 2006 flood indicated the flood event deposited considerable amounts of sediment (probably occurring mostly during the descending limb of the July 2006 flow) throughout much of the upper half of the middle Rincon Creek reach. For example, transect two (pool A) appeared to be almost filled in with sediment in August 2006. However, based on the results of the channel morphology surveys of 2007, it appears that large amounts of sediment deposited during the July 2006 flooding have been evacuated by flow events that occurred between the flood of July 2006 and the December 2007 survey of channel morphology. Particularly with regard to the upper half of middle Rincon Creek, it appears that channel morphologic conditions are similar to that which existed prior to July 2006.

Of the specific areas surveyed or observed along middle Rincon Creek, an exception to the above generalization may be middle Rincon Creek's pools. For example, both pools B and C experienced major channel morphologic change during the period between the 2005 and 2007 surveys, and more specifically as a result of the July 2006 flood. However, these changes were probably due more to changes in channel obstructions - which, in turn, affected pool hydraulic characteristics than to watershed scale changes in sediment and water runoff. Prior to July 2006, Pool B was dominated by large boulders and cascading flow conditions, while Pool C was dominated by the large trunk of a sycamore tree. Both of these obstructions were removed during the course of the July 2006 flow, resulting in major channel morphologic change. Pool B still exists owing, at least in part, to a large ash that fell across the center of the pool, impinging flow and causing turbulent flow conditions similar to that created by the large boulders that dominated this pool prior to the July 2006 flooding. In contrast, the removal of the sycamore from the left bank of Pool C resulted in almost the complete loss of pool characteristics at that site.

Two general conclusions can be drawn from the assessment of channel morphologic change since the 2005 survey. First, pools seem to be part of the long-term make up of the middle Rincon Creek system. Although Pool C was removed during the July 2006 flooding, the other pools survived, albeit in some cases (e.g., Pool B) with altered morphology. Morphologic change at Pool C was particularly dramatic in that the loss of the sycamore allowed the channel to straighten, thereby eliminating many of the hydraulic characteristics that led to the pool's formation in the first place. In contrast, Pool B persists owing to its heavily armored nature (large boulders evacuated from the immediate area appear to have been replaced by others) as well as the downing of large Arizona ash, which now straddles the center of the pool, providing another impediment to flow that appears to be maintaining some of the pool's pre-July 2006 morphologic characteristics.

Although any definitive conclusion with regard to the long-term viability of middle Rincon Creek's pool system will probably have to wait for the results of future monitoring, the occurrence of a high magnitude, statistically rare flood like that which passed through the system in July 2006 reinforces the concept that pools are a long-term feature. In this regard, the occurrence of a 14,000 cfs flow event during the course of the study was of great benefit to the study as it provided the basis to see first hand what would happen to channel morphologic conditions when a high magnitude, statistically rare flow event occurred. Put another way, the lack of flow during much of the study period provided no indication that the pools are a fleeting morphologic trait that could possibly be removed by the next high magnitude flood event. The fact that most of the pools did persist after the large flood of 2006 gives credence to their staying power.

Though not directly related to quantifying the water needs for bottomland vegetation, this conclusion is important given the importance of the pools to surface water availability, which in turn provide conditions needed for the persistence of emergent plants and numerous species of fauna.

The July 2006 flow evacuated and redeposited large debris and sediment plugs from the middle Rincon Creek reach. Some of the pools were altered; others were filled in with sediment, but returned to resemble their pre-July 2006 morphologic characteristics as accumulated sediment was evacuated during subsequent flow events (see Appendix). At least with regard to middle Rincon Creek's pool system, it is likely that some pools are short-lived, forming during scouring flow, later 'disappearing' during periods of aggradation, and possibly forming again when sediment is evacuated. Pools A through D may not be found in their current form or may be altogether absent if a similar study is conducted ten years from now. Nonetheless, it appears likely that pools of similar characteristics and form will be found, . They may not be pools A through D, but it seems likely that pools will probably be present, providing surface water storage for a plethora of wildlife as long as surface flow continues to persist and remains unaffected by human perturbations.

Second, despite dramatic changes to some of middle Rincon Creek's pools caused by the removal and addition of flow obstructions; it appears that the July 2006 flood event produced little long-term morphologic change to the middle Rincon Creek system. Certainly, morphologic changes occurred, but it appears that much of the morphologic change that occurred as a result of the July 2006 flood (e.g., alluvial deposition) had little staying power and the creek's overall morphology appears similar to conditions prior to July 2006.

The results indicate that channel morphologic conditions (particularly as related to the amount of sediment entering and leaving the study reach) are relatively stable and are not likely to experience sudden and dramatic changes in morphologic form. Such stability provides a measure of confidence with regard to the persistence of middle Rincon Creek's bottomland plant community, at least with regard to plant/channel morphologic relations. In other words, It does not appear that sudden changes in channel morphologic conditions (e.g., sudden increases in channel width as a result of channel incisement) will be a major concern with regard to factors that are likely to affect the long-term viability of middle Rincon Creek's bottomland plant community.

Channel incision would lead to decline in shallow groundwater elevation that, in turn, could compromise the viability of middle Rincon Creek's deciduous riparian and emergent plant communities. As channel incision did not occur to any great extent during the course of the study (as well as during the July 2006 flood event) reduces

concern that degradational processes could dominate the middle Rincon Creek reach in the future (see also Conclusion Chapter).

With regards to the stage-discharge model, the model predicts that a discharge of 60 cfs (1.7 cms) will inundate low-flow floodplain surfaces on the majority of the channel cross-sections that were surveyed. Comparing this discharge to the long-term streamflow record at the US Geological Survey streamflow gauge indicates that a daily mean discharge of 60 cfs occurs roughly 3.51% of the time, or on average once every 28 days (or a little over 12 times per year). Of particular importance to the long-term viability of middle Rincon Creek's bottomland plant community is that such an inundation flow occurs during the spring (to promote propagation) and summer (to augment water availability) months.

As mentioned previously, it is doubtful that pumping (even pumping that is occurring at considerably higher rates than what is occurring today) will affect the frequency or even the magnitudes of such flow events. For example, a 60 cfs discharge (i.e., a discharge capable of producing overbank flow along much of the middle Rincon Creek reach) occurring over a 15 minute period gives a volume of 54,000 ft³ (1,529 m³). A groundwater withdrawal rate of 1,600 gallons per minute (6.1 cubic meters per minute) equates to a volume of 3,209 ft³ (91 m³) over the same 15-minute time period. Even if future pumping levels increase five-fold above this maximum level, the difference between the volume of water removed by pumping is magnitudes less than the volume of water that enters the system naturally at flood stage. Therefore, it is probably safe to conclude that the instantaneous affect of pumping on the magnitude and frequency of overbank flow events is probably minimal.

Of course, the concern is not with pumping over a 15 minute period, but with the hydrologic consequences of drawing 1,600 gpm from the aquifer over numerous years. Of particular concern in this regard is the potential effects pumping will have on groundwater levels and on streamflow of considerably smaller magnitude than bankfull. Overdraft of groundwater will lead to groundwater decline, which could drop below the root zone of most riparian deciduous trees, leaving them high and dry during the hot and dry months of May and June (when their dependence on shallow groundwater is at its greatest). In addition, a decline in groundwater elevation could affect streamflow, particularly low discharge flow events that become increasingly 'swallowed' by the increased volume of the nonsaturated zone of the soil profile (i.e., the portion of alluvium above the elevation shallow groundwater levels). Such impacts could affect on both the duration and frequency of low discharges, potentially leading to an increase in the number of no-flow days that occur on average during a given year.

The results of the stage-discharge model appear to diminish concern with regard to the effects of pumping on discharges at or greater than bankfull. Although flooding is critically important to the long-term viability of middle Rincon Creek's bottomland plant community and will probably not be affected by ground-water withdrawals. In other words, flows of discharge magnitudes at or greater than bankfull will continue to occur at frequencies and durations that will probably be unaffected by withdrawals. Certainly, the frequency and duration of bankfull discharges could be affected by a variety of other factors such as upper watershed activities, climate change, channel incision, etc.

CHAPTER V. MIDDLE RINCON CREEK'S POOL SYSTEM

OVERVIEW

The position of the middle reach of Rincon Creek along the pediment of the Rincon Mountains makes it a middle-order stream that transitions between reaches that are dominated for the most part by bedrock and reaches that are mostly alluvial. From the confluence of Rincon Creek and Chimenea Creek, the slope of the Rincon Creek channel is much less than that of its headwater reaches. Channel form is not completely dominated by geology, and there are portions of this study reach that have substantial floodplain development, with alluvial depositional features dominated by a diversity of alluvial material sizes, ranging from boulders to sand/silt. From the upstream end of the study reach, the stream traverses shallow alluvial basins that are contained and intersected by shallow bedrock. From the upper end of middle Rincon Creek, the general trend is one of deeper and more extensive alluvium in the downstream direction.

Within this range of channel materials and form, middle Rincon Creek has four major pools, which collect and hold water for long periods of time following the cessation of flow. These pools are labeled A, B, C, and D (upstream to downstream) and are located 400 ft (122 m), 1,473 ft (449 m), 1,713 ft (522 m), and 3,455 ft (1,053 m) downstream of the confluence of Rincon Creek and Chimenea Creek, respectively (Fig. 16).

In the semi-arid climate of the Southwest, surface moisture is less available during the hot, dry months of May and June, which makes the pools and the moisture they hold of great importance to a whole range of species, from wetland plants, aquatic invertebrates, herpetofauna, birds, and mammals. As a month of consecutive no-flow days is not uncommon during these dry periods, the surface water that the pools offer is potentially the only source of water for wildlife in the immediate area. This fact alone makes them important for many wildlife species and is the reason for focusing on them in particular as one aspect of this investigation.

