Final

Methods for Evaluating Development Impacts on Water Resources and Riparian and Aquatic Ecosystems Near Montezuma Castle and Tuzigoot National Monuments, Arizona

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LOTTERY DOLLARS WORKING FOR WILDLIFE

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Chapter 1. Introduction

PURPOSE AND SCOPE

The purpose of this report and accompanying computer programs is to provide information and quantitative analysis tools to enable National Park Service (NPS) personnel to maintain and enhance natural riparian and aquatic environments at Montezuma Castle and Tuzigoot National Monuments (Monuments). Specifically, the materials will enable NPS staff to defend and promote NPS interests in local and regional planning proceedings by presenting credible, quantitative evaluations of potential impacts of nearby development on biological resources at the Monuments. Similarly, the materials may be used to substantiate NPS water requirements in the current Verde River water rights adjudication proceedings.

BACKGROUND AND SETTING

Background

This report and the analysis tools presented build on previous studies of natural resources at the Monuments. Climatological data for the Verde River watershed were summarized by Sellers and Hill (1974). Hydrologic studies by the U.S. Geological Survey (USGS) (Owen-Joyce and Bell 1983, and Owen-Joyce 1984) documented general groundwater and surface water conditions in the upper Verde River area and investigated hydrogeology, water use, water quality, and stream-aquifer interactions. Most of the data presented in the reports were for the main Verde River valley. Few data were specifically for conditions at the Monuments. Data from these and other reports were compiled by NPS into a Water Resources Management Plan for Montezuma Castle and Tuzigoot National Monuments (National Park Service 1992). The plan describes a management program that identifies management issues and specific projects designed to address those issues.

Several studies and inventories have been done of biota at the Monuments. Ruffner and Johnson (1990) described and mapped seven distinct plant communities at all three Monuments. Cole and Barry (1973), Cole (1982), and Boucher et al. (1984) described the unique biota of Montezuma Well and its value as a research resource. More recently, researchers at Northern Arizona University began studies to fully document biota at the Monuments, including algae and aquatic invertebrates (Blinn and Oberlin 1994), terrestrial invertebrates (Price and Fondreist 1994), fish and herpetofauna (Montgomery et al. 1994), reptile and amphibian communities (Van Riper et

al. 1994), avian communities (Van Riper and May 1994), and vegetation (Rowlands and Brian 1994). The autecology of sycamore trees at Montezuma Castle was described by Reichhardt (1990).

Development of the database and impact analysis tools presented in this report was funded by NPS and a Heritage Grant from the Arizona Game and Fish Department (AGFD). This work is a step toward achieving several of the management objectives listed in the Water Resources Management Plan, including to:

- understand stream influences on riparian and wetlands ecosystems;
- acquire and maintain an adequate information base to define natural features and processes, and to identify impacts on them; and
- detect and evaluate external influences (e.g., growth, land use, and groundwater development) that may impact NPS water resources and water-related attributes.

Setting

This section presents a brief summary of physiographic and climatological characteristics of the Verde River watershed and the Monument sites. Only characteristics that directly affect biological and water resources are included. More complete information is presented in the Water Resources Management Plan (National Park Service 1992).

The Verde River watershed is located mainly within the Central Highlands and Plateau Uplands water provinces of Arizona between Phoenix and Flagstaff (Figure 1-1). The Mogollon Rim is an escarpment of sedimentary rocks that separates the high plateaus (approximately 6,000-9,000 feet above sea level) in the upper or northeastern part of the watershed from the canyons and Verde River valley to the southwest (2,700-6,000 feet above sea level). The total watershed area of the Verde River above a point about 20 miles downstream of Camp Verde is 2,600 square miles (mi^2). Montezuma Castle and Montezuma Well are on Beaver Creek, one of five perennial streams that enter the Verde River from the uplands area. Tuzigoot National Monument is on a hilltop in the loop of a former oxbow bend of the Verde River near Clarkdale.

Although the climate is semiarid, with annual precipitation of approximately 11-14 inches near the National Monuments (Sellers and Hill 1974), the area is wetter than those in the surrounding water provinces. Precipitation occurs in all months but derives from different types of storms in different seasons. Winter precipitation is from large frontal storms moving eastward from the Pacific Ocean. This precipitation often falls as snow at the higher elevations and helps support sustained flow in Beaver Creek and the other perennial creeks. Summer precipitation is from thunderstorms, which are typically localized and intense. The driest months are April through June, during which there is an average combined total of only about 12% of the annual precipitation. The seasonal

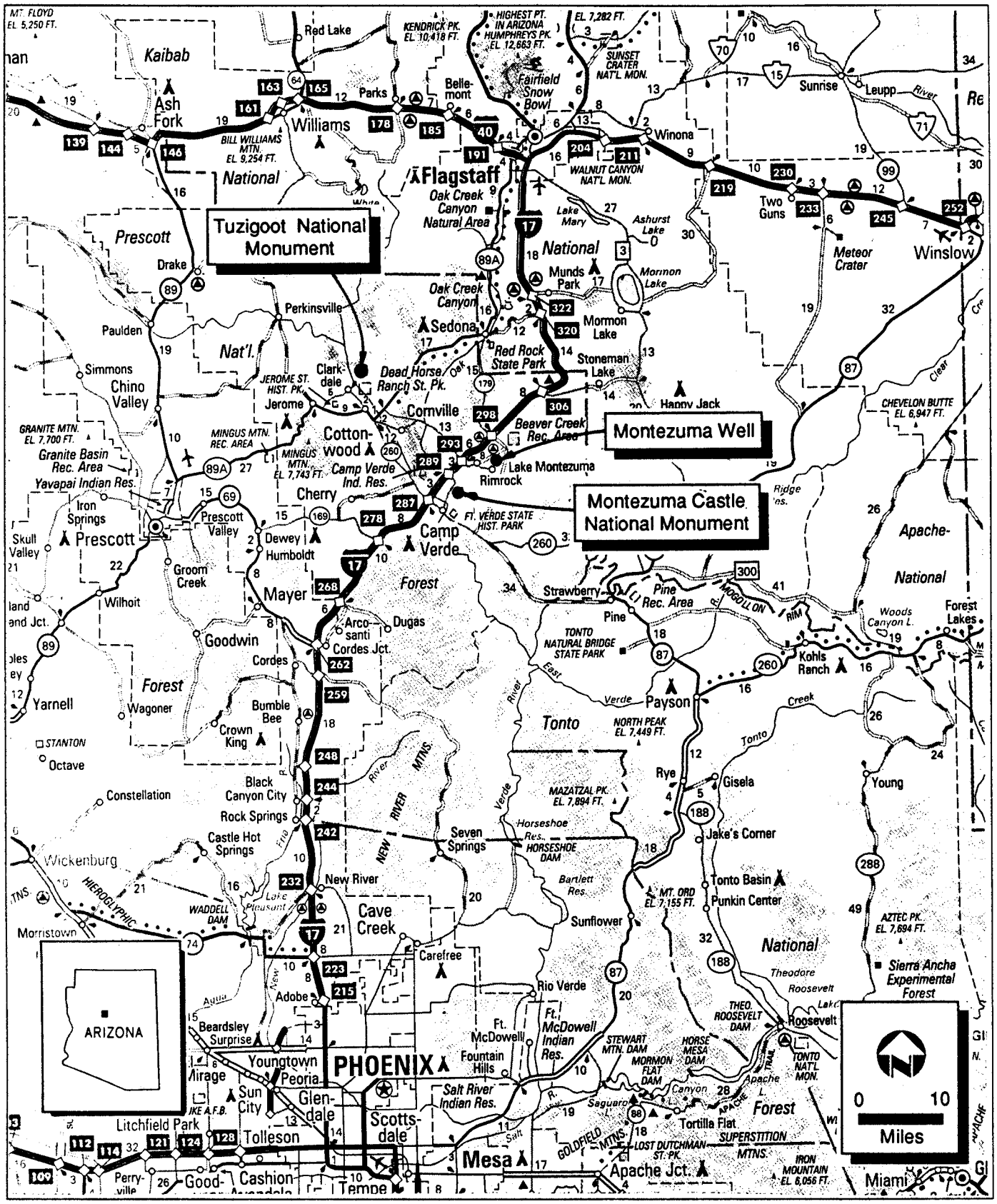

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Figure 1-1
Regional Location

distribution of rainfall is relatively uniform compared with total annual rainfall, which has historically ranged from less than 4 to more than 22 inches.

Two aspects of regional geology have important influences on hydrologic conditions and, subsequently, on riparian and aquatic biota. First, the consolidated sedimentary rocks that underlie the entire drainage basin have sufficient porosity and permeability to sustain perennial flow in springs or creeks at all three Monuments. These rocks include the Verde, Coconino, and Supai formations. Second, unconsolidated alluvial deposits are present along stream and river floodplains, providing a suitable substrate and relatively shallow groundwater for riparian vegetation.

Most of the Verde River watershed is undeveloped, although population and development have been increasing rapidly in the Verde River valley. The population of Yavapai County, which includes all of the major towns in the valley, grew at an annual rate of approximately 6% during the early 1980s and 3-4% during the late 1980s and early 1990s (Gelhert pers. comm.), with most of the increase occurring in the major towns (Sycamore, Clarkdale, Cottonwood, and Camp Verde). Approximately 30,000 people lived in the valley in 1990. In 1979, irrigated cropland occupied 7,781 acres (ac) in the Verde River valley, or approximately 0.5% of the total watershed area (Northern Arizona Council of Governments 1979).

Chapter 2. Inventory of Water Resources and Riparian and Aquatic Ecosystems

REGIONAL

Water Resources

The presence of perennial base flow in surface waterways is essential for aquatic and riparian biota. The Verde River and several of its eastern tributaries have perennial base flow sustained by groundwater discharge from the regional groundwater system. The large size of the groundwater reservoir provides a relatively steady source of streamflow that is much less variable on a seasonal and annual basis than rainfall or direct rainfall runoff. The Verde River has perennial flow along a 125-mile reach extending from Sullivan Lake, 30 miles upstream of Tuzigoot National Monument, to Horseshoe Reservoir, about 40 miles downstream of Camp Verde. The eastern tributaries with perennial flow include Sycamore Creek, Bitter Creek, Oak Creek, Beaver Creek, West Clear Creek, and the East Verde River. There are approximately 340 stream miles of perennial flow in the Verde River and its tributaries above Horseshoe Reservoir. This represents 7% of the combined length of perennial flow reaches in all rivers in Arizona. (Valencia et al. 1993.)

A statistical summary of daily flows in the Verde River near Clarkdale is shown in Table 2-1 and illustrates the seasonal and annual variability for flow in the river. From 1915 to 1921 and from 1965 to 1993, the highest median monthly flow was 150 cubic feet per second (cfs) in March. The lowest median flow was 77 cfs in June. Maximum flows are two orders of magnitude greater than median flows during winter and only about one order of magnitude greater during summer. In general, this indicates highly variable flows in winter with periodic, large events when flows rise and fall rapidly. During summer, a more consistent base flow regime dominates.

Floodflows are also important to riparian ecosystems because they create fresh deposits of vegetation-free sediment near riverbanks, which are needed for successful establishment of early-succession riparian plants such as willows and cottonwoods. Streamflow data (some estimated) for a gage on the Verde River above Horseshoe Dam (approximately 50 miles downstream of Camp Verde) indicate that the six largest floods from 1891-1975 occurred prior to 1953, with moderately large floods occurring in 1967 and 1970. A similar analysis of streamflow records for a gage on the Verde River near Clarkdale showed a substantially different ranking of flood years, indicating that peak flows are somewhat localized and variable throughout the Verde River drainage basin.