Given the dynamic nature of stream hydrology, it is a given that these pools will form and then disappear over time due to a variety of factors, including the presence of boulders and large woody debris, which create conditions of flow convergence, divergence, and sediment retention. In addition, fluxes of sediment will work their way through middle Rincon Creek, creating localized aggradation conditions (sometimes burying pools), which is reversed later on as sediments are slowly evacuated (reestablishing pool conditions). The rate that accumulated sediments are evacuated are determined by factors such as including the size of the alluvial material, fluxes of sediment brought in during future flow events, streamflow characteristics, and many other factors (Montgomery 1999). During high magnitude, high energy flow events, much alluvial material can be mobilized and transported downstream, in some cases

resulting in pools being both created and lost (filled in) during the same hydrologic event. Indeed, all four of the pools studied either disappeared or were substantially altered during high flow events during the summer of 2006.

Although the overall position, form, and size of the four pools are largely determined by such factors as geology and in-channel obstacles, their capacity to provide surface water for long periods when Rincon Creek is not flowing (e.g., the dry, hot months of the early summer) is determined largely by flow conditions prior to a long no-flow period as well as by their volume, which changes based on the balance between rates of sediment deposition and evacuation.

Pools are generally present and are a critical part of middle Rincon Creek's bottomland ecosystem. The four pools present during the course of this study are not an abnormality and probably represent a long-term average of pool water storage conditions along this reach of Rincon Creek.

Results of studies of middle Rincon Creek's population of selected herpetofauna and aquatic invertebrates found that these biota have specific water requirements affected by changes in pool surface area and pool volume (i.e., going from full to dry) (pers. comm., David Walker (2006); pers. comm., Don Swann (2006)). The pool volume/pool surface area requirements varied depending on the species being studied, the time of the year (in this case, when during the May-June period), and a variety of physical factors that have a bearing on water availability throughout the Rincon Creek bottomland system, including precipitation, temperature, wind velocities, etc.

As far as the quantification of the water needs for bottomland vegetation is concerned, the streamflow needed to maintain pools at near capacity during May and June was deemed critical (as opposed to other times of the year when Rincon Creek flows more frequently and surface water is available in many other parts of the bottomland ecosystem).

There are two main objectives of this chapter. First, review morphologic survey results of middle Rincon Creek's four main pools, discussing their over all size, shape, and volume. Second, describe water occurrence in the pools during the dry months of May and June.

METHODS

These two objectives were realized in four main steps:

- 1) Compile field survey results of wetted longitude along middle Rincon Creek over a three-year period,
- 2) Based on the results of pool surveys, develop pool surface area/surface water elevation and pool volume/surface water elevation relations,
- 3) Correlate wetted longitude measurements to surface area and pool volume thresholds, and,
- 4) Correlate distinct pool surface area and pool volume with streamflow conditions, and then describe water occurrence in the pools during the dry months of May and June.

Wetted longitude is defined as the length of stream channel containing at least some surface water. Beginning in March of 2003, Sagu personnel began measuring the wetted longitude of middle Rincon Creek using GPS technology to 'mark' the upstream and downstream end of each continuous occurrence of surface water. In this context, surface water means both flowing and standing water. Wetted longitude measurements were conducted at least once every two weeks during times when the creek was not completely dry. Given a sufficient length of a no-flow period, middle Rincon Creek's wetted longitude eventually centered on the channel's four major pools. Usually the time period between cessation of flow and the wetted longitude coalescing on middle Rincon Creek's major pools was rapid as the surface area of channel surface water was lost through the processes of transmission (in areas where the stream channel was dominated by alluvium), evapotranspiration, and evaporation. Once the wetted longitude become pool-focused, the decrease in wetted longitude length slowed as the ratio of surface area susceptible to evaporation is reduced.

Although relatively easy to measure in the field, wetted longitude is difficult to relate to specific water requirements for aquatic invertebrates and herpetofauna. A more appropriate measurement in this regard is pool volume and pool surface area as both parameters can be related to fecundity and diversity of herpetofauna and aquatic invertebrates studies (Walker, pers. comm. (2006) and Swann, pers. comm. (2006)). The correlation between wetted longitude and pool volume/pool surface area was developed in two main steps. First, the four main pools were surveyed in detail. Second, survey data were then entered into a geospatial software program called Surfer, which allowed pool volume and surface area to be estimated based on inputs of surface elevation.

For each pool data set, at least ten different surface elevations were entered, ranging from zero depth to full. Using the Surfer software, pool volume and surface area were

calculated for each of the surface elevations, results were graphed (two graphs for each pool: surface elevation-pool volume and surface elevation-pool volume), and polynomial equations were developed such that investigating biologists could convert any surface elevation measurement (or its surrogate, pool depth) of interest to an estimate of pool surface area and/or pool volume.

During the same time period, biologists studying middle Rincon Creek's aquatic invertebrate and herpetofauna population identified critical pool depths required to maintain the long-term viability of selected target species. Pool depths were easily converted to pool surface elevations, which were converted to pool volumes and pool surface areas using the polynomial equations developed for each pool.

In this manner, the relations were developed needed to correlate streamflow to pool requirements for aquatic invertebrates and herpetofauna. In summary, pool biological requirements were identified (quantified as pool depth, which is easily converted to pool surface elevation), pool surface elevations were converted into pool volumes and/or surface area, surface area was then converted to wetted longitudes, which were matched with field data and correlated to streamflow as recorded at the USGS flow gauge.

Using the developed equations, pool surface areas can be easily estimated for all pool depths of interest (as well as pool volumes). Similarly, pool surface areas were converted into wetted longitude measurements by directly measuring wetted longitudes from graphic representations. Wetted longitude thresholds were then compared to collected wetted longitude data such that streamflow characteristics required to maintain these water requirements could be developed. To develop the streamflow characteristics needed to maintain these critical pool levels, mean daily streamflow as recorded at the US Geological Survey gauge was tabulated and analyzed for a period of twenty days prior to the wetted perimeter measurement.

RESULTS

Pool Survey and Development of Relations between Wetted Longitude, Water Surface Elevation, Surface Area, and Volume

Pool A

Pool A was long and narrow, bordered on its sides by bedrock and a shallow alluvial base. Based on the 2005 survey of Pool A's morphology, the maximum volume of the pool is estimated at almost 29 m³ (1,024 ft³), with a maximum surface area of just over 100 m² (1,076 ft²) (Fig. 28 and Table 7). At its maximum capacity, depth at the deepest

part of pool A is about 0.6 m (1.9 ft), which corresponds to a wetted longitude of 23.6 m (77.4 ft).

Table 7. Summary of depth, surface area, pool volume, and wetted longitude with increasing water surface elevation at Pool A.

Depth (m)	Water Surface Elevation (m)	Surface Area (m ²)	Volume (m ³)	Wetted Longitude (m)
0	961.11	0	0	0
0.01	961.12	0.038	0.001	0.1
0.03	961.14	0.615	0.0048	0.85
0.09	961.2	11.465	0.361	5.5
0.14	961.25	19.92	1.14	11.6
0.19	961.3	27.258	2.308	12.78
0.24	961.35	36.54	3.88	13.4
0.29	961.4	44.89	5.859	16.9
0.39	961.5	72.19	11.81	20.3
0.49	961.6	87.35	19.58	23.3
0.59	961.7	100.77	28.67	23.6

Pool B

As surveyed in 2005, Pool B shorter and deeper than Pool A. As with Pool A, Pool B is bordered on its sides by bedrock and has a base consisting of a veneer of alluvium that overlies bedrock. At its maximum isolated capacity (surface water elevation where pool B is at capacity, yet isolated from upstream and downstream flow), is almost 53 m³ (1,872 ft³), with a maximum surface area of just over 103 m² (1,109 ft²) (Fig. 29 and Table 8). At its maximum capacity, depth at the deepest part of pool A is about 1.2 m (3.9 ft), which corresponds to a wetted longitude of 15.71 m (51.5 ft).

Table 8. Summary of surface area, pool volume, wetted longitude with increasing depth at Pool B.

Depth (m)	Water Surface Elevation (m)	Surface Area (m ²)	Volume (m ³)	Wetted Longitude (m)
0	958.25	0	0	0
0.05	958.3	0.52	0.007	0.41
0.1	958.35	1.6	0.061	1.43
0.15	958.4	3.17	0.17	2.07
0.2	958.45	7.33	0.42	4.21
0.25	958.5	11.59	0.89	5.93
0.3	958.55	15.49	1.56	6.14
0.35	958.6	19.5	2.41	7.21
0.45	958.7	27.87	4.73	9.36
0.55	958.8	38.99	7.89	13.43
0.65	958.9	52.11	12.33	13.57
1.1	959.35	94.04	43.5	15.29
1.2	959.45	103.42	52.78	15.71

Pool C

With a maximum isolated capacity of 11.4 m³ (403 ft³), pool C is the smallest of middle Rincon Creek's major pools. At this surface elevation, Pool C has a depth of 0.5 meters (1.6 ft) and a wetted longitude of 11.5 m (38 ft) (Fig. 30 and Table 9). Its oblique shape is due to both bed morphology as well as a large sycamore that established on the left bank (this tree was removed during the July 2006 flooding, considerably altering Pool C's morphologic appearance), forcing flow toward the right bank. Unlike Pools A and B, Pool C is completely bedrock dominated with no alluvial aggradation along its bed during the years of study. At its maximum capacity, depth at the deepest part of pool A is about 1.2 m (3.9 ft), corresponding to a wetted longitude of 11.46 m (38 ft).

Table 9. Summary of surface area, pool volume, wetted longitude, and water surface elevation with increasing depth at Pool C.

Depth (m)	Water Surface Elevation (m)	Surface Area (m ²)	Volume (m ³)	Wetted Longitude (m)
0	957.8	0	0	0
0.1	957.9	0.61	0.053	0.27
0.2	958	2.69	0.16	2.16
0.25	958.05	6.58	0.37	5.48
0.3	958.1	12.47	0.816	9.1
0.35	958.15	22.27	1.63	10.54
0.42	958.22	35.71	3.61	10.65
0.45	958.25	39.75	4.7	10.71
0.5	958.3	44.5	6.74	10.75
0.6	958.4	51.64	11.38	11.46

Pool D

With a maximum isolated capacity of over 52 m³ (1,836 ft³), pool D is capable of holding larger amounts of water. At its full isolated capacity, Pool D has a depth of 0.8 meters (2.6 ft) and a wetted longitude of over 30 m (98 ft) (Fig. 31 and Table 10). It is long in shape with little alluvial aggradation along its bed during the years that was studied. At its maximum isolated capacity, the greatest depth is 0.8 m (2.6 ft) and its surface area is the largest of all of middle Rincon Creek's pools, at over 180 m². Wetted longitude at maximum capacity is 30.71 m (100.7 ft).

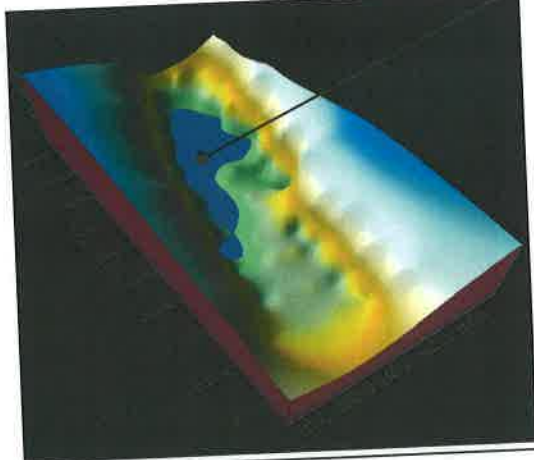
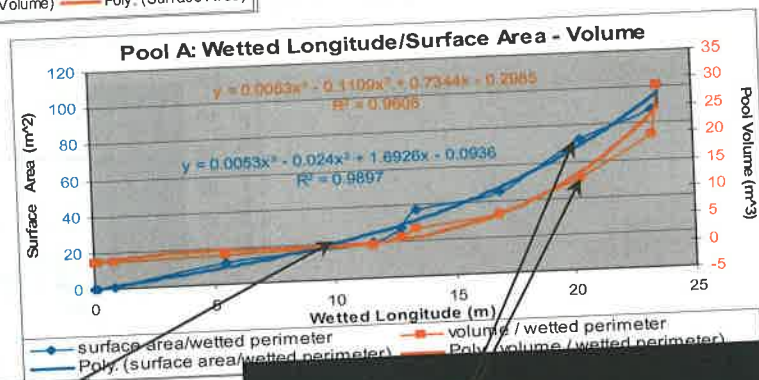
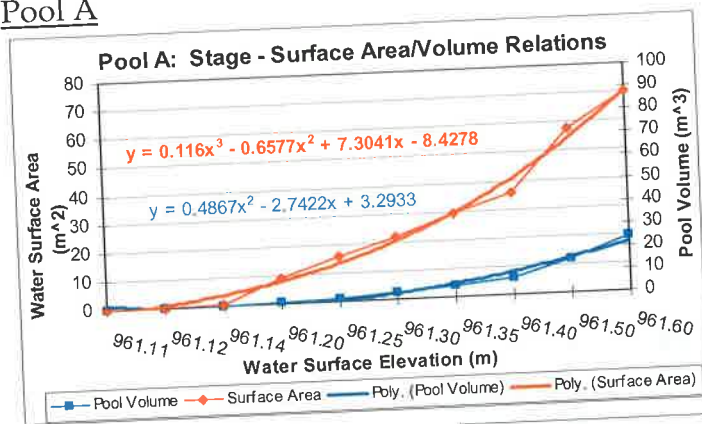
Table 10. Summary of surface area, pool volume, wetted longitude, and water surface elevation with increasing depth at Pool D.

Depth (m)	Water Surface Elevation (m)	Surface Area (m ²)	Volume (m ³)	Wetted Longitude (m)
0	953.8	0	0	0
0.1	953.9	2.62	0.09	1.5
0.2	954	11.99	0.76	7.86
0.3	954.1	30.3	2.69	11.43
0.4	954.2	59.3	7.1	20.71
0.5	954.3	84.4	14.2	22.29
0.6	954.4	111.28	23.8	24.29
0.7	954.5	146.04	36.34	29.29
0.8	954.6	180.81	52.37	30.71

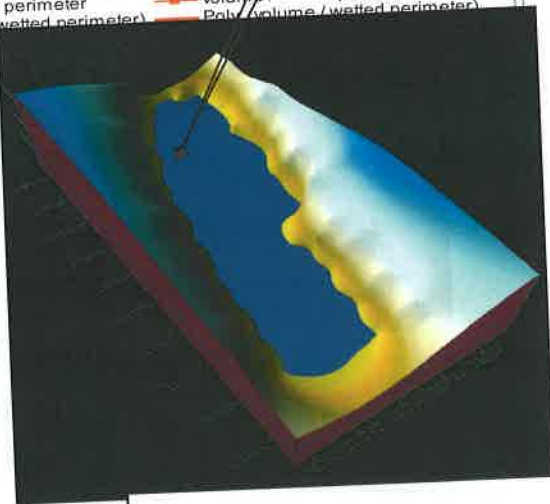
Correlating Wetted Longitude with Streamflow

Four different wetted longitude categories were developed based on the presence or absence of surface water and how the surface water in the area of the pools relate to surface water along the entire middle Rincon Creek study reach. A dry (D) category indicates no surface moisture in the pools or elsewhere along the channel of middle Rincon Creek. A wet disconnected (WD) category was given when the pools contained water, yet portions of the middle Rincon Creek channel were dry, making the pool surface moisture isolated (or disconnected) from the most of the bottomland environment. A wet connected (WC) indicates that surface moisture at the time of measurement extended larger distances up- and downstream of the pools; that is, at the time of measurement, pool waters were connected with waters along the middle Rincon Creek channel. And, finally, a totally wet (TW) category indicates that the entire (or grand majority) of the middle Rincon Creek channel contained water. For the most part, a TW classification indicates that flow was occurring at the time of measurement.

Pool A



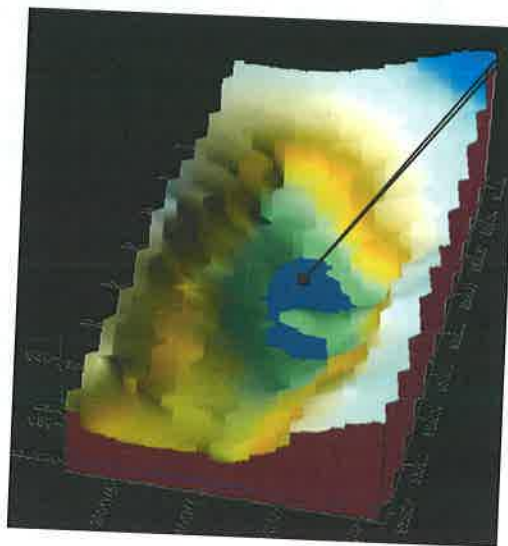
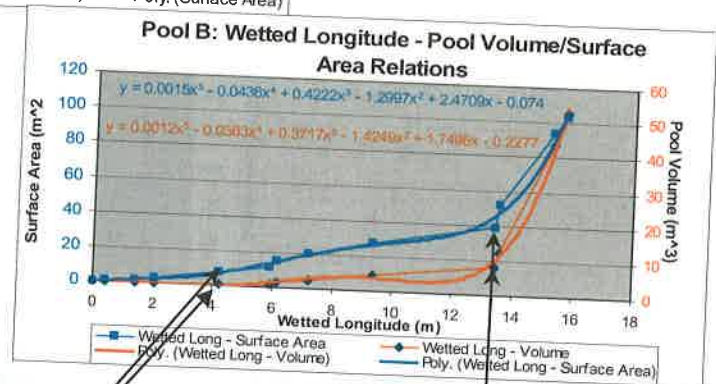
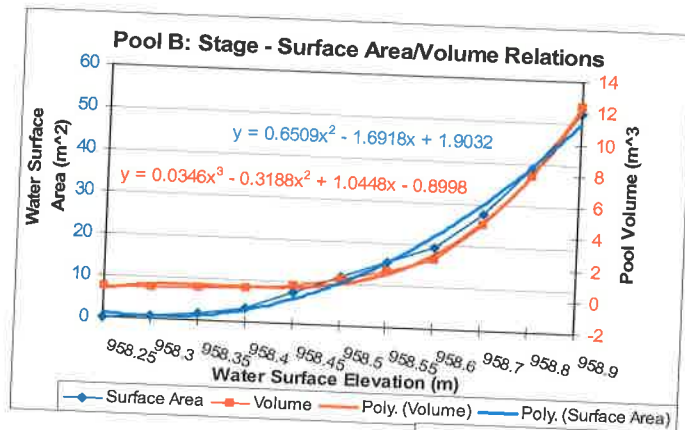
Idealize graphic of pool A with surface water elevation of 961.25 m (3,154 ft).



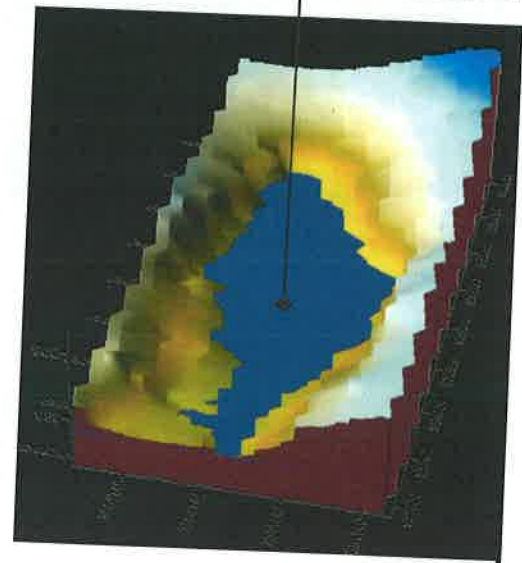
Idealize graphic of pool A with surface water elevation of 961.5 m (3,154.52 ft).