Table 2-1. Minimum, Medium, and Maximum Daily Flows, by Month, for Selected Gaging Stations Near the National Monuments
(all values are in cubic feet per second)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Wet Beaver Creek Near Rimrock, AZ (WY 1962-1985, 1989, 1992, 1993)												
Minimum	6	6.2	5.8	6.8	6.8	6.8	5.7	5.6	5.4	5.4	5.6	5.9
Median	7.1	7.3	7.6	8.2	10	55	10	7.4	6.9	6.9	7.1	7.1
Mean	17.14	17.29	46.38	55.21	77.33	107.9	70.98	12.19	6.99	8.61	12.63	11.5
Maximum	2910	2520	4780	5230	2580	2920	799	395	14	455	1780	1760
Dry Beaver Creek Near Rimrock, AZ (1961-1993)												
Minimum	0	0	0	0	0	0	0	0	0	0	0	0
Median	0	0	0	0	8.75	92	12	0	0	0	0	0
Mean	10.21	20.64	71.65	66.09	115.1	164.7	112.5	9.15	0.0063	0.202	2.12	12.64
Maximum	3630	3190	13100	5880	4950	4590	1350	903	2	70	724	5930
Wet Beaver Creek at Montezuma Well (estimated as Wet Beaver Creek discharge near Rimrock*1.732) **Range name: WELL**												
Minimum	10.4	10.7	10.0	11.8	11.8	11.8	9.9	9.7	9.4	9.4	9.7	10.2
Median	12.3	12.6	13.2	14.2	17.3	95.3	17.3	12.8	12.0	12.0	12.3	12.3
Mean	29.6	30.0	80.4	95.6	133.9	186.9	123.0	21.1	12.1	14.9	21.8	19.9
Maximum	5,040	4,365	8,279	9,058	4,469	5,057	1,384	684	24	788	3,083	3,048

Table 2-1. Continued

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Beaver Creek at Montezuma Castle (estimated as Wet Beaver Creek discharge near Rimrock * 1.945 + Dry Beaver Creek discharge near Rimrock * 1.292)												
Range name: CASTLE												
Minimum	11.7	12.1	11.3	13.2	13.2	13.2	11.1	10.9	10.5	10.5	10.9	11.5
Median	13.8	14.2	14.8	15.9	30.8	225.8	35.0	14.4	13.4	13.4	13.8	13.8
Mean	46.4	60.3	182.9	192.8	299.1	422.7	283.4	35.6	13.6	17.0	27.2	38.6
Maximum	10,350	9,023	26,222	17,769	11,414	11,610	3,298	1,935	30	975	4,398	11,085
Verde River Near Clarkdale, AZ (1915-1921, 1965-1993)												
Minimum	65.0	69.0	70.0	70.0	73.0	72.0	66.0	65.0	59.0	59.0	55.0	55.0
Median	79	83	85	86	90	150	85	80	77	80	81	80
Mean	123	133.4	212.3	225.9	505.8	517.9	214.4	89.53	76.99	107.1	105.4	105.3
Maximum	11000	13300	14200	19400	30000	18100	5000	1100	137	1000	963	8490

The mineralogical characteristics of the geologic formations in the Verde River watershed influence the quality of groundwater and base flow in perennial creeks and the Verde River. The Verde Formation, which consists of marine mudstone, sandstone, and limestone of Tertiary age, underlies all three of the Monuments and is a large source of dissolved solids in groundwater. In some areas, the concentrations of chloride, sulfate, and dissolved solids exceed drinking water standards, but the concentrations generally increase from north to south and are highest in the Verde River valley downstream of the Monuments (Owen-Joyce and Bell 1983). Concentrations of iron, manganese, selenium, mercury, and arsenic also exceed drinking water standards in some wells, and the concentration of boron occasionally exceeds the maximum level for irrigating boron-sensitive crops. Although some of these constituents are potentially harmful to aquatic and riparian vegetation and fauna, there have been no reports of adverse effects attributable to water quality.

Consumptive use of surface water and groundwater in the Verde River watershed consists principally of evapotranspiration by riparian vegetation (35,000 acre-feet per year [af/yr]); consumptive use by irrigated crops in the Verde Valley (31,000 af/yr); and municipal and domestic water supply (8,000 af/yr, most of which returns to groundwater). Thus, natural consumptive use approximately equals consumptive use for human activities. Together, these uses constitute approximately 37% of total outflow from the hydrologic system, with the remainder comprising groundwater outflow (17%) and surface outflow in the Verde River (43%). Almost all irrigation uses are supplied by surface water diversions, and almost all municipal and domestic uses are supplied by wells. (Owen-Joyce and Bell 1983.)

Owen-Joyce and Bell (1983) found that there was no net change in water levels for the regional aquifer in the upper Verde River groundwater area between 1963 and 1983. USGS reported net changes of +1 to - 9 feet in the area from 1985 to 1990 (Anning and Duet 1994). Groundwater withdrawal in the upper Verde River groundwater area has been increasing from approximately 4,000 af/yr in 1974 to 19,000 af/yr in 1993 (Anning and Duet 1994, Bills pers. comm.). Recent USGS (1995) estimates of pumpage in the upper Verde River groundwater area are provided in Table 2-2.

Table 2-2. Estimated Groundwater Pumpage in the Upper Verde River Groundwater Area (acre-feet)

Year	Total	Year	Total	Year	Total
1985	11,994.9	1988	17,796.7	1991	22,146.8
1986	9,667.4	1989	24,417.0	1992	21,526.4
1987	14,412.6	1990	22,924.6	1993	18,846.9

Irrigation and municipal uses account for most of the groundwater pumped in the basin (approximately 10,000 af/yr each) with industrial use accounting for only 1,000 af/yr.

Riparian and Aquatic Ecosystems

Natural vegetation in the watershed transitions from mesic riparian and mesquite associations near perennial creeks and rivers to several types of upland plant communities in the surrounding watershed areas. The lower reaches of Wet Beaver Creek, including the areas around Montezuma Castle and Montezuma Well, support Sonoran Desert Scrub - Arizona Upland Subdivision, which is dominated by creosote bush and crucifixion-thorn. Higher in the watershed, the vegetation transitions to Great Basin Conifer Woodland, which consists of piñon-juniper woodland at intermediate elevations and montane conifer forest at the highest elevations. (Brown 1973.)

The Verde River and its tributaries (excluding the East Verde River) support approximately 8,000 ac of riparian vegetation along a total of 221 stream miles (Owen-Joyce and Bell 1983). The total area of riparian vegetation is approximately 3% of the total area of riparian vegetation along perennial stream reaches in Arizona (Valencia et al. 1993). The Verde River Greenway is a 6-mile-long stand of cottonwood-willow forest and is one of only five significant stands remaining in Arizona (Thornburg and Tabor 1991). American Rivers, a nonprofit organization that seeks to protect natural river resources, ranked the Verde River as one of the 15 highly threatened rivers in the United States, principally because of the threat of increased groundwater extractions and other effects of urban development (Thornburg and Tabor 1991).

MONTEZUMA WELL

Water Resources

Groundwater

Montezuma Well is the most remarkable feature of the groundwater system at Montezuma Castle National Monument. The "well" consists of a steep-walled pit several hundred feet in diameter and about 50 feet deep formed in bedrock near Wet Beaver Creek. The bottom of the pit is filled with a pool fed by subsurface springs. The water level is controlled by the outlet that consists of a fissure through the bedrock wall between the well and the creek. Where the water reemerges from the fissure outside the well, it is diverted into an irrigation ditch that parallels the north side of the creek for 1 mile before discharging to the creek. The ditch has been used to irrigate crops on the floodplain since prehistoric times. Although the ditch is close to the low-flow channel of Wet Beaver Creek, seepage from the ditch probably helps support the stands of riparian vegetation

through which it passes. The flow from the well averages more than 2 cfs and is almost always between 1 and 3 cfs.

The source of water that sustains the well is unknown but appears to be independent of the shallow alluvial groundwater system associated with Wet Beaver Creek. The water level in the well is approximately 20 feet higher than the level of the creek surface and is substantially higher than groundwater levels in the alluvium. Preliminary attempts to simulate the well and surrounding groundwater conditions using a groundwater flow model indicated that the contrast in water levels could be created by an impermeable fault between the well and the creek and alluvium, but there is no geologic evidence for such a fault. Successful simulations of water levels in the well were also achieved when the fissures feeding the well were assumed to be highly permeable conduits for upward flow from the underlying Supai Formation (Leake pers. comm.). The water quality of the well also suggests that the source might be the Supai Formation (Cole and Barry 1973, Glotfelty 1985). Coconino Sandstone has also been identified as a source of artesian springs maintaining base flow in Wet Beaver Creek (Owen-Joyce and Bell 1983).

If Montezuma Well is fed directly from the relatively deep Coconino or Supai Formations, pumping from wells in the overlying alluvium would probably have little effect on it. Shallow pumping would tend to be offset by seepage from Wet Beaver Creek, so it is unlikely that the upward water-level gradient between the Coconino or Supai Formations and the alluvium would be significantly altered.

The local groundwater system at Montezuma Well consists of an unconfined aquifer in the alluvium on the valley floor and the underlying Verde Formation. Groundwater in the alluvium is probably in hydraulic connection with the creek (Owen-Joyce and Bell 1983). As a result of this connection, groundwater pumping for consumptive use reduces streamflow by inducing seepage out of the creek where groundwater is below creek level, or intercepting groundwater that would have discharged into the creek where groundwater is above creek level.

From 1976 to 1980, an inventory for the upper Verde River groundwater area, extending from the Verde's headwaters on Mogollon Rim to its confluence with the East Verde River, identified 23 wells in the vicinity of Wet Beaver Creek around Montezuma's Well and Lake Montezuma (Owen-Joyce and Bell 1983). The principal aquifer reported for all of these wells is the Verde Formation. Yields, reported for only six wells, range from 20 to 100 gallons per minute. The wells are used primarily for residential purposes although some are used for public supplies, stock water, and irrigation. Local groundwater elevations reported in these wells vary from approximately 40 feet above water level in Wet Beaver Creek to approximately 70 feet below, but generally are around 10 feet below the level of the creek. The groundwater around Montezuma Well and Lake Montezuma and, in particular, originating in the Verde Formation can contain moderate to high levels of dissolved solids, sulfate, arsenic, chloride, and other elements.

Surface Water

Wet Beaver Creek flows near or along the southern boundary of the Montezuma Well unit. Wet Beaver Creek is perennial from springs about 14 miles upstream of Montezuma Well to the confluence with Dry Beaver Creek, about 6 miles downstream of the well. A streamflow gage (Wet Beaver Creek near Rimrock) has been operated by USGS at a location about 2 miles upstream of Montezuma Well since 1961. Daily average flows at Montezuma Well were estimated by adjusting the gage data to reflect the additional drainage area and average annual rainfall in the additional drainage area between the gage and the well. These calculations indicated that flow at the well is 1.732 times the flow at the gage. Figure 2-1 shows the areas and average annual rainfall for subunits of the drainage areas upstream of the Monuments.

Table 2-1 lists the minimum, median, mean, and maximum monthly average flows in Wet Beaver Creek at Montezuma Well estimated from the monthly average flows at the Rimrock gage using the equation shown in Figure 2-1. The calculation involves multiplying the daily flows at the gaged location by the ratios of drainage area and annual preciptiation, expressed as the value at the National Monument divided by the value at the gage. This procedure is reasonably reliable for estimating high flows derived from direct rainfall runoff. Estimated low flows can be inaccurate if low flows are substantially affected by groundwater seeping into or out of the creek. A similar adjustment of the flow-duration curve for daily average flows at the Rimrock gage (Owen-Joyce and Bell 1983) indicates that base flows less than 14 cfs occur approximately 80% of the time, with substantially higher flows (up to 3,000 cfs) occurring the rest of the time, in response to rainfall events.

The most recent large flood in Wet Beaver Creek was in January 1993. High-water marks were still visible in September 1994, although there was less evidence of scour and fill than was at the Montezuma Castle unit farther downstream. Peak instantaneous flow at the Rimrock gage was 16,000 cfs on January 8, 1993, with a daily average flow of 5,230 cfs. The next day (January 9), the daily average flow was 431 cfs, indicating that streamflow rapidly recedes on Wet Beaver Creek even after large storm events. A frequency analysis of annual peak discharge for Wet Beaver Creek at the Rimrock gage from 1961-1993 (assuming a log Pearson type-III distribution) indicated that the peak discharge for January 8, 1993 was an approximately 22-year event; that is, the probability in any year of a peak discharge greater than 16,000 cfs is estimated to be 4.5% (Figure 2-2). Since there is only a short record (33 years) of instantaneous peak flows, estimates of floodflows greater than a 50-year event are not reliable.