Figure 28. Portrayal of the correlation of water surface elevation with water surface area and pool volume (left graph) and wetted longitude with water surface area and pool volume (right graph).

Pool B



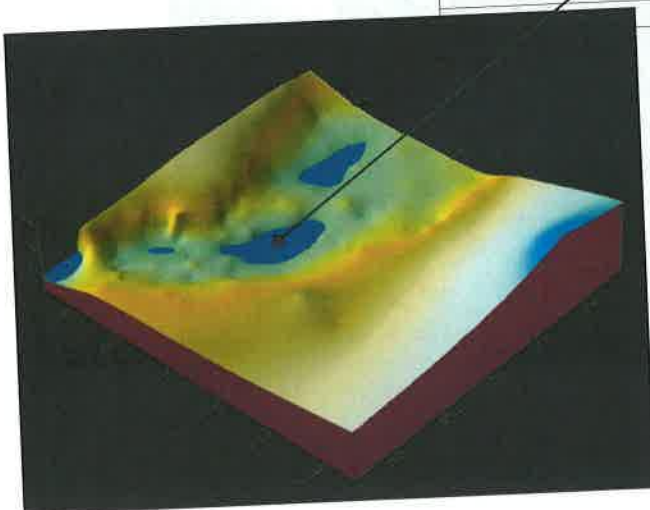
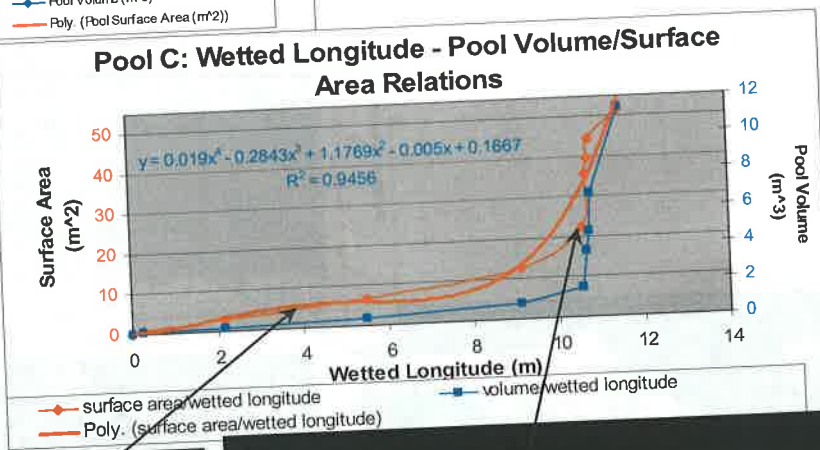
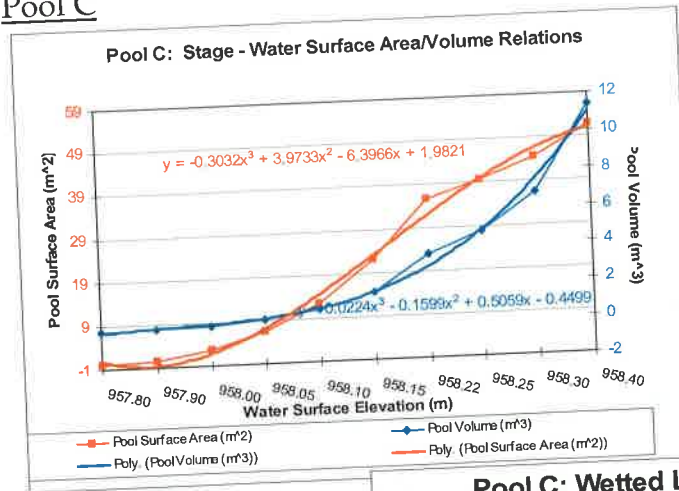
Idealize graphic of pool B with surface water elevation at 958.45 m (3,144.52 ft).



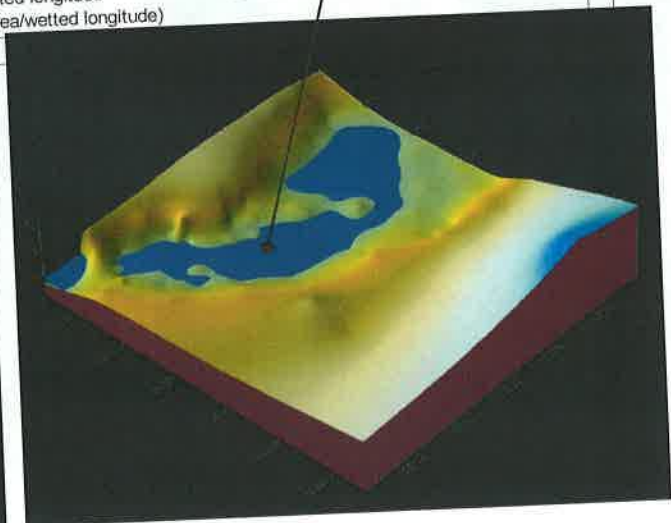
Idealize graphic of pool B with surface water elevation at 958.8 m (3,145.67 ft).

Figure 29. Portrayal of the correlation of water surface elevation with water surface area and pool volume (left graph) and wetted longitude with water surface area and pool volume (right graph).

Pool C

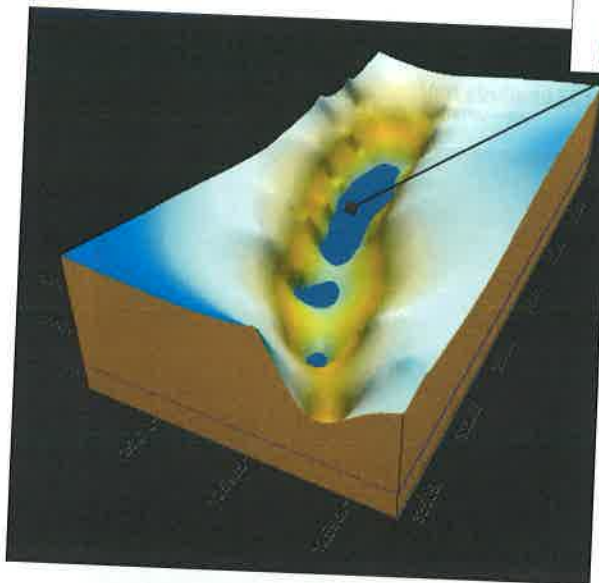
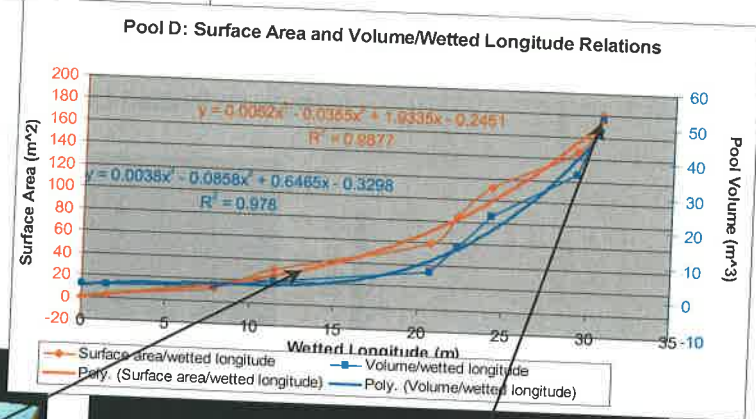
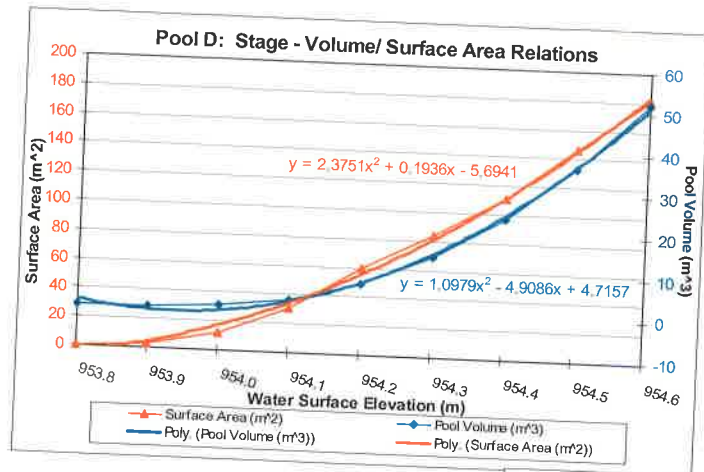


Idealize graphic of pool C with surface water elevation at 958.05 m (3,143.21 ft).

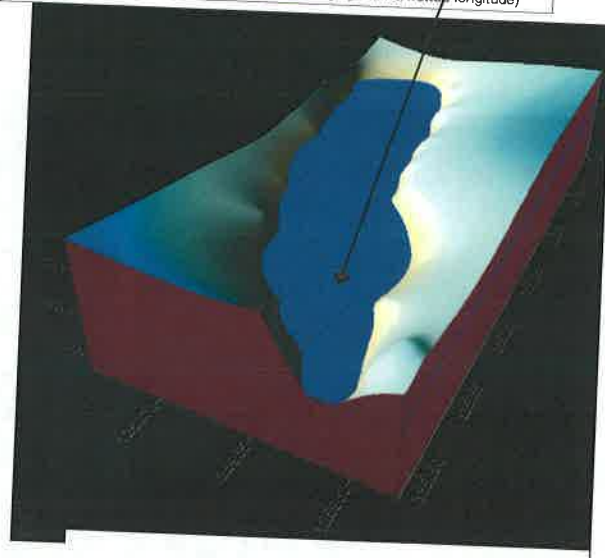


Idealize graphic of pool C with surface water elevation at 958.15 m (3,143.54 ft).

Figure 30. Portrayal of the correlation of water surface elevation with water surface area and pool volume (left graph) and wetted longitude with water surface area and pool volume (right graph).