The streambed of Wet Beaver Creek along the reach outside of but close to the southern boundary of the Montezuma Well unit was graded in 1993 or 1994. Bulldozer tracks were still visible during a site visit in September 1994. The purpose of the grading was apparently to provide flood protection for a home on low ground on the south side of the creek by creating a berm on that side of the channel. The grading left a broad, shallow, cobbly, unshaded low-flow channel with short, herbaceous vegetation along the edges.

Map Subunit	Description	Drainage Area (mi^2)	Average Annual Precipitation (in)	Equation for Estimating Flow
1	Flow at gage "Dry Beaver Creek near Rimrock" (DB)	140.4	24.85	N.A.
2	Tributary inflow between DB and McGuireville (McG)	56.3	18.09	0.292*DB
3	Flow at gage "Wet Beaver Creek near Rimrock" (RR)	107.5	24.37	N.A.
4	Tributary inflow between RR and Montezuma Well (MW)	86.7	22.14	0.732*RR
5	Tributary inflow between MW and McG	24.2	18.61	0.172*RR
6	Tributary inflow between McG and Montezuma Castle (MC)	5.7	18.77	0.041*RR
3+4	Flow at MW	194.2	23.37	1.732*RR
1+2+3+4+5+6	Flow at MC	420.8	22.82	1.945*RR+1.292*DB

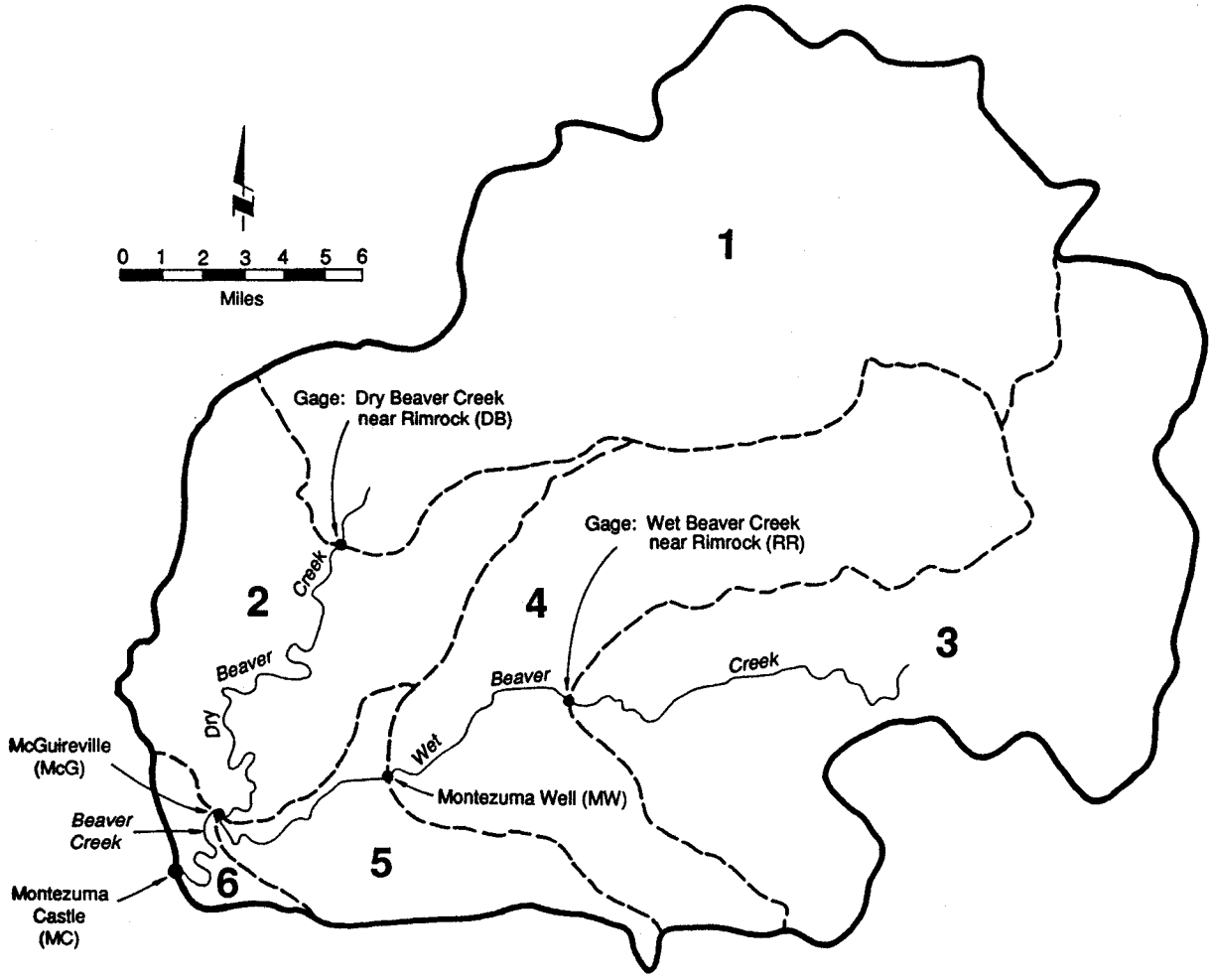

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Figure 2-1

Areas and Average Annual Precipitation for Subunits of Drainage Area Upstream of Montezuma Castle and Montezuma Well National Monuments

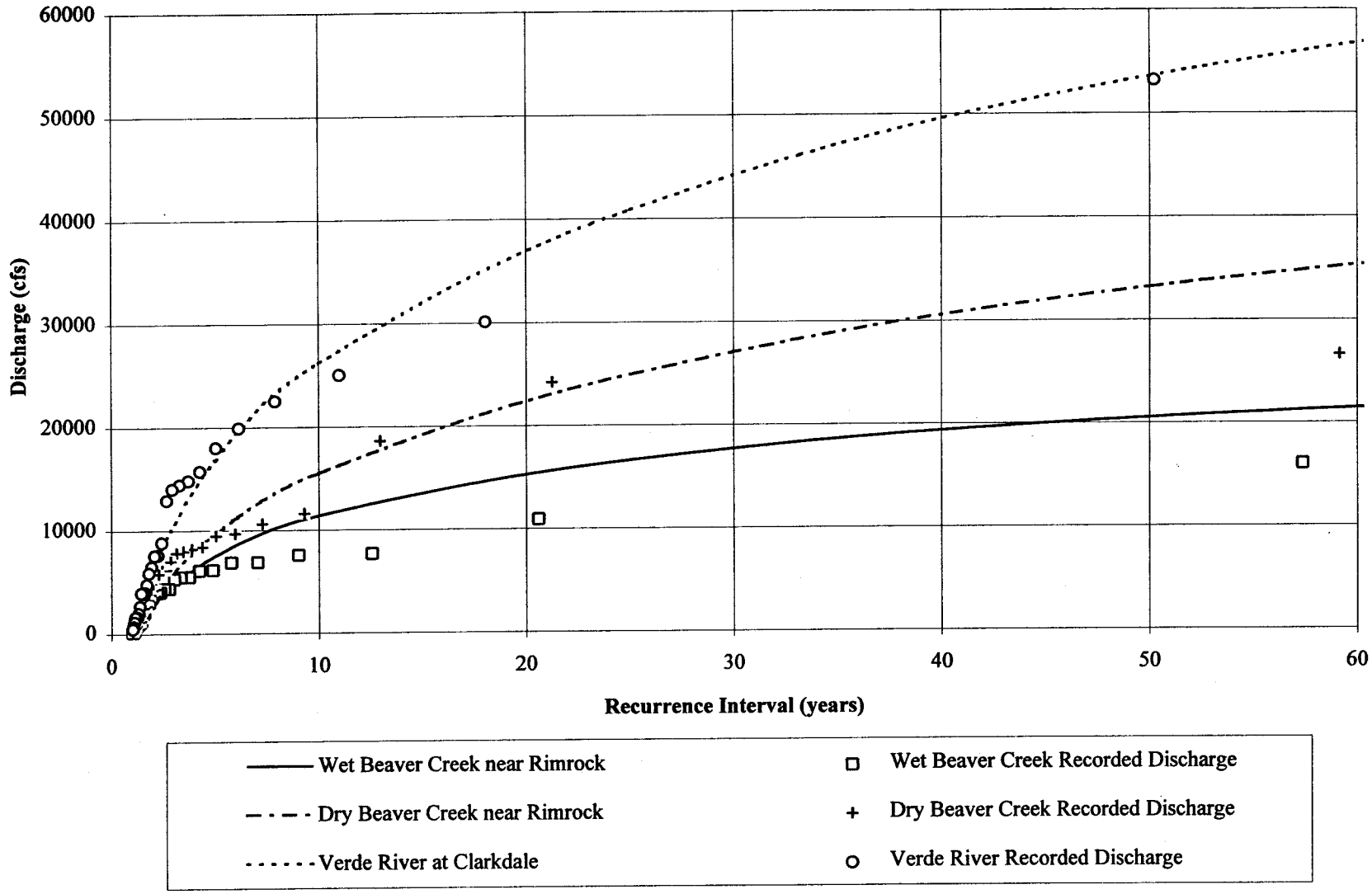

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Figure 2-2
Peak Flow Frequency Using Log Pearson III Distribution

Surface-water diversions in the Wet Beaver Creek watershed upstream of Montezuma Well constitute approximately 12,479 af/yr. The use specified for 11,239 af of the total surface-water diversion is "other". In the Coconino National forest, 82.2 af/yr is diverted from Wet Beaver Creek mainly for stock watering (Wistrand pers. comm.). Coconino National Forest has also applied for a 5.4 cfs instream flow right on Wet Beaver Creek.

Riparian and Aquatic Ecosystems

Riparian vegetation at the Montezuma Well unit consists principally of a diverse, mature forest of variable width along the right (north) bank of Wet Beaver Creek. For example, at a location near the picnic area approximately 0.5 mile downstream of Montezuma Well, the forest occupies a terrace about 200 feet wide and approximately 6 feet above the low-flow water level in the creek. The vegetation is a mixture of mature cottonwood, ash, sycamore, juniper, mimosa, mesquite, alder, desert willow, and even prickly pear cactus, a diverse assemblage of species not often found intermixed. During a site visit in September 1994, there were seedlings of cottonwood, sycamore, and juniper, indicating that those species are successfully regenerating at that location.

Slightly higher terraces farther from the channel have historically been cultivated. In September 1994, mesquite was beginning to colonize some fields that had been fallow for over 40 years, and mature planted cottonwoods appeared healthy. Mature stands of cottonwood, ash, and sycamore are present along the irrigation ditch fed by the outlet from Montezuma Well, even where the ditch is 0.25 mile from the creek channel. Seepage from the ditch sustains the riparian vegetation in these relatively distant, elevated locations.

Riparian-type vegetation is also present along the shoreline inside Montezuma Well. Vegetation observed in September 1994 included cattails, shrub willows, tree willows, Arizona walnut, hackberry, jimson weed, and Arizona wild grape.

In 1993, 44 taxa of aquatic invertebrates were found in the irrigation ditch fed by Montezuma Well and 82 taxa were found in Wet Beaver Creek (Blinn and Oberlin 1994). Midges and black flies were the dominant invertebrates in the creek. Nine taxa of invertebrates were found in the hyporheic zone within the creekbed. Fish in Wet Beaver Creek in the Montezuma Well unit were sampled in spring 1993 (following a winter with a large flood). Sonora sucker, a native fish, constituted 92% of the fish caught by electrofishing (Montgomery et al. 1994). Four species of frogs and toads, including non-native bullfrogs, were found at the National Monuments in 1993 (Van Riper et al. 1994). Also sighted were 14 species of lizards and 14 species of snakes. Ringneck snakes were commonly sighted in riparian areas.