Idealize graphic of pool D with surface water elevation at 954.1 m (3,130.25 ft).



Idealize graphic of pool D with surface water elevation at 954.6 m (3,131.89 ft).

Figure 31. Portrayal of the correlation of water surface elevation with water surface area and pool volume (left graph) and wetted longitude with water surface area and pool volume (right graph).

All wetted longitude measurements were correlated to Rincon Creek streamflow as recorded at the USGS streamflow gauge. With the exception of the TW classification (when flow was occurring), the state of surface water at the time when the longitudinal measurement was taken is not solely indicative of streamflow conditions at the time of measurement, but is also a reflection of flow conditions for an period of time prior to the wetted longitudinal measurement.

The analysis and correlation of streamflow data versus wetted longitudinal data indicates that the wetted longitude changes comparatively rapidly as the 'wetted' classification goes from TW to WC to WD during times when flow dropped precipitously (or went to zero). As surface water along the channel bed dries and concentrates in the pool areas during times of no-flow, the rate of change in wetted perimeter slows. The entire cycle is repeated when flow re-occurs (Fig. 32 through 34).

A twenty-day period was selected as adequate to make the correlation between wetted longitude and streamflow conditions prior to when the wetted perimeter measurement was taken. The twenty day period included the day the wetted longitudinal measurement was taken and the 19 days preceding the measurement (Table 11).

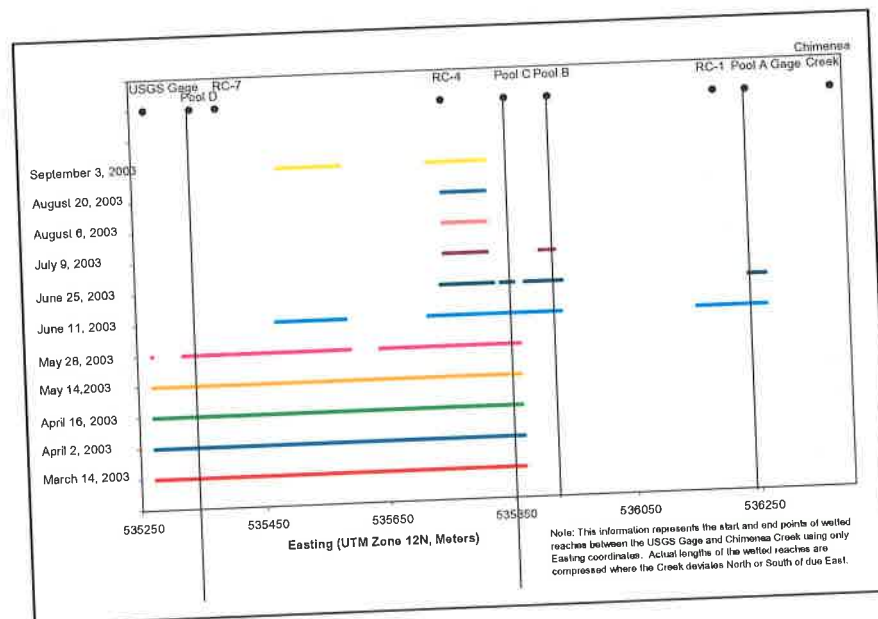


Figure 32. Wetted longitude measurements 2003 (adapted from Davis 2006).

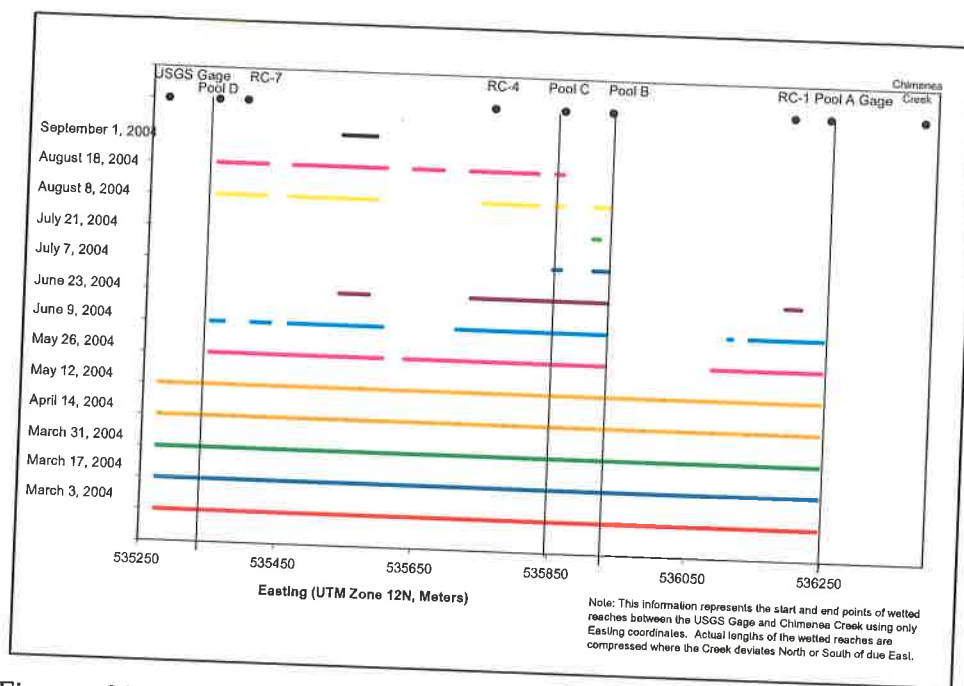


Figure 33. Wetted longitude measurements 2004 (adapted from Davis 2006).

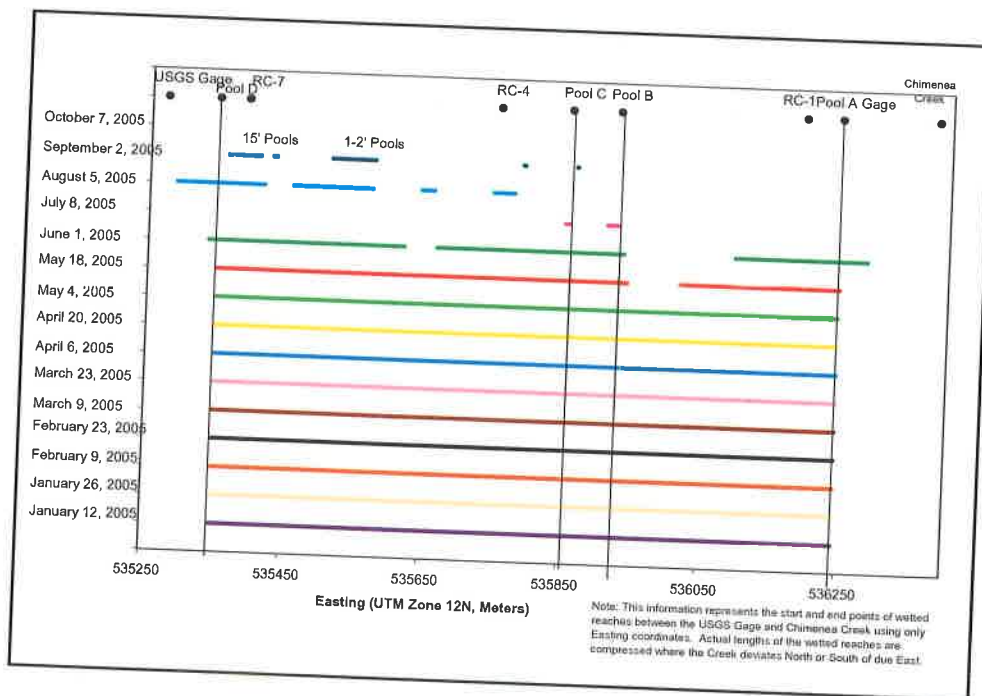


Figure 34. Wetted longitude measurements 2005 (adapted from Davis 2006).

Table 11. Summary of wetted pool longitude (WPL) of pools A through D as categorized as dry (D), wet-disconnected (WD), wet-connected (WC), and totally wet (W).

Date	Pool Data				20-day mean discharge prior to WPL measurement (cfs)
	A	B	C	D	
3/14/2003	D	D	WC	WC	34.59
4/2/2003	D	D	WC	WC	5.91
4/16/2003	D	D	WC	WC	16.72
5/14/2003	D	D	WC	WC	0.41
5/28/2003	D	D	WC	WC	0.17
6/11/2003	WD	WD	WD	D	0.02
6/25/2003	WD	WD	WD	D	0.00
7/9/2003	WD	WD	D	D	0.00
8/6/2003	D	D	D	D	0.00
8/20/2003	D	D	D	D	0.01
9/3/2003	D	D	D	D	6.00
3/3/2004	TW	TW	TW	TW	36.11
3/17/2004	TW	TW	TW	TW	8.36
3/31/2004	TW	TW	TW	TW	16.72
4/14/2004	TW	TW	TW	TW	0.43
5/12/2004	TW	TW	TW	TW	0.20
5/26/2004	WC	WC	WC	WC	0.03
6/9/2004	WD	WD	WC	D	0.00
6/23/2004	D	WD	WD	D	0.00
8/4/2004	D	WD	WD	D	0.00
8/18/2004	D	D	WD	D	0.00
9/1/2004	D	D	D	D	13.35
1/12/2005	TW	TW	TW	TW	5.87
1/26/2005	TW	TW	TW	TW	13.24
2/9/2005	TW	TW	TW	TW	49.52
2/23/2005	TW	TW	TW	TW	11.32
3/9/2005	TW	TW	TW	TW	1.50
3/23/2005	TW	TW	TW	TW	0.57
4/6/2005	TW	TW	TW	TW	0.26
4/20/2005	TW	TW	TW	TW	0.17
5/4/2005	TW	TW	TW	TW	0.13
5/18/2005	WC	WC	WC	WC	0.06
6/1/2005	WC	WC	WC	WC	0.00
7/13/2005	D	WD	WD	D	0.00
8/5/2005	D	D	D	WD	0.00
9/2/2005	D	D	WD	D	0.00
10/7/2005	D	D	D	D	0.00

The focus is on streamflow-wetted longitude analyses for the months of May and June, which are typically the driest of the year and when water stored in pools potentially provide the most benefit to area wildlife. This is not to say that the pools do not provide benefit to wildlife during other times of the year, it is that the months of May and June are typically so dry and hot, that the surface moisture that the pools contain may be the only surface moisture available in Rincon Creek's bottomland system.

During May and June, surface water along middle Rincon Creek channel rapidly dries following the cessation of flow, going from a TW category to WC, then to WD in just a few days. Once the water is concentrated in the pool areas, it may take weeks or longer for the water to go from a WD category to D, or dry. Therefore, analyzing streamflow during May and June when wetted longitude measurements were categorized as either TW or WC was deemed most critical. That is, analyzing streamflow conditions 20 days prior to a wetted longitude classification of WD or D would often give a mean of zero, as it can take 20 days following the cessation of flow for pools to go from WD to D.

During the time period when wetted longitude measurements were taken, there were five times when the surface water was categorized as either TW or WC for all four pools. The dates and average flow for the day the wetted longitude measurement was taken and the 19 days preceding are as follows: 5/12/04 (.43 cfs), 5/26/04 (.20 cfs), 5/4/05 (.17 cfs), 5/18/05 (.13 cfs), and 6/1/05 (.06 cfs). Taken together, the average flow for these five events is 0.2 cfs (.006 cms).

CONCLUSION

Pools A, B, C, and D provided a total storage capacity of 5,128 ft³ (145.2 m³) (Table 12). Although small when compared to lakes and even small ponds, such an amount of water allows for the occurrence of surface moisture during the driest and hottest times of the year.

Table 12. Summary and comparison of maximum depth, surface area, pool volume, and wetted longitude for Pools A, B, C, and D (results of surveys conducted in 2005).

Pool	Maximum Depth ft (m)	Max Surface Area ft ² (m ²)	Maximum Volume ft ³ (m ³)	Maximum Wetted Longitude ft (m)
A	1.94 (0.59)	1,084.29 (100.77)	1,012.34 (28.67)	77.41 (23.6)
B	3.94 (1.2)	1,112.8 (103.42)	1,863.66 (52.78)	51.53 (15.71)
C	1.97 (0.6)	555.65 (51.64)	401.83 (11.38)	37.59 (11.46)
D	2.62 (0.8)	1,945.52 (180.81)	1,849.18 (52.37)	100.73 (30.71)
Totals		4,698.25 (436.64)	5,127 (145.2)	

Pools A, B, C, and D vary in their form and size. Bedrock is present immediately under pools A, B, and C, while the thickness of alluvium near Pool D was much larger. Pools B and C appear to be controlled by in-channel obstructions to a greater extent than the other pools. Large boulders just upstream of Pool B create turbulent flow conditions that probably contribute to sediment evacuation and therefore the maintenance of its relatively large storage volume. A large sycamore tree lines (prior to the July 2006 flooding) the left bank of Pool C, forcing water to the creek's right bank that also creates turbulent flow conditions and local increases in flow energies that prevents long-term sediment accumulation.

Pool B is the deepest of the four major pools and has the greatest storage capacity (Table 13). It is also the least exposed of middle Rincon Creek's four major pools. When these characteristics are considered together, Pool B typically contains moisture for longer periods of time than the other three main pools (Swann, pers. comm., 2005).

The study period demonstrated both the intermittent nature of the middle Rincon Creek pool system. The large flood event of July 2006 removed the Arizona sycamore was on the left bank of Pool C and contributed so much to its formation and persistence. The loss of this tree has contributed to a major change in Pool C's character. Pool A and Pool B were also altered, but less so. Sediment deposited in Pool A during the July 2006 flood event appears to have been largely evacuated by subsequent flow. Although the large boulder that dominated Pool B was pushed downstream by the force of the July 2006 flow, a large Arizona ash collapsed across the pool and appears to be contributing to hydraulic conditions conducive for the maintaining this pool (see chapter describing middle Rincon Creek's channel morphology).

Although the pools will likely change in the future (some will probably disappear altogether), it is likely middle Rincon Creek will have substantial pools as part of its overall morphologic makeup far into the future.

Correlating streamflow conditions in May and June to survey measurements of middle Rincon Creek's wetted longitude during the same two months indicate that an average flow of 0.2 cfs (.006 cms) will be sufficient to maintain water in all of the pools. However, the 0.2 cfs estimate is based on a small sample size (five flow events during the period wetted longitude was measured). In addition, the 0.2 cfs estimate was developed based on flow required to maintain water levels in all the pools at maximum capacity.

Prevailing weather conditions as well as timing of flow events during May and June are major determinants for the occurrence of water in pools. For example, a series of small flow events occurring intermittently during May and June will probably have a greater likelihood of maintaining at least some water in the pools (particularly the upstream pools) than would larger flow events that occur only at the beginning of May and towards the end of June. The number of consecutive days that middle Rincon Creek experiences no-flow has the greatest impact on pool moisture availability during these dry, hot months, regardless of average monthly flow.

CHAPTER VI. CONCLUSIONS AND RECOMMENDATIONS

On December 10, 2002, NPS filed a water-right application through ADWR for instream flow maintenance with the state of Arizona to protect the water resources of the reach of Rincon Creek that passes through Saguaro National Park East. NPS requested an annual total volume of 1,210 acre-feet (1,492,513 m³). The overall goal of this study is to characterize middle Rincon Creek's bottomland plant community, hydrology, pool systems, and channel morphology, providing the biophysical context to determine the water requirements of bottomland vegetation as well as identify potential threats to the availability of water.

Middle Rincon Creek's bottomland plant community is rich, diverse, and rare. Almost every major low elevation riparian deciduous tree can be found along middle Rincon Creek, including sycamore (*Platanus wrightii*), walnut (*Juglans major*), cottonwood (*Populus fremontii*), willow (*Salix gooddingii*), ash (*Fraxinus velutina*), mesquite (*Prosopis velutina*), netleaf hackberry (*Celtis reticulata*). During wet periods when streamflow persists for extended periods of time, reeds, sedges, rushes establish along the channel bed in dense clusters. Within the greater Tucson Basin, only a few other streams possess similar plant community attributes (e.g., Sabino Canyon, Bear Canyon), underscoring the value and relative uniqueness of middle Rincon Creek's bottomland ecosystem.

The pools along middle Rincon Creek are important with regard to their ability to capture and hold water for long periods of time following the cessation of streamflow. In the semi-arid environment of the southwestern U.S., such attributes are critically important, providing sources of moisture for a plethora of flora and fauna. Although the distribution and number of pools along middle Rincon Creek will vary over time, it appears that pool morphology is a general characteristic that can be applied to middle Rincon Creek over the long-term. That is, the four pools that were studied during the course of this investigation appear not to be a fleeting manifestation of short-term geomorphologic processes that just happened to coincide with the period of study.

The July 2006 flood event evacuated and redistributed large amounts of sediment and organic debris, the overall impact on middle Rincon Creek's pools seems to be more along the lines of morphologic alteration rather than complete removal. Although one of the four main pools that were studied was eliminated, the others remained intact and viable despite changes in their morphology. If a similar investigation was conducted twenty years from now, it seems likely that middle Rincon Creek will still be characterized by pools. These 'future' pools may not be the same pools studied during the course of this study, but it is likely that pools will be present, providing the same beneficial habitat as they do today (given the persistence of current streamflow conditions).

One scenario that could go against this forecast would be the occurrence of a catastrophic fire in the upper parts of the Rincon Creek watershed. A widespread burn followed by heavy monsoonal rains, for example, can introduce substantial amounts of sediment into the system, potentially leading to aggradation throughout Rincon Creek that would essentially bury the pools. Indeed, this situation has occurred on several occasions over the last decade along some of the smaller Rincon Mountain drainages, resulting in critical pools disappearing for extended periods of time (Swann, Don; pers. comm., 2006). In addition, even if such a scenario did occur, runoff occurring during the years following the fire would carry less sediment (as vegetation reestablished in the upper parts of the watershed) and would begin to evacuate accumulated sediment, including sediment deposited in the pools. It could take several years, but the pools would likely reestablish. Indeed, the results following the rare, high magnitude flooding in late July 2006 bare this out.

Of particular importance for riparian and wetland plant community is the need to maintain the near-surface soil saturation zone at elevations suitable for shallow-rooted riparian and emergent wetland plants. For obligate riparian deciduous plants like cottonwood and willow, this means that the saturated zone of the soil profile cannot drop more than nine feet (two meters) below the soil surface during May and June.

Increased Groundwater Pumping Impacts Flooding Frequencies

Despite real concerns regarding the effects of increased pumping on shallow groundwater levels, the results of the stage-discharge model appear to diminish concern with regard to the effects of pumping on discharges at or greater than bankfull (i.e., flooding). Flooding is critically important to the long-term viability of middle Rincon Creek's bottomland plant community. Flows of discharge magnitudes at or greater than bankfull will continue to occur at frequencies and durations that will probably be unaffected by ground-water withdrawals. Certainly, the frequency and duration of bankfull discharges could be affected by a variety of other factors such as upper watershed activities, climate change, channel incision, etc.

Construction of Impoundment Structures

Impoundment structures change natural patterns of flooding, sedimentation, and groundwater fluctuations. In turn, these changes can alter the condition of riparian ecosystems both upstream and downstream from the impoundment structure. The reduction of overbank flows caused by the buffering effect of impoundment structures has contributed to the disappearance of native riparian habitat along rivers all over the world, in general, and the southwestern U.S. in particular, including the Lower Colorado River, Salt River, and Lower Verde River, Arizona; and the Rio Grande, New Mexico, amongst others. Construction of impoundment structures of sufficient size to affect

streamflow conditions along Rincon Creek (on private lands above middle Rincon Creek, for example) would lead to considerable ecologic deterioration along middle Rincon Creek.