MONTEZUMA CASTLE

Water Resources

Groundwater

At Montezuma Castle, groundwater occurs in alluvium and old terrace deposits along Beaver Creek and in the underlying Verde Formation. Alluvium is found in the valley bottom in deposits that are approximately 1/4 mile wide and 20-30 feet deep with depths up to 100 feet (Owen-Joyce 1984). The well that provides water for visitor and administrative facilities draws from the Verde Formation. Groundwater levels are generally below the level of the creekbed, as indicated by the decrease in streamflow between the upstream end of Davis Hole (the large pool in Beaver Creek in the large eastward meander upstream of the visitor center) and the downstream monument boundary. In spring 1993, flow decreased from an about 3.1 cfs to about 0.1 cfs along this 1.5-mile reach (Linn et al. 1994). One well measurement indicated that groundwater was 40 feet below creek level (Owen-Joyce 1984).

The water table does not drop rapidly away from the channel, however, as indicated by the large area of mesquite vegetation on the terrace on the right bank of the creek along the inside curve of the large meander upstream of the visitor center. Mesquite is a phreatophyte that generally grows on elevated terraces where the depth to groundwater is no more than about 30 feet (Judd et al. 1971, Minckley and Clark 1984).

Statements of water use filed for the Verde River basin water rights adjudication indicate that groundwater use is approximately 92 af/yr in the vicinity of Montezuma Castle and 104 af/yr for the entire Beaver Creek basin.

Surface Water

Beaver Creek flows for approximately 2.5 miles through Montezuma Castle National Monument, including a large meander to the east, upstream of the visitor center, and a large meander to the west, immediately downstream of the center. The creek is intermittent along this reach because much of the base flow is diverted into an irrigation ditch upstream of the National Monument (Owen-Joyce and Bell 1983). There is some flow (a few cfs) most of the time.

Unimpaired flows (i.e., flows that would occur in the absence of the upstream diversions) at Montezuma Castle were estimated by adjusting gaged flows in Wet Beaver Creek and Dry Beaver Creek to reflect differences in the size and average annual precipitation of the total drainage area. The hydrologic subunits used and the estimating equation are shown in Figure 2-1. Table 2-1 shows the minimum, median, mean, and maximum estimated monthly flows at Montezuma Castle. This

adjustment provides a reasonably accurate indication of high flows. Estimated low flows can be inaccurate if there is substantial seepage into or out of the creek. In this case, minimum monthly flows at Montezuma Castle are smaller than would be predicted by the gage adjustment because of upstream diversions and significant seepage losses from the creek near Montezuma Castle. For example, during a period of steady base flow in April 1993, measured flow along the reach that passes through the monument was 0.1-3.1 cfs, which is smaller than the minimum calculated monthly flow in any month (10.9-13.2 cfs). Thus, the calculated numbers should be relied upon principally to indicate high and possibly average monthly flows.

The January 1993 flood, described earlier for the Montezuma Well unit, resulted in more obvious scour and fill at the Montezuma Castle unit. Mature trees near cutbanks had fallen in a few places, and second-year saplings were evident on some fresh sand bars in September 1994. While discharge is not recorded for Beaver Creek, peak flows are likely to represent a combination of discharge from Wet and Dry Beaver Creeks. Because Dry Beaver Creek annual peak flows are larger than corresponding peak flows in Wet Beaver Creek, they can be used to estimate the recurrence intervals of annual peak flows downstream at Montezuma Castle. Based on a flood frequency analysis of annual peak discharge on Dry Beaver Creek for 1961-1993, the 1993 flood has a recurrence interval of less than 10 years (i.e., the probability that the peak flow in any year will exceed that magnitude is greater than 10%) (Figure 2-2). It is likely that the January 1993 peak discharge on Beaver Creek at Montezuma Castle had a similar probability.

The streambed of Beaver Creek in the Montezuma Castle unit is quite variable. Near the upstream meander, Davis Hole forms a large pool as wide as 200 feet. There are multiple channels in some places, although water is generally present in only one channel under low-flow conditions. There are some gravel bars with fairly dense, mature vegetation and others with sparsely vegetated expanses of cobbles and gravel. A gabion or dike constructed of rock in a wire mesh forms the right bank of the low-flow channel along a 1,400-foot reach between the visitor center and the cliff dwellings. The gabion was installed to prevent erosion of the sycamore grove and potential damage to visitor facilities. The low-flow channel appears to have downcut somewhat in response to this constraint on lateral movement, as evidenced by exposed tree roots on the opposite bank. The ground level now drops about 8 feet from the outboard side of the gabion to the channel side. Near the downstream end of the Montezuma Castle unit, limestone bedrock is exposed in the creekbed and probably forms a control point that prevents further downcutting along the upstream reach.

Statements of water use filed for the Verde River basin water rights adjudication indicate that surface-water users of Beaver Creek between Montezuma Well and Montezuma Castle divert approximately 4,592 af/year. Most (2,700 af/yr) of this water is used for irrigation, with domestic uses accounting for 1,325 af/yr. The total surface-water use for Beaver Creek above Montezuma Castle is approximately 16,967 af/yr.

Riparian and Aquatic Ecosystems

There are three dominant vegetation communities at Montezuma Castle: creosote bush-crucifixion thorn, mesquite, and sycamore-ash-cottonwood (Ruffner and Johnson 1990). The creosote bush-crucifixion thorn association is found in the uplands at Montezuma Castle. The mesquite association is located on floodplains and terraces where depth to groundwater is shallow to moderate (less than about 30 feet). This association is becoming more abundant as mesquite spreads into floodplains that had been cultivated (Ruffner and Johnson 1990). Sycamore-ash-cottonwood riparian forests form the dominant vegetation assemblage along Wet Beaver Creek at Montezuma Castle. An inventory of riparian trees in the area between the cliff dwellings and the creek channel by the visitors center (Reichenbacher 1990) found 246 netleaf hackberry (*Celtis reticulata*), 221 Arizona sycamore (*Platanus wrightii*), 20 velvet ash (*Fraxinus pennsylvanica* ssp.), and six Arizona black walnut (*Juglans major*). This association lacks perennial understory that is present in other areas (e.g., Montezuma Well) where the floodplain is inundated annually (Ruffner and Johnson 1990).

Two fish surveys at Montezuma Castle in spring and fall 1993 found eight species of fish, three of which are native (Sonora sucker, Desert sucker, and Longfin dace). A total of 37 individuals were found at three sites during the spring survey, and 59% of the individuals were natives. A similar survey in fall 1993 found 69 individuals, 17% of which were natives. Smallmouth bass and Green sunfish were the most abundant nonnative species.

TUZIGOOT

Water Resources

Groundwater

Tuzigoot National Monument is located on an alluvial floodplain adjacent to the Verde River approximately 1 mile east of Clarkdale. The hydrogeology of the area is similar to that of Montezuma Castle and Montezuma Well, with a shallow alluvial aquifer hydraulically connected to deeper aquifers in the Verde, Coconino, and Supai formations. In the area between Clarkdale and Cottonwood (about 4 miles downriver), the alluvium generally is less than 50 feet thick and water levels range from 3 to 43 feet below the land surface (Owen-Joyce and Bell 1983). Shea Spring, at the base of Verde Formation cliffs east of Tuzigoot, discharges groundwater to Tavasci Marsh at a rate of approximately 2.5 cfs. Because the marsh and the Verde River are on alluvium, both are probably in hydraulic continuity with groundwater.

Groundwater is used in the vicinity of Tuzigoot for irrigation and domestic purposes. From 1900 to 1986, an estimated 89 wells had been drilled in the area, with an increasing trend over time (Arizona Department of Water Resources 1988). Available data on groundwater pumping does not indicate the quantity of water pumped in the immediate vicinity of Tuzigoot National Monument. Cottonwood Water Works (serving Clarkdale) pumped approximately 1,300 af/yr during 1991-1993 (Bills pers. comm.).

Groundwater discharge into the Verde River upstream of Clarkdale provides base flow for the reach near Tuzigoot. Owen-Joyce and Bell (1983) found no change in Verde River base flow between 1915 and 1921 and between 1965 and 1978 and concluded that "the groundwater system upstream from Clarkdale still represents equilibrium conditions". Development of groundwater resources in the upper Verde River basin, however, could diminish base flow in the river.

Surface Water

Surface waters in the vicinity of Tuzigoot National Monument include the Verde River, Pecks Lake, Tavasci Marsh, and Shea Spring. The Verde River at Clarkdale is characterized by variable peak discharges and consistent low flow. It has a predominantly cobble channel with narrow alluvial terraces confined by a rock canyon. An analysis of annual peak flow on the Verde River at Clarkdale indicates that the January 1993 event was the largest from 1966 to 1993. The peak discharge on the Verde River at Clarkdale for this event was 53,200 cfs, which represents approximately a 50-year event (Figure 2-2).

Pecks Lake is a 77-acre, eutrophic, oxbow lake that was formed when the prehistoric Verde River changed course, bypassing a meander in its channel. The lake is the only spring-fed, naturally formed oxbow lake in Arizona (Sullivan and Richardson 1993). Since 1920, a diversion dam on the Verde River has allowed river water to be diverted to the lake. Water can flow out of the lake in the Tavasci ditch, which skirts Tavasci Marsh. Shea Spring discharges water directly to Tavasci Marsh. The marsh covers approximately 35 acres within the legislated boundary of the National Monument (National Park Service 1992). Tavasci Marsh appears to be an old extension of Pecks Lake that, over time, has filled with sediment. During large flood events (greater than 100-year events), water from the Verde River can inundate Tavasci Marsh (Sullivan and Richardson 1993).

Riparian and Aquatic Ecosystems

Tuzigoot National Monument has the same three biological associations as Montezuma Castle plus two additional, unique associations: cattail and cottonwood (Ruffner and Johnson 1990). These associations are classified as wetland and riparian, respectively. The wetland species occur around Pecks Lake and Tavasci marsh. Cattail (*Typha* spp.) is the dominant wetland species along with other emergent species including rushes (*Scirpus* spp., *Eleocharis parishii*), sedges (*Carex* spp.,

Cyperus spp.), and buttercup (*Ranunculus* spp.). Cattle grazing and channelization is most likely to have reduced the abundance and diversity of wetland plant species in the marsh (Ruffner and Johnson 1990). The marsh is used by a variety of wildlife including 73 species of birds. Two uncommon bird species include sora and Virginia rails, which are likely to breed at the marsh (National Park Service 1992).

The cottonwood association occurs along watercourses in Tuzigoot National Monument as riparian gallery forest and include other species such as Gooding's willow, velvet ash, desert willow, and bermuda grass (Ruffner and Johnson 1990). River terraces and floodplains are dominated by mesquite, while creosote bush-crucifixion thorn association covers upland areas of the Verde formation.

Peck's Lake supports a variety of plant and fish life. The lakeshore is dominated by the same emergent wetland species as mentioned above for Tavasci Marsh. Eurasian milfoil (*Myriophylum spicatum*) was introduced into the lake in the 1930s and is a nuisance, especially in summer (Sullivan and Richardson 1993). There is a variety of warmwater game fish in the lake.

Chapter 3. Information Needs for Water Resources Management

Water is a keystone resource for the Monuments. It is integral to ecosystem functions and supports biological resources, as well as having intrinsic value (e.g., as at Montezuma Well). Water resources, however, are affected by many different activities in the Verde River basin that largely occur outside of National Park Service (NPS) jurisdiction. As a result, water resources management at the Monuments entails participation in two basic forums: the water rights process and regional planning. They are summarized here to point out the types of information used for managing water resources in Arizona.

APPROPRIATION OF WATER IN ARIZONA

Use of water resources in Arizona is governed by the prior appropriation doctrine for surface waters and the Groundwater Management Act of 1980 (Act). Under prior appropriation, surface-water users must claim a right to appropriate a given quantity of surface water from a specific location for a specific use. These elements form the basis for a water right and a state-issued permit, which are assigned a priority date. The priority date is used to determine who receives water when appropriation exceeds available supply, with senior claims honored before junior claims. Disputes among water users are sometimes resolved by adjudication in which a state court rules on priority and quantity of claimed water rights. Water rights in the Verde River are being reviewed as part of the Gila River adjudication (Thornburg and Tabor. 1991). Water rights decisions, both at the administrative and judicial levels, require information on the type of use, the quantity of water appropriated from and returned to surface waters, and the availability of surface water in a stream basin.

Groundwater use has been regulated only recently with the passage of the Act (Tarlock et al. 1993). The Act created two categories of areas where groundwater use is restricted: Active Management Areas (AMAs) and Irrigation Non-Expansion Areas. Except for new domestic wells, new groundwater users in AMAs generally require permits. The Act authorizes user fees, planning, and conservation to limit use to "safe yield". Four groundwater basins with large population centers or substantial irrigated acreage (Phoenix, Tucson, Prescott, and Pinal) were initially designated as AMAs by the Act. Information required for groundwater management includes the category of use (municipal, industrial, or agricultural), the quantity of water withdrawn, and the safe yield of the aquifer of concern.

Reserved and Instream Water Rights

There are two categories of water rights that differ from water rights for municipal, industrial, or irrigation uses: reserved rights and instream rights. Reserved rights are claims made by the federal government to waters for use on "Indian Reservations, National Forests, Recreational and Wildlife Areas, and other government lands and works" (Arizona v. California, 83 S. Ct. 1468). These rights are reserved typically for irrigation, fire suppression, military installations, and other activities occurring on federal lands.

Instream rights are claims for a specified level of flow to remain in a stream to support fish and wildlife habitat, recreational uses, and aesthetic value. Instream uses have only recently been recognized and claimed as beneficial uses of surface waters. The federal government generally does not reserve instream flow except for Wild and Scenic Rivers (16 USCA 1271-1287). The Arizona Department of Water Resources has received instream flow permit applications from Prescott National Forest for 25 cfs in the Upper Verde River at Beasely Flat (Thornburg and Tabor 1991) and from Coconino National Forest for 5.4 cfs in Wet Beaver Creek (Stuart pers. comm.). Reserved and instream water rights require the same types of information as do appropriative rights: type of use, amount of use, and the availability of surface water in the basin. The priority date of use for reserved rights is usually the date of the land reservation. The priority date for instream flow rights is usually the filing date of the water right application or, in the case of transfers, the priority date of the right that is being transferred.

REGIONAL PLANNING ACTIVITIES

The Verde River Corridor Project is a regional planning effort that produced a Final Report and Plan of Action in 1991. The plan includes recommendations for water resources management in the basin. The plan identifies a number of different organizations that are involved in the Verde River Basin including the Verde Natural Resources Conservation District, Verde Valley Water Users Association, flood control and irrigation districts, Yavapai County Board of Supervisors, various city agencies developing water plans, Arizona State Parks, Arizona Game and Fish Department, Arizona Department of Water Resources, U.S. Soil Conservation Service (now Natural Resources Conservation Service), U.S. Fish and Wildlife Service, and U.S. Forest Service. Because the Verde River is a tributary of the Gila River, any changes in water resources management that apply to the Gila River basin or the Central Arizona Project could affect the Verde River.

The plan also provides a list of water-related information needed for management purposes, including existing and projected streamflow and the types, locations, and amounts of existing and projected uses of water. For instream uses, information is also needed describing water requirements for fish, riparian habitat, and recreation. This information, according to the plan, could be used to develop a water balance for the basin and would provide a basis for managing water resources.

Arizona State Parks developed a Management Plan in 1993 for the Verde River Greenway. Water issues are fundamental to the management of the greenway. One goal of the plan is to determine "optimal levels for the water flowing in the Verde River Greenway". The plan recognizes that these levels are not known and that to establish them will require information regarding existing water rights, actual water use, and riparian and aquatic ecology.

This report provides some of the information needs identified in these earlier plans for effective water resources management, including calculations of flow, groundwater conditions, water use, and water requirements of riparian and aquatic ecosystems. Much of the available information is for general or regional areas and less than ideal for managing water resources and ecosystems at specific locations such as the Monuments. Existing information will have to suffice until more site-specific information becomes available. This report attempts to present the existing information in as understandable and useful a format as possible.

Chapter 4. Methods for Evaluating Development Impacts

OVERVIEW

This chapter contains one of the two principal analytical tools described in this report for evaluating the potential effects of proposed developments on water resources and riparian and aquatic ecosystems at the Monuments. The purpose of the tools is to enable anyone with a background in natural sciences and moderate computer skills to perform a reasonably rigorous and credible quantitative analysis of impacts on hydrology and biology. It is, in effect, a type of "expert system".

The tool described in this chapter is a spreadsheet that calculates water demand and changes in surface water and groundwater hydrology associated with a proposed project. This systematic, comprehensive tabulation of all hydrologic effects of a project reveals the net effect a project would have on streamflow and groundwater levels. This information can be used in conjunction with the second tool, which is a database of hydrological/biological information. By selecting appropriate search parameters, the user can obtain information describing the biological effects that would be associated with the changes in hydrology. The database is described in Chapter 5, "Database of Hydrological/Biological Information".

The hydrology spreadsheet contains data, calculations, and evaluation criteria organized in a decision-tree format. Step-by-step instructions and worksheets are provided so that the experience of completing the analysis is similar to the experience of preparing an income tax return. This chapter provides documentation for the data included in the tables and worksheets, the equations and principles used in the analysis, and the criteria used to evaluate the results.

TYPES OF DEVELOPMENT AND IMPACTS

Several regional studies have enumerated the types of human activities most likely to adversely affect riparian ecosystems in Arizona. The Thornburg and Tabor (1991) identified arroyo-incision and streamflow depletion as two types of impacts that can result from livestock grazing, logging, and residential development in the Verde River basin. Specifically, actions that can deplete streamflow include new urban development that directly diverts surface water or that extracts groundwater near creeks, and water transfers that would similarly remove surface water or groundwater from the area. According to the Verde River Corridor Project, water transfers are the most threatening action. In addition to these water quantity concerns, there are water quality issues

related to domestic sewage, acidic drainage from mines, and turbidity problems associated with various land uses (livestock grazing, recreation, construction, agriculture, mining, urban stormwater, and waste disposal).

Direct diversions of streamflow for water supply affect all ranges of the streamflow regime, but the percentage change in streamflow is typically greatest for low flows. Impoundments in streams can decrease peak floodflows because of the "spillway effect", even if no water is being diverted from the creek. Groundwater extractions can deplete streamflow by inducing seepage out of the creek or intercepting water that would have flowed into the creek. Daily and monthly variations in groundwater pumping are often buffered by the effects of groundwater storage so that the resulting streamflow depletion is relatively constant.

Development can also result in direct impacts to riparian areas. Residential development often occurs in or near riparian corridors, reducing and fragmenting the habitat available for riparian plants and animals. Recreational uses of riparian areas have significant environmental impacts because soil is compacted and eroded, plants are destroyed, and wildlife disturbed.

Urban and residential development increases the amount of impervious area in a watershed and increases rainfall runoff. Unless stormwater detention facilities are constructed, this can increase peak floodflows.

IMPACTS MOST LIKELY TO OCCUR AT EACH MONUMENT

The types of impacts most likely to occur at each Monument can be identified based on the physical characteristics of the local setting (e.g., surface water and groundwater conditions and existing vegetation distribution), and the types of development most likely to occur, which can be inferred from the surrounding topography, land ownership, and proximity to existing roads and towns.

The potential developments and impacts identified through this screening process are by no means the only ones that might occur. The process provides a basis for prioritizing the efforts of NPS staff in monitoring biological conditions and becoming involved in the local planning and approval process for proposed developments near the Monuments.

Montezuma Well

The watershed of Wet Beaver Creek upstream of Montezuma Well is almost entirely in Coconino National Forest. Consequently, substantial urban development and associated impacts on streamflow and water quality are considered unlikely. Changes in management practices for

livestock grazing, timber harvesting, and mining are the most likely actions in the upper watershed area that could affect streamflow near Montezuma Well. Livestock grazing and timber harvesting already occur in the watershed and management plans for those activities are updated every 5-10 years. There have been significant changes in management practices in recent years as a result of endangered species concerns, and additional changes are likely (Brayles pers. comm.). Mining also occurs in the watershed. It is regulated under mining laws and statutes, and filing of a claim requires compliance with the National Environmental Policy Act (Matthias pers. comm.). Changes in any of these activities could affect rainfall runoff, and flood peaks and base flows in the creeks.

Invasion of cattle from adjoining lands into the Monuments is a threat to vegetation and other biota. Cattle had access to Montezuma Castle National Monument in spring and summer 1993 after drift fences along the Monument boundaries were damaged during winter floods. The cattle preferentially grazed in riparian areas where they created noticeable changes in vegetation structure and may have adversely affected resident reptiles and amphibians. (Van Riper et al. 1994.)

Residential development on private lands adjacent to or near Montezuma Well is probably the greatest threat to water resources and biota in the Montezuma Well unit. The most likely source of water for this type of development would be wells drilled into the alluvium and possibly the underlying Verde Formation. If residential development replaces irrigated pasture or cropland, the net change in annual consumptive use may be small. If the development is on nonirrigated land, the consumptive use for the development represents additional use of groundwater resources. If the wells are close to the Monument boundary, groundwater levels within the Monument could potentially be lowered enough to adversely affect phreatophytic vegetation.

In any case, groundwater pumping would ultimately be supplied by inducing a higher rate of seepage out of Wet Beaver Creek. Under existing conditions, the creek loses water to seepage along the reach between Montezuma Well and Montezuma Castle. Groundwater is probably in direct hydraulic connection with the stream, as it is in the Verde River valley, so any decrease in groundwater levels would increase the rate of seepage out of the creek. The impact on flow would be fairly uniform throughout the year if the wells are a considerable distance from the creek. A decrease in base flow as a result of increased consumptive water use would decrease available fish habitat and increase the water temperature in downstream reaches. Both flow and temperature could be limiting factors for fish along those reaches. In spring 1993, following a winter with a relatively large flood, flow decreased from 9 cfs at Montezuma Well to about 0.1 cfs near the downstream end of Montezuma Castle, and flow appears to be intermittent below Montezuma Castle (Linn et al. 1994); therefore, any decrease in flow could shorten the flowing reach and decrease available habitat.

Water temperature increased in the downstream direction with afternoon water temperatures of 23.8-24.5 °C near Montezuma Castle on one sampling date in spring 1993 (Linn et al. 1994). Any additional warming as a result of decreased flow upstream of Montezuma Castle could prompt some species to abandon that reach and move upstream.

Streambed alteration is an additional impact that is already occurring at Montezuma Well. During a site visit in September 1994, there was visual evidence of recent grading activity in the channel, including a berm along the south side of the creek approximately 0.5 mile downstream of Montezuma Well. The purpose of the grading was apparently to provide flood protection for a home on that side of the creek and was presumably instigated by the resident. The resulting low-flow channel was relatively wide (60-80 feet), shallow (less than 2 feet), and unshaded. Such conditions promote rapid warming of the water and expose fish to predation by birds.

Finally, nearby residential development could increase recreational use of Monument lands by local residents. Increased presence of humans and pets could disturb wildlife; however, because this type of impact is not related to hydrologic changes, it is not considered further in this report.

Montezuma Castle

The most likely potential impacts to the riparian ecosystem in Montezuma Castle would be habitat fragmentation, streamflow and streambed alteration, and groundwater declines associated with nearby urban or residential development. Residential development has already occurred in riparian areas along the Verde River in Camp Verde (Arizona Department of Environmental Quality 1993). Clearing vegetation eliminates riparian habitat and fragments remaining habitat into "islands". Fragmented habitat is less desirable for some wildlife species and is less stable because of greater "edge" effects. Development in Camp Verde and Lake Montezuma could disrupt the continuity of riparian habitat along Beaver Creek upstream and downstream of Montezuma Castle and effectively isolate riparian species at the monument.