In this regard, it is important to note that river impoundment often leads to increases in average monthly flow (particularly during dry months along impounded rivers of semi-arid climates) as waters trickle out of dams and maintain wet conditions nearly year round. Such artificial increases in water availability during dry months coupled with loss of flow dynamics, alteration of seasonal flow, and introduction of exotic invasive plants has been the death of many bottomland ecosystems (e.g., Rio Grande downstream of Elephant Butte reservoir choked with *Tamarix ramosissima* and *Arundo donax*).

For river impoundment to affect conditions along middle Rincon Creek, the dam would have to be of considerable size and several dams would have to be constructed along the Rincon Creek proper as well as its two most major tributaries: Madrona Creek and Chimenea Creek. However, water management projects in the western U.S. have a long history of outlandishness which, in and of itself, makes noting this concern worthwhile. In addition, Rincon Creek already has a history of dubious private landowner projects. For example, a landowner not far downstream of middle Rincon Creek constructed a poorly designed road crossing in 1992. When the road crossing was removed by flooding in 1993, it caused much disturbance at and downstream of the area where it was constructed.

Although not an impoundment structure, the road crossing project points to the potential of landowners undertaking (more or less on their own) in-stream construction efforts that have the potential of affecting bottomland conditions upstream and downstream of their immediate footprint. In summary, the construction of impoundment structures upstream of middle Rincon Creek is probably remote. Yet, it would not take much for SAGU to be vigilant and, if such a project is ever proposed, to resist the project based on impoundment's affect on streamflow conditions.

Shallow Groundwater Elevation Affected by Groundwater Pumping

The question of whether groundwater pumping will affect shallow groundwater elevations underscores one of the main debates regarding pumping and its affect on middle Rincon Creek's shallow water table. Although large increases in pumping levels may affect the deep regional aquifer, the presence of an aquitard or some barrier between the deep and shallow water tables would prevent the shallow riparian water table from being adversely affected by pumping.

If the saturated soil zone does drop below the root zone of many of middle Rincon Creek's riparian and emergent wetland plants, the very existence of middle Rincon

Creek's bottomland plant community could be threatened. The most vulnerable time for riparian and emergent plants to be affected by a drop in the elevation of the water table is during May and June. Precipitation (and therefore surface flow) is not abundant during this time of the year, leaving riparian plants almost completely dependent on near-surface saturated soils for their survival.

A change in shallow groundwater elevations (brought on by larger increases in groundwater withdrawals) would be reflected by changes in streamflow. If changes in streamflow are large enough, streamflow levels might be reduced.

Consider the following scenario. During the first week of May, a flow averaging 20 cfs (.57 cms) occurs over a seven-hour period, and a similar flow occurs during late June of sufficient means. In-between these two flow events the weather is hot and dry (i.e, a period of 50 days of no-flow). Following the cessation of surface flow, the saturation zone of the soil profile can recede quickly. If the elevation of the riparian water table lies below the root zone of most of the riparian plants, the above scenario could equate to an extended period of time where many of middle Rincon Creek's riparian plants are left high and dry. Such a scenario – particularly if it occurred several years in a row - could lead to an extensive loss of middle Rincon Creek's obligate riparian community.

The underlying question here is whether transmission losses between the NPS gauge and USGS gauge are large enough to affect streamflow measurements between these two points. That is, could there be situations where flow (minor flow) measured at the NPS gauge equates to no flow at the USGS gauge (due to transmission losses)? Could such a situation be conceivably more likely if shallow groundwater levels drop due to pumping?

Underscoring this question/concern is the physical character of middle Rincon Creek changes from its upstream end to its lower. Such longitudinal zonation is typical of streams everywhere, with longitudinal zones having inherent differences in gradient, valley constraint, geomorphic processes, sediment and litter composition, amongst other factors. Middle Rincon Creek lies just on the pediment of the Rincon Mountains, with the channel in its upper half dominated by bedrock outcrops that bracket small alluvial basins, and its lower half dominated to a much greater extent by deeper alluvium as the creek descends toward the floor of Rincon Valley. Rincon Creek can experience flow on its upper reaches with flow being completely absent further downstream.

Only in rare cases would it be possible for flow at the USGS gauge to occur without flow occurring at the NPS gauge. For example, heavy precipitation from localized convectional cells that dumped considerable amounts of water on the southern flanks of the middle Rincon Creek watershed could produce flow along middle Rincon Creek's

lower half with no flow occurring along the upper half. However, the likelihood that such a situation would occur is probably rare. Rarer still would be that scenario occurring with sufficient frequency to warrant concern with regard to streamflow monitoring versus shallow groundwater elevations.

Channel Incision

Finally, considering only the hydrologic record leaves out any consideration of how other physical bottomland characteristics may have changed and how such changes may affect the needs of the bottomland ecosystem. For example, changes in channel morphology (e.g., channel incisement) can have a greatly impact on the form and function of the riparian plant community (e.g., channel incisement along a ciénega can lead to a substantial increase in the extent and distribution of woody vegetation over herbaceous), which, in turn, can alter its water / flow needs.

Portions of the middle Rincon Creek channel appear to be moderately incised with steep channel banks that rise abruptly from the channel bed. If channel degradation continues to occur, the resulting increase in elevation between the channel bed and floodplain surfaces could become problematic for the riparian plants growing on them. Channel incision often leads to local decline in shallow groundwater levels. The more channel incision occurs, the greater the difference in elevation between in-channel and off-channel floodplain surfaces and the saturated zone of the soil profile. The greater this difference, the more the roots of riparian and emergent vegetation will have to travel to reach the water they need to survive, potentially reaching a point where the saturated soil zone drops permanently below the root zone of these species, threatening not only future regeneration, but the mature plants that have already established.

However, despite the channel incision that has already occurred, for several reasons it seems unlikely that major processes will occur in the future. First, there are numerous artificial and natural controls that will prevent further degradation. Well downstream of middle Rincon Creek, Old Spanish Trail road is preventing headcuts resulting from the degraded Pantano Wash from traveling further upstream. In addition, the cross-channel bedrock along middle Rincon Creek itself also act as controls that will prevent future channel degradation. In addition, it appears that aggradation, not degradation, is the overriding process along much of the middle Rincon Creek. Buried root flares of in-channel vegetation, filled in pools, the presence of numerous sediment slugs all seem to indicate less alluvium leaving the middle Rincon Creek reach than entering. Of the three concerns (large decline in shallow groundwater levels, channel incision, and impoundment) raised in this chapter, additional channel incision probably ranks second, somewhere in between shallow groundwater decline and construction of river impoundment structures.

CHAPTER VII. RECOMMENDATIONS

Saguaro National Park East will need to develop a monitoring program that will provide the data needed to assess middle Rincon Creek's biophysical condition. Overarching questions that the monitoring program will need to answer include:

- Are streamflow conditions as stipulated in the water right being met?
- If not, is the lack of sufficient streamflow due to below average precipitation?
- Can collected data point to ground-water withdrawals as a cause of streamflow decline?

Priority monitoring parameters include: streamflow, precipitation, and shallow groundwater elevations. In its basic form, the monitoring program will describe the parameters that are being monitored, why they are being monitored, how they are being monitored, timetables, and responsibilities.

Channel cross-sections should be set up for routine monitoring by assessing survey results of the same channel cross-section at different points in time. Of particular interest in this regard would be to note trends of prolonged aggradation or degradation, which may indicate channel instability that may be caused by upper watershed perturbations (e.g., dramatic fire), changes in land use, groundwater conditions, etc. This was done as part of assessing morphologic change following the July 2006 flooding and repeat surveys of both cross-sections and the creek's longitudinal profile should be part of an overarching monitoring routine (with resurveys triggered by the occurrence of peak flows of specified magnitude).

Monitoring precipitation within the Rincon Creek watershed is needed. Correlating precipitation levels with streamflow is one of the first major hurdles to tying lack of streamflow to groundwater withdrawals, specifically showing that below average streamflow is occurring despite average or even above average precipitation. Given the often spotty nature that characterizes precipitation in the greater Tucson Basin, it is important that precipitation data be collected from within the Rincon Creek watershed.

A main step that needs to be considered (along with developing the monitoring program) is to define ecologically related thresholds that, if crossed, will illicit (i.e., will trigger) special attention by Saguaro National Park on middle Rincon Creek's biophysical condition and how its overall ecological condition is possibly being affected by groundwater withdrawals.

At the least, thresholds need to be developed for streamflow and shallow groundwater elevations. A few questions are offered here to underscore some of the details that will need to be worked out:

Obviously, the average monthly streamflow amounts as outlined in the water right application will be the foundation for developing monitoring thresholds. Yet, is it that one dry (i.e., no streamflow) May or June constitutes a 'violation' of the water right that will trigger some level of concern/response by Saguaro National Park? Or, maybe longer term (e.g., seasonal) triggers will be more appropriate. For example, spring streamflow that is well-below the amounts stipulated in the water right application. Or, maybe several consecutive years of below average streamflow will be necessary before action is triggered.

Of course, streamflow measurements will need to be tied to precipitation. If precipitation is well below average, so too will be streamflow. However, average or above average precipitation levels accompanied by streamflow amounts below average may be an indication that something is amiss. In other words, such a situation may be an indication that streamflow is being affected by such human activities as groundwater pumping. In this regard, at the very least, SAGU will need to monitor streamflow and precipitation. But, where will precipitation be measured? Ideally, a network of precipitation gauges needs to be established in the upper Rincon Creek watershed. Precipitation timing, amounts, and type will need to be correlated with streamflow in such a manner that will allow SAGU to address this important issue.