Streamflow and streambed alteration presents a potential threat to Montezuma Castle. Flood control activities, which might be seen as necessary if development is allowed in the floodplain, are likely to alter streamflow and the streambed. Impacts could include removal of riparian vegetation, a decrease in the frequency and duration of floodplain inundation, and channel incision or bank erosion as flow is concentrated in the channel rather than spreading out onto the floodplain. A decrease in inundated area during floods can also decrease recharge of the alluvial aquifer.

Groundwater is commonly used to supply new residential and urban development in the area. As residential use increases, groundwater levels could decline in shallow alluvial aquifers. This could cause a decline in vigor or induce mortality in riparian vegetation that relies on shallow groundwater.

Tuzigoot National Monument

The potential impacts to Tuzigoot National Monument are also most likely to result from nearby urban or residential development. Increased consumptive use of groundwater, increased diversions from the Verde River to Peck's Lake, and channel modifications to provide flood control are the most likely mechanisms for generating impacts. For example, the proposed Verde Valley Ranch project would result in some of these impacts. This proposed development is described in greater detail in Chapter 6 "Case Study: Verde Valley Ranch Development".

IMPACT ANALYSIS PROCEDURE

Installing IMPACT.WK4 Spreadsheet

The step-by-step procedure described in this section for evaluating potential impacts of proposed development near the Monuments is designed to be used in conjunction with a computer spreadsheet program that stores selected data, performs calculations, and provides graphical displays of the results. The program is a Lotus 1-2-3 version 5.0 for Windows spreadsheet named "IMPACT.WK4". Although the spreadsheet is not large (380,000 bytes), it will function most effectively on an IBM (286 or faster) computer with a color monitor.

To install IMPACT.WK4 onto a personal computer, insert diskette 1 at the back of this report into the floppy disk drive (A: drive assumed here), attach to that drive by typing **A:**, and type the following command to decompress the spreadsheet file and copy it onto the C: drive: **pkunzip -d impact C:**. This installation process will create a new directory called "IMPACT" on the C: drive and will copy the Lotus 1-2-3 version 5.0 for Windows spreadsheet file (IMPACT.WK4) to that directory. A copy of the spreadsheet that runs under Lotus 1-2-3 version 2.4 for DOS (IMPACT.WK1 and IMPACT.FMT) is also provided in case the only version of Lotus software available is older than version 5.0. After the program is installed, start the Lotus 1-2-3 software on the computer and retrieve the spreadsheet file. The spreadsheet may also be imported into EXCEL, although there will be minor differences in formatting. The instructions in this section assume that the user is familiar with basic Lotus 1-2-3 commands.

The spreadsheet is divided into several worksheets that perform calculations related to water demand, groundwater levels, streamflow depletion, and stormwater runoff. The worksheet includes labels and instructions to guide the user through the calculations. This section provides additional information describing the input data required for each worksheet within the spreadsheet. These items are highlighted in green in the worksheets and must be specified by the user for each project analyzed. The nonzero values entered in some of the green fields in the copy of the spreadsheet distributed with this report are for illustration purposes only and represent estimated values for the

Verde Valley Ranch project. This section also identifies variables in the worksheets for which default values are used that could be updated if new information becomes available. These items include estimates of irrigation efficiency, water use by month, and historical streamflow. While a user will not routinely modify such items, modification is possible if better estimates or additional data become available. Finally, this section explains the main assumptions, algorithms, and outputs for each worksheet within the spreadsheet.

Worksheet 1: Water Demand

This worksheet program calculates gross water demand, return flows, and net consumptive use at annual and monthly time scales for nine categories of land use. It provides input to all of the other worksheets, so it should be completed first. Figure 4-1 shows the first part of the water demand worksheet as it appears in the spreadsheet, including the highlighted cells where the user must enter data for each case study. The user must specify the number of units of each land use category (in terms of number of dwelling units or acres, depending on the type of land use).

The user can update the following items if new information becomes available:

- annual water demand per unit of land use,
- indoor use (the percentage of water used indoors in each land use category),
- irrigation efficiency (the percentage of total water used for irrigation that is consumed), and
- the monthly distribution of annual water demand for each type of use.

The worksheet includes the following calculations for each land use category:

- annual gross water demand = number of units times annual demand per unit,
- annual wastewater return flows = annual gross demand times percent indoor use,
- annual irrigation return flows = annual gross irrigation demand times (one minus irrigation efficiency),
- annual consumptive water demand = annual gross irrigation demand minus return flows,
- monthly gross demand = annual gross demand times fraction of annual demand used each month,

WATER DEMAND WORKSHEET

This worksheet calculates gross and net monthly water demand for the proposed development. Gross water demand is the total amount of surface water diversion or groundwater pumping. Net demand is the consumptive use of water, which equals gross demand minus return flows.

Enter the relevant data values in the highlighted boxes. The non-highlighted boxes are calculated by formulas documented in the user's manual.

Parameter	Land Use								
	Residential					Permanent Crops		Field Crops	
	Primary	Seasonal	Commercial	Industrial	Turf	#1	#2	#1	#2
Unit of measure	Service connection	Service connection	Service connection	Service connection	Acre	Acre	Acre	Acre	Acre
Number of units	825	0	0	0	275	0		0	
Annual water demand per unit (af/yr) (see table of suggested values at right)	0.2	0.1	0.8	1.1	3	2.5		3.2	
Indoor use (% of total use)	50	80	80	95	0	0	0	0	0
Irrigation efficiency (%)	50	50	50	50	80	70	70	70	70
Annual demand summary									
Gross demand (af/yr)	197.95	0	0	0	825	0	0	0	0
Consumptive use (af/yr)	49.4875	0	0	0	660	0	0	0	0
Return flow (af/yr)									
Wastewater	98.975	0	0	0	0	0	0	0	0
Irrigation	49.4875	0	0	0	165	0	0	0	0

Suggested Water Demand Factors for Verde Valley Area

Land Use	Annual Water Demand (acre-feet)
Residential	
Primary residence	0.2
Seasonal residence	0.1
Commercial	0.8
Industrial	1.1
Crops (applied water)	
Turf or pasture	4.0
Alfalfa	4.2
Grains	1.2 - 2.5
Vegetables	2.0
Deciduous orchard	3.0
Vineyard	3.4

MONTHLY DEMAND DISTRIBUTIONS

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	AVERAGE	TOTAL
Fraction of Annual Demand														
Residential (primary)	0.06	0.06	0.06	0.07	0.08	0.12	0.13	0.12	0.09	0.08	0.07	0.06	0.08	1.00
Residential (seasonal)	0.17	0.17	0.17	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.17	0.08	1.00
Commercial	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	1.00
Industrial	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	1.00
Turf	0.03	0.04	0.07	0.08	0.13	0.14	0.14	0.13	0.10	0.07	0.05	0.03	0.08	1.00
Field crops	0.01	0.01	0.05	0.10	0.16	0.18	0.18	0.16	0.12	0.01	0.01	0.01	0.08	1.00
Permanent crops	0.03	0.04	0.07	0.08	0.13	0.14	0.14	0.13	0.10	0.07	0.05	0.03	0.08	1.00

Figure 4-1. First Part of Water Demand Worksheet.

- monthly return flows = annual return flows times fraction of annual demand used each month, and

- monthly consumptive water demand = annual consumptive use times fraction of annual demand used each month.

The values for primary residential, commercial, and industrial water demand were developed from several years of monthly water production data obtained from Cottonwood Water Works, Camp Verde Water Company, and Verde Lakes Water Corporation. The annual agricultural water demand values are for high desert areas in southeastern California (California Department of Water Resources 1975), and the monthly distribution follows monthly evaporative demand during the growing season (Replogle pers. comm.).

Worksheet 2: Groundwater

This worksheet program calculates changes in groundwater levels that would result from pumping new water supply wells. Figure 4-2 shows the first and second parts of the groundwater worksheet, in which short-term (up to 1 year) water level drawdowns around a pumping well are calculated using the Cooper-Jacob equation (Bear 1979, Lohman 1979) and assuming a constant pumping rate. This calculation may be particularly useful to evaluate impacts of individual wells located in or adjacent to areas with phreatophytic riparian vegetation. The third part of the worksheet is shown in Figure 4-3 and calculates monthly drawdowns at a location of interest from a well or cluster of wells with seasonally varying pumping rates. This calculation uses the principle of superposition and the Cooper-Jacob equation to calculate monthly drawdown for 4 years. This reveals both the attenuation of water-level fluctuation with distance from the pumping well and the long-term water-level trend, if any.

If a development proposes to use more than one well and the wells are located near each other, the effects on water levels a great distance from the wells is essentially indistinguishable from the effects of a single large well. As a rule of thumb, if the distance to the potentially affected resource (e.g., a creek, well, or riparian area) is more than two times the diameter of the cluster of pumping wells, the effects are equivalent to a single well located at the center of the cluster with a pumping rate equal to the sum of the individual well pumping rates.

The user must provide the following information for the groundwater calculations:

- aquifer transmissivity (values are suggested for aquifers in the Verde Valley region),

- aquifer storativity (suggested values are also provided), and

- the distance from the well or well cluster to the affected resource.

GROUNDWATER WORKSHEET

Use this worksheet to estimate the effect of individual wells or well clusters on groundwater levels at another well, a creek, a phreatophyte area, or some other location of interest .

Part 1. Aquifer characteristics and distance to affected resource.

	Value at Well Location	Average Measured or Estimated Values for Geologic Formations		
		Alluvium	Verde	Coconino /Supai
Transmissivity (square feet per day)	2,558	1,000	301	2,558
Storativity (dimensionless)	0.01	0.15	0.01	0.01
Distance from well to affected resource (feet)	400			

Part 2. Single well or well cluster, constant pumping rate, effects after 1-365 days.

(Hint: here are the equivalent pumping rates (gpm) for the gross demand

		JAN	FEB	MAR	APR	MAY	JUN
Well pumping rate (gal/min)	175	271	386	515	597	875	1,040

Estimated water-level drawdown at affected resource after indicated duration of pumping (feet)

Pumping duration (days)	1	7	30	60	90	182	365
Drawdown (feet)*	-1.35	-3.40	-4.93	-5.67	-6.09	-6.84	-7.57
Validity check: results valid only when u<.05. u=	0.156372	0.022339	0.005212	0.002606	0.001737	0.000859	0.000428

* Negative number indicates drawdown (water level below initial level).

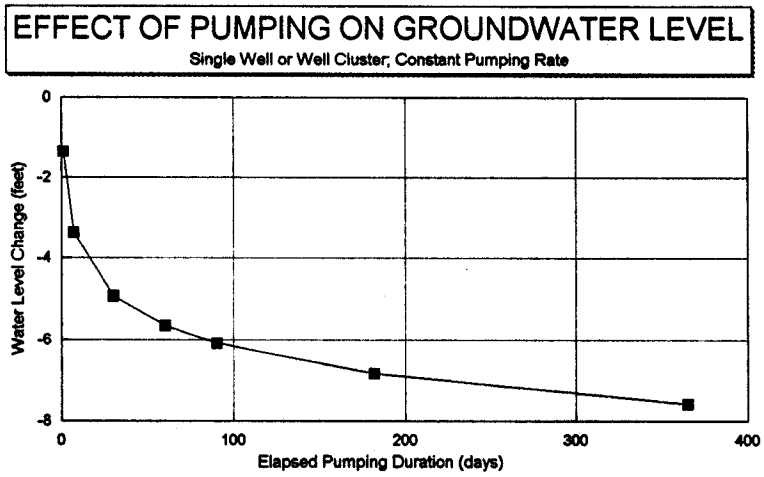


Figure 4-2. First and Second Parts of Groundwater Worrksheet.

Part 3. Seasonal and long-term drawdown effect of variable monthly pumping at a well or well cluster.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG
af:	37.1	47.8	70.6	79.2	119.9	137.9	139.8	127.2
gpm:	356	525	589	892	1,026	1,040	946	719
Frac. of avg	0.44	0.56	0.83	0.93	1.41	1.62	1.64	1.49
Avg. (af)	85.2							

Net drawdown in fourth year of repeated 12-month cycle of pumping rates.

Calculated using superposition of drawdown from each month and recovery beginning in the following month. Cooper-Jacob Equation. 48 months total. See tables to right for drawdown and recovery components for all 48 months.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG
Monthly drawdown (feet)*:	-21.4367	-29.9226	-33.1818	-48.4747	-55.4144	-56.3355	-51.7586	-40.3916

Long-term average drawdown (feet)*: -35.8208

* Minus sign indicates drawdown (water level lower than original level).

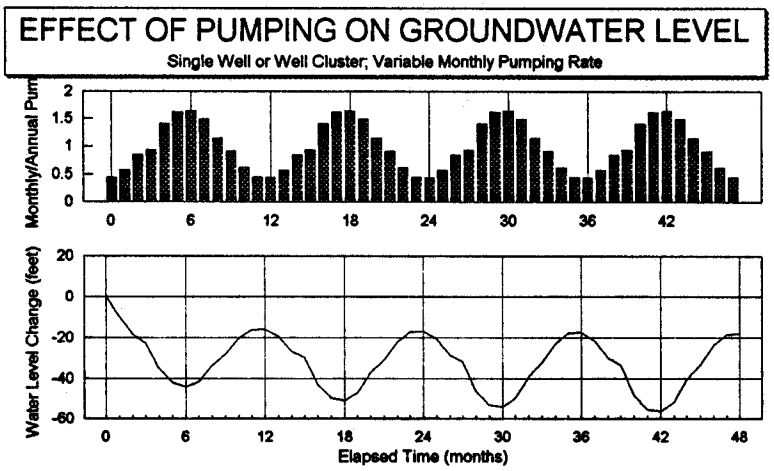


Figure 4-3. Third Part of Groundwater Worrksheet.

For the short-term drawdown calculation, the user must specify the pumping rate. The program prompts the user with pumping rates equivalent to the monthly gross water demand rates. For the long-term variable-pumping drawdown calculations, the calculations assume that monthly pumping rates equal the monthly gross water demand rates.

In addition to calculating drawdown near a potentially affected resource, the groundwater worksheet indicates the validity of the Cooper-Jacob equation by showing the value of the parameter "u" for each calculation time interval.

Worksheet 3: Streamflow Depletion

The streamflow depletion worksheet program calculates the effect on streamflow of direct diversions, nearby groundwater pumping, wastewater discharges, and irrigation return flow. Direct diversions are simulated as if they were wells located at the creek. In effect, the pumping rate is subtracted directly from streamflow rate. Groundwater pumping near the creek is assumed to deplete streamflow by an amount that, in the long run, equals the pumping rate at the well. In the short run, groundwater pumping is supplied by decreases in groundwater storage near the well. As the cone of depression in the water table expands outward around the well, it eventually reaches the stream. Assuming hydraulic connection between groundwater and the creek (i.e., that the creek is not perched over an unsaturated zone), the decrease in groundwater level near the creek will induce an increase in the rate of seepage out of the creek. If existing groundwater levels are higher than the level of the creek, the water level decline will decrease the rate of seepage into the creek. If pumping continues, a steady-state condition will eventually be reached in which the rate of induced seepage equals the pumping rate of the well. The first part of the streamflow depletion worksheet is shown in Figure 4-4, with a hypothetical distance of 400 feet between the well and a creek.

If groundwater pumping varies monthly in response to seasonal variations in water demand, a sinusoidal annual cycle of drawdown will result. The cycle of water level fluctuations at a distance from the well will be delayed and have a smaller amplitude than the cycle of fluctuations close to the well. The worksheet calculates the timing and magnitude of water level fluctuations at the potentially affected resource as a percentage of long-term average drawdown. Monthly variations in induced seepage (as a percentage of the annual average seepage rate) are assumed to be the same as the monthly variations in water level because seepage is proportional to the water-level gradient between the creek and the water table. The effects of streamflow depletion on monthly streamflow is calculated in the second part of the worksheet, which is shown in Figure 4-5.

Treated wastewater is assumed to return directly to the creek in the same month that the supply water is produced. Because studies of wastewater generation have found that about 98% of water used indoors becomes wastewater (California Department of Water Resources 1983), is it assumed that all water used indoors becomes wastewater. Irrigation return flow is assumed to consist of irrigation water that percolates to the water table and flows via the subsurface back to the

STREAMFLOW DEPLETION WORKSHEET

This worksheet calculates the effect of water withdrawals on streamflow. If the withdrawals are by a well or wells, the groundwater worksheet must be completed first. If the withdrawals are direct diversions of surface water, you may skip the groundwater worksheet and simply enter 0 for the distance from the diversion point to the creek.

Distance from diversion point to creek (feet)	400
Radius of well influence after 12 months (feet)	5,292

1. Streamflow depletion from groundwater pumping

Monthly distribution of drawdown at creek (from groundwater worksheet)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Average
Fraction of long-term average drawdown	0.598	0.835	0.926	1.353	1.547	1.573	1.445	1.128	0.926	0.657	0.510	0.502	1.000

Monthly distribution of induced seepage (distribution assumed to be same as drawdown distribution)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Average	Total
Seepage (acre-feet)	51.0	71.2	79.0	115.4	131.9	134.1	123.2	96.1	78.9	56.0	43.5	42.8	85.2	1023.0

2. Streamflow Augmentation from wastewater discharge and irrigation return flow

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Average	Total
Wastewater (acre-feet) (assumes direct discharge to creek)	5.8	5.7	6.4	7.4	8.4	11.6	12.6	11.6	8.7	8.1	6.5	6.1	8.2	99.0
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Average	Total
Irrigation return flow (acre-f (assumes subsurface return flow)	17.9	17.9	17.9	17.9	17.9	17.9	17.9	17.9	17.9	17.9	17.9	17.9	17.9	214.5

3. Net change in stream flow

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Average	Total
acre-feet	-27.4	-47.6	-54.7	-90.1	-105.6	-104.6	-92.7	-66.6	-52.3	-30.0	-19.1	-18.8	-59.1	-709.5
cfs	-0.4	-0.9	-0.9	-1.5	-1.7	-1.8	-1.5	-1.1	-0.9	-0.5	-0.3	-0.3	-1.0	n.a.

Figure 4-4. First Part of Streamflow Depletion Worksheet.

4. Comparison with existing flow

Place cursor on green (upper left) cell of table below, then copy the data block of flow statistics for the correct location (range WELL, CASTLE, or TUZIGOOT) to the table below (e.g. /C CASTLE <CR><CR>).
The data tables for each monument are stored at the bottom of this worksheet.
The with-project flows are calculated by subtracting streamflow depletions (see above) from existing flows.
Monthly depletions are assumed to be the same regardless of existing flow levels.

Existing flow at the affected monument (cfs)

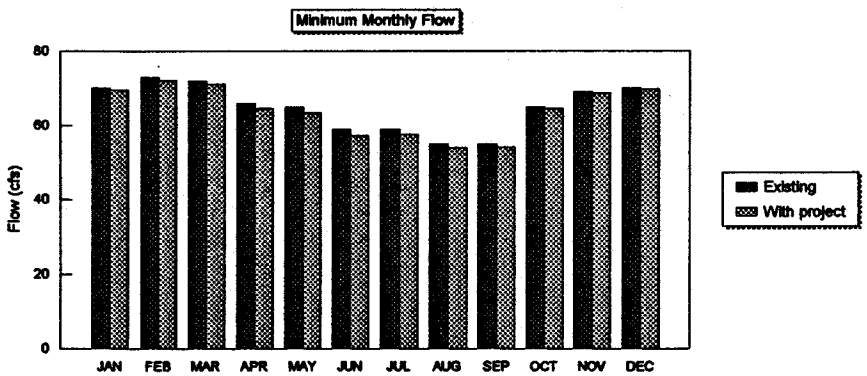
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Average
Minimum	70.0	73.0	72.0	66.0	65.0	59.0	59.0	55.0	55.0	65.0	69.0	70.0	64.8
Median	86.0	90.0	150.0	85.0	80.0	77.0	80.0	81.0	80.0	79.0	83.0	85.0	88.1
Average	225.9	505.8	517.9	214.4	89.5	77.0	107.1	105.4	105.3	123.0	133.4	212.3	199.9
Maximum	19,400	30,000	18,100	5,000	1,100	137	1,000	963	8,490	11,000	13,300	14,200	10,113.5

With-project flow at the affected monument (cfs)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Average
Minimum	69.6	72.1	71.1	64.5	63.3	57.2	57.5	53.9	54.1	64.5	68.7	69.7	63.8
Median	85.6	89.1	149.1	83.5	78.3	75.2	78.5	79.9	79.1	78.5	82.7	84.7	87.1
Average	225	505	517	213	88	75	106	104	104	123	133	212	198.9
Maximum	19,400	29,999	18,099	4,998	1,098	135	998	962	8,489	11,000	13,300	14,200	10,112.5

Change in stream flow as percent of existing flow

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Average
Minimum	-0.6	-1.2	-1.2	-2.3	-2.6	-3.0	-2.6	-2.0	-1.6	-0.8	-0.5	-0.4	(1.6)
Median	-0.5	-1.0	-0.6	-1.8	-2.1	-2.3	-1.9	-1.3	-1.1	-0.6	-0.4	-0.4	(1.2)
Average	-0.2	-0.2	-0.2	-0.7	-1.9	-2.3	-1.4	-1.0	-0.8	-0.4	-0.2	-0.1	(0.8)
Maximum	-0.0	-0.0	-0.0	-0.0	-0.2	-1.3	-0.2	-0.1	-0.0	-0.0	-0.0	-0.0	(0.1)



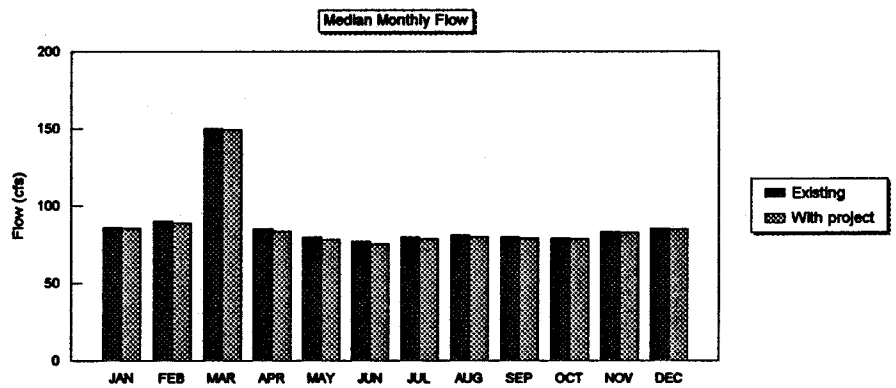


Figure 4-5. Second Part of Streamflow Depletion Worksheet.

creek, as occurs in the Verde River valley (Owen-Joyce and Bell 1983, Owen-Joyce 1984). The return flow rate is assumed to be constant because of the attenuating effects of subsurface flow, and the rate equals the gross irrigation water use rate minus the consumptive use rate (which equals the gross rate times the irrigation efficiency).

The with-project streamflow regime is calculated from existing streamflows by subtracting direct diversions and induced seepage and adding wastewater discharge and irrigation return flow. These adjustments are made directly to the summary statistics for existing monthly flows (i.e., the net change in flow is assumed to apply to the minimum, median, average, and maximum monthly flows for each month of the year). As a result, the changes expressed as a percentage of existing flow are always greatest for minimum flows.

The streamflow depletion worksheet requires no new user input. The values needed for the calculations are obtained from the water demand and groundwater worksheets.

Worksheet 4: Stormwater Runoff

This worksheet program calculates the effect of changes in land use on runoff rates during a real or hypothetical storm event. The change in runoff characteristics for each type of land use within the developed area are combined to obtain an area-weighted average change for the entire development. Changes in the runoff lag time are calculated assuming the developed area is approximately square or circular in shape.