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An Overview of Middle Rincon Creek's Channel Morphologic, Streamflow, Pool System and Bottomland
Plant Community Characteristics
Briggs
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APPENDIX

Graphs Depicting Results of Cross-Channel Surveys Conducted at Selected
Monitoring Stations Along Middle Rincon Creek in 2005 and 2007

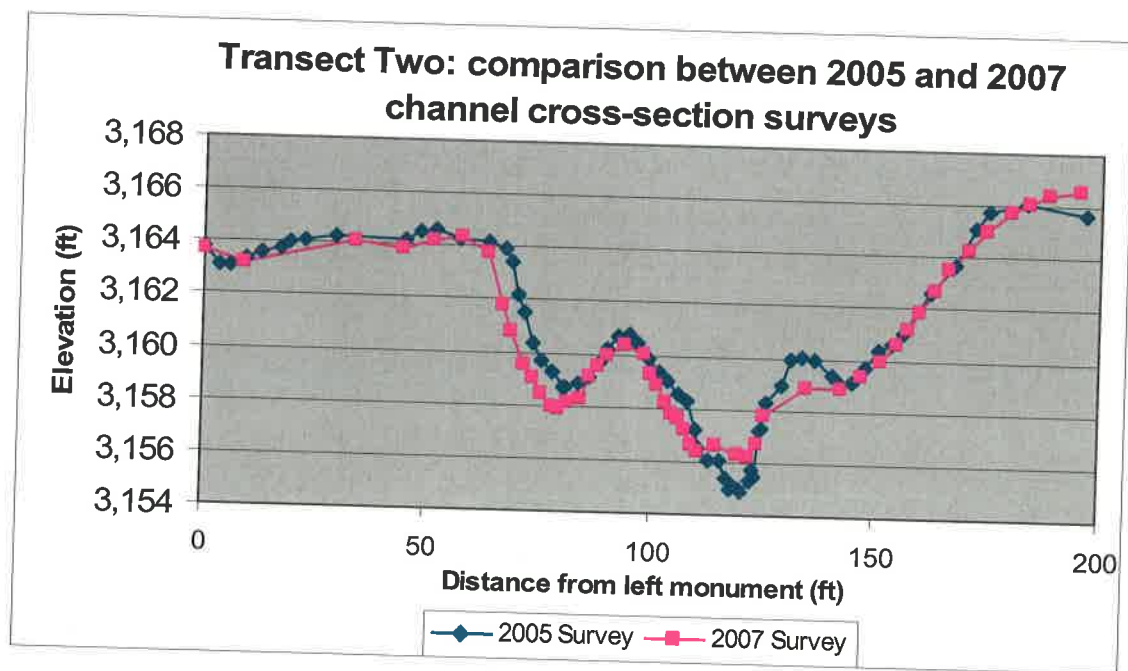


Figure 35. Comparison of channel cross-section surveys conducted at site two in 2005 and 2007.

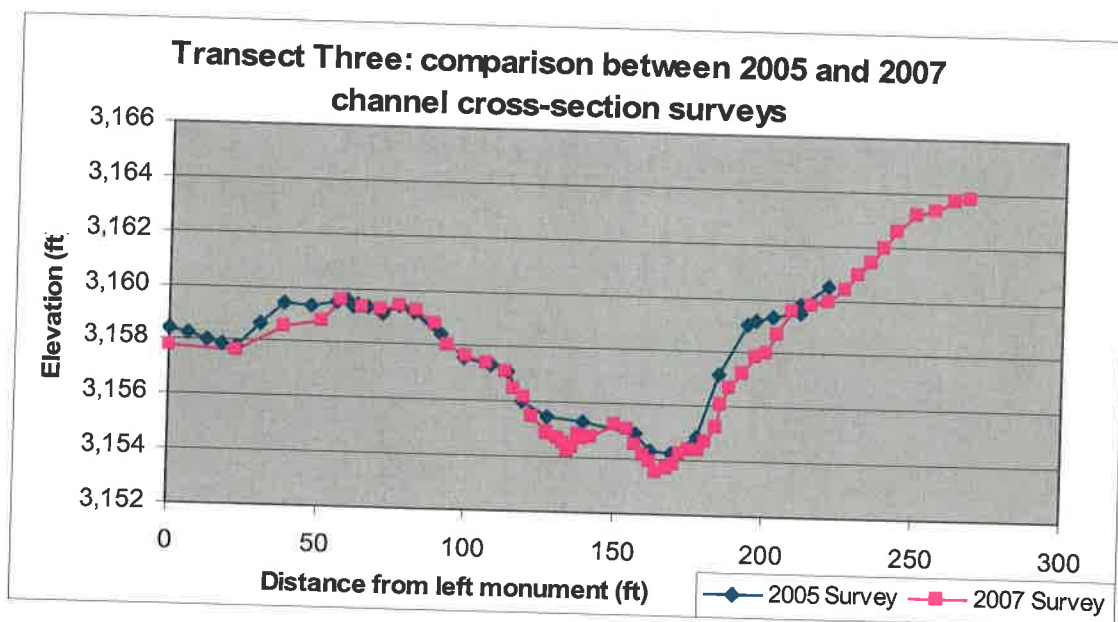


Figure 36. Comparison of channel cross-section surveys conducted at site three in 2005 and 2007.

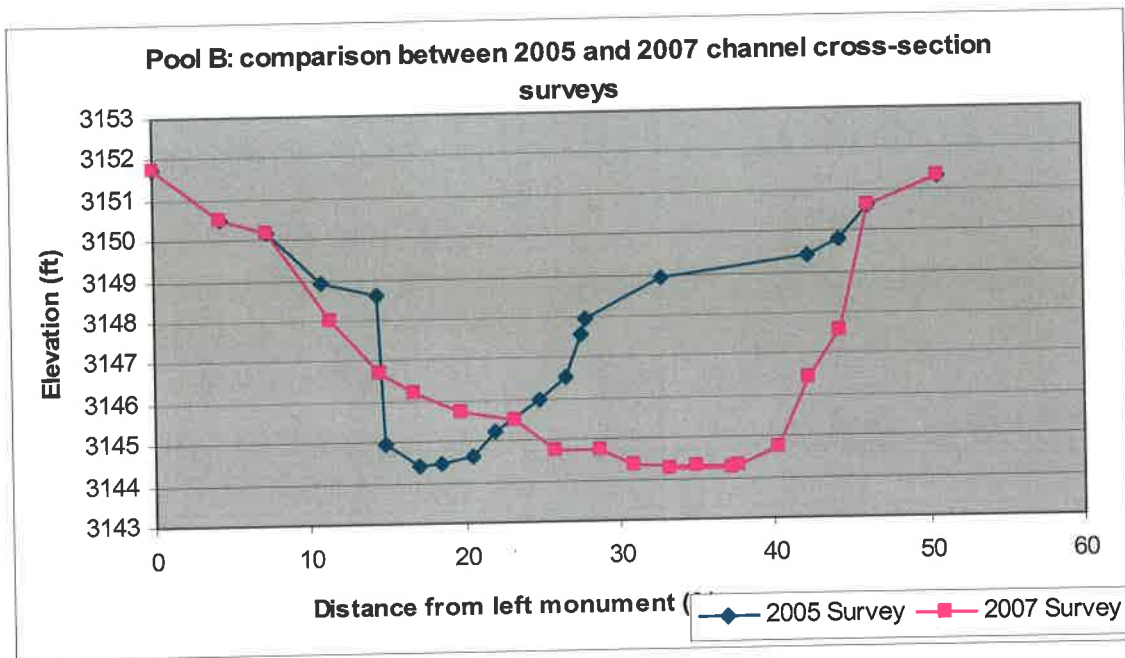


Figure 37. Comparison of channel cross-section surveys conducted across the central axis of Pool B in 2005 and 2007.

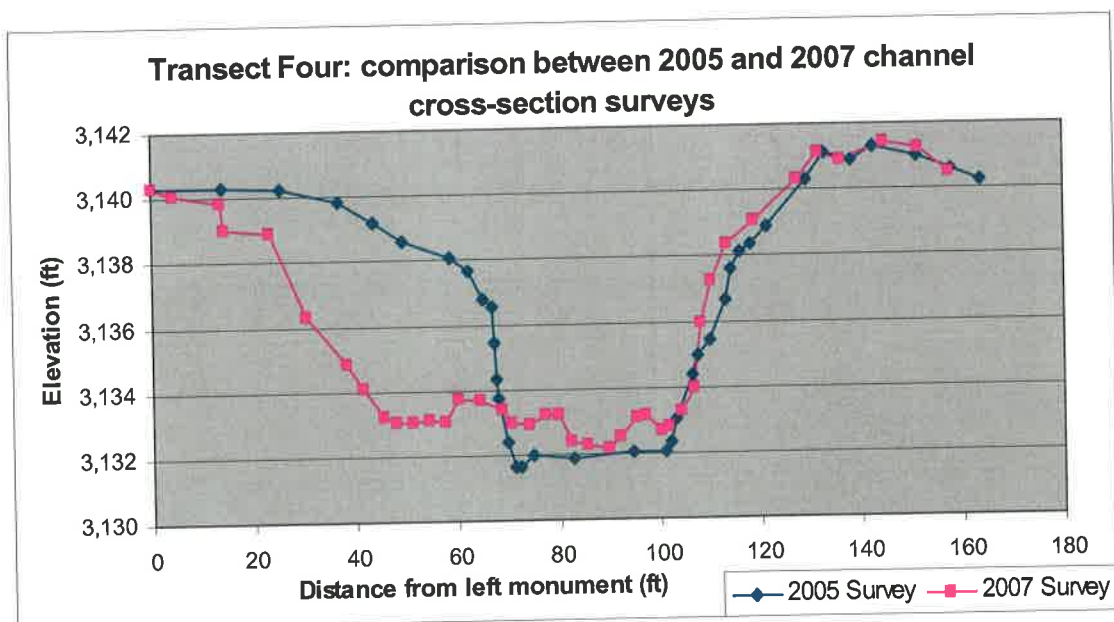


Figure 38. Comparison of channel cross-section surveys conducted across the central axis of Pool B in 2005 and 2007.