The user must specify the following variables for the stormwater runoff calculations:

- the area of each existing land use type,
- saturated soil hydraulic conductivity for each existing land use type (suggested values are provided),
- the area of each proposed land use type,
- saturated soil hydraulic conductivity for each proposed land use type (suggested values are provided), and
- rainfall amounts in half-hour intervals for the simulated storm.

The first part of the worksheet is shown in Figure 4-6 and allows the user to specify existing and with-project land use and soil type. The values entered in the data fields in the figure are for the Verde Valley Ranch case study. The subsequent part of the worksheet calculates and displays the existing and with-project runoff hydrographs, as shown in Figure 4-7. Runoff from the site can be compared with estimated flow in the receiving creek to estimate the percentage change in

STORMWATER RUNOFF WORKSHEET

Variable	Land use: Natural vegetation	Residential	Commercial/ Industrial	Cropland	Range	Mining	Timber		
Runoff characteristics									
% Impervious (see table at right)	2	20	90	0	2	10	2		
Depression storage (in)	0.25	0.1	0.1	0.5	0.3	0.25	0.25		
Existing conditions								Total	Average
Area (acres)	400	0	0	0	0	370	0	770	n.a.
Hydraulic conductivity (in/hr)									
Pervious areas (select value from table at right)	0.5					0.02			
Impervious areas	0	0	0	0	0	0	0		
Area-weighted average	0.49	0	0	0	0	0.018	0		
Log of K (runoff factor)	-123.922	0	0	0	0	-645.549	0	n.a.	0.100158
								-769.471	
Area-weighted depression storage (in)	(see right ===>)							192.5	
									Lag Factors
Lag factor								0.03108	0.25
									0.25
									0.25
									0.25
	Natural vegetation	Residential	Commercial/ Industrial	Cropland	Range	Mining	Timber		
With-project conditions									
Planned area (in acres)	100	400	50	160	0	0	0	770	n.a.
Hydraulic conductivity (in/hr)									
Pervious areas (select value from table at right)	0.5	0.036	0.5	0.02					
Impervious areas	0	0	0	0	0	0	0		
Area-weighted average	0.49	0.0288	0.05	0.02	0	0	0		
Log of K (runoff factor)	-30.9804	-708.679	-65.0515	-271.835	0	0	0	n.a.	0.039984
								-1076.55	
Area-weighted depression storage (in)	(see right ===>)							156	
									Lag Factors
								0.03108	0.25
									0.25
									0.25
									0.25

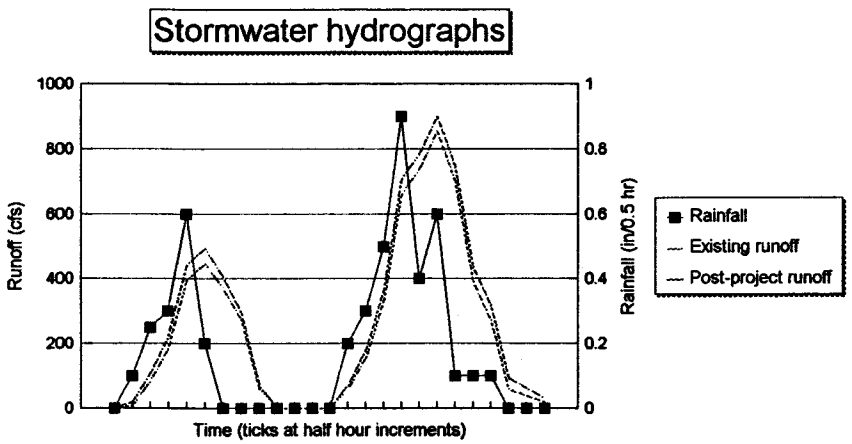
Soil Texture	Hydraulic conductivity (in/hr)
sand	4.60
loamy sand	1.20
sandy loam	0.40
loam	0.25
silt loam	0.15
silt	0.10
sandy clay loam	0.06
clay loam	0.04
sandy clay	0.02
silty clay loam	0.04
silty clay	0.02
clay	0.01
impervious	0.00

Typical percent impervious area:
(from ADOT's AZ Hydrology Manual)

Residential	
Primary, moderate ur	40
Primary, suburban	20
Seasonal (cabins)	10
Commercial	90
Industrial	90

Figure 4-6. First Part of Stormwater Runoff Worksheet.

Stormwater Hydrograph



Time (hours)	Rainfall (in)	Cumulative Rainfall (in)	Storage remaining (in)	Rainfall excess (cfs)	Runoff (cfs)	Storage remaining	Rainfall excess (cfs)	Runoff (cfs)
0	0	0	0.03108	0	0	0.03108	0	0
0.5	0.1	0.1	0	29.25638	7.314096	0	75.97669	18.99417
1	0.25	0.35	0	310.4437	84.92502	0	357.164	108.2852
1.5	0.3	0.65	0	388.0854	181.9464	0	434.8057	216.9866
2	0.6	1.25	0	853.9354	395.4302	0	900.6557	442.1505
2.5	0.2	1.45	0	232.802	446.3166	0	279.5223	493.0369
3	0	1.45	0	0	368.7057	0	0	403.7459
3.5	0	1.45	0	0	271.6843	0	0	295.0445
4	0	1.45	0	0	58.20051	0	0	69.88058
4.5	0	1.45	0	0	0	0	0	0
5	0	1.45	0	0	0	0	0	0
5.5	0	1.45	0	0	0	0	0	0
6	0	1.45	0	0	0	0	0	0
6.5	0.2	1.65	0	232.802	58.20051	0	279.5223	69.88058
7	0.3	1.95	0	388.0854	155.2218	0	434.8057	178.582
7.5	0.5	2.45	0	698.652	329.8848	0	745.3723	364.9251
8	0.9	3.35	0	1319.785	659.8312	0	1366.506	706.5515
8.5	0.4	3.75	0	543.3687	737.4729	0	590.089	784.1932
9	0.6	4.35	0	853.9354	853.9354	0	900.6557	900.6557
9.5	0.1	4.45	0	77.51869	698.652	0	124.239	745.3723
10	0.1	4.55	0	77.51869	388.0854	0	124.239	434.8057
10.5	0.1	4.65	0	77.51869	271.6229	0	124.239	318.3432
11	0	4.65	0	0	58.13902	0	0	93.17924
11.5	0	4.65	0	0	38.75934	0	0	62.1195
12	0	4.65	0	0	19.37967	0	0	31.05975

First peak (0-6 hours) = 2-year event:

Total runoff in acre ft	1,800	2,031
Peak discharge if cfs	446	493

Second peak (6-12 hours) = 50-year event:

Total runoff in acre ft	4,234	4,651
Peak discharge if cfs	854	901

Figure 4-7. Second Part of Stormwater Runoff Worksheet.

streamflow. In many cases, the percentage change will be small because the proposed development area will be a small percentage of the total watershed area, and streamflow in the creek will already be fairly high as a result of runoff from surrounding areas generated by the same rainfall event.

IMPACTS REQUIRING SPECIAL ANALYSIS

Certain types of development have effects that cannot be generalized because they depend closely on the site characteristics and project design features. These include onstream impoundments, channel modifications, and water quality effects of waste discharges. These types of developments must be evaluated on a case-by-case basis and the services of a hydrologist or engineer may be needed.

If onstream impoundments are fairly small and are maintained in a full condition, as is usually the case for small diversion dams, the principal effect on downstream flows will be a slight attenuation or smoothing of the flood peak hydrograph in small flood events. Larger reservoirs operated for water supply storage or flood control can affect all aspects of the flow regime in all months. Small impoundments may tend to increase downstream temperatures by detaining water and exposing it to the warming effects of the sun. Large reservoirs may have the opposite effect if they are deep enough to store substantial amounts of water below the thermocline, which is typically at a depth of 15-30 feet.

Channel modifications could include gravel mining, vegetation removal, bank stabilization, levee construction, or channel realignment or enlargement for flood control. In general, these tend to decrease shading, decrease overbank flooding, prevent meandering and gravel bar formation, and possibly increase flow velocities during floods. These changes could result in increased water temperatures, decreased food supply for aquatic organisms, a decrease in suitable sites for regeneration of early-succession riparian plants, and changes in scour and deposition patterns.

The water quality effects of wastewater discharges depend greatly on the source of the wastewater. In the case of municipal wastewater, the dissolved solids concentration is typically about 200 milligrams per liter greater than that of the supply water. Because municipal water supplies in the Verde Valley region are almost exclusively derived from groundwater, the dissolved solids concentration of the raw water supply may already be greater than the concentration in the creek. Toxic compounds not removed during wastewater treatment pose a potential risk to aquatic organisms. Naturally occurring toxic elements, such as arsenic, may be more concentrated in groundwater than in surface water, so municipal wastewater may have higher concentrations than water in the creek. For some elements (including mercury and selenium), the toxicity threshold for wildlife is lower than the drinking water standard for human consumption.

Chapter 5. Database of Hydrological/Biological Relationships

Water resources are integral to the aquatic and riparian ecosystems at the Monuments, and protection of ecosystems is a central objective of water resources management by NPS. Three aspects of water resources relate directly to biota: hydrologic functions (e.g., flood frequency and magnitude, groundwater discharge); habitat features for riparian and aquatic species (e.g., shallow groundwater, stream base flow); and water quality. The relationship between hydrology and biology, however, is complex and has been approached by previous investigators from both hydrological and biological perspectives. As a result, NPS must integrate diverse and disparate information from both hydrological and biological references in its management of water resources. A database of available information on hydrobiological relationships was created for this study to allow NPS staff to access information relevant to specific issues encountered as they participate in water resources management for the Verde River basin.

OVERVIEW

FACTOID is a searchable database program for information regarding the hydrological requirements and tolerances of aquatic and riparian biota in arid and semiarid regions. The purpose of the database is two-fold. For natural scientists who do not specialize in aquatic or riparian biology, it provides rapid access to key information on that subject from a large body of literature. For those who do specialize in that area, it provides a convenient means of filing and retrieving information.

Database entries consist of short (generally one- to two-sentence) statements or "factoids" summarizing data, results, or conclusions from investigations documented in journal articles, agency reports, and other technical publications. In most cases, several pieces of information are extracted from each reference source and are entered in the database as separate factoids. Each factoid is assigned attributes or descriptive keywords for each of several attribute categories. These attributes allow factoids to be selectively retrieved by screening the database for specified topics. Presently, the database has four attribute categories, each with 8-17 descriptor options, as shown in Table 5-1.

Table 5-1. Attribute Categories and Options in the FACTOID Database

Attribute Category	Location	Biota Type	Life Stage	Hydrologic Parameter
Attribute Options	All California Desert southwest Great Basin Midwest None Northeast Pacific northwest Rockies and high plains Verde River basin	All Amphibians Aquatic Birds & mammals Cottonwood Fish General riparian Herbs Invertebrates Marshes Mesquite None Shrubs Sycamore Tamarisk Trees Willow	Adult All Germination/ spawning Hibernating None Seedling/juvenile Succession	All Channel form Channel location Erosion Flow regulation Flow season Grazing Groundwater Hillslopes Low flows None Peak flows Rainfall/ET Substrate Water quality Water use - consumptive

As an example, the following factoid was extracted from an article by Stromberg et al. (1991) describing riparian vegetation along the Hassayampa River in Arizona:

> Hassayampa R., AZ: Max. height of cottonwood seedlings above low-flow level during 1988-89 was 2.6 meters; average was 0.7-2.1 meters. If seeds are too high, they die of desiccation; if too low, they die from scour in subsequent floods (e.g., summer rainstorms).

This factoid was assigned the following attribute options: desert southwest, cottonwood, seedling/juvenile, channel location, and low flows. Note that two options from the hydrologic parameter category fit this factoid.

The database uses FoxPro version 2.6, a generic database program. Programming for the FACTOID database was done by David C. Hudson & Associates, who borrowed program elements from the similar California Natural Diversity Data Base, which they had previously developed. The program is menu-driven and uses tab and arrow keys to select menu options and move between data fields in each menu window.

To search the database for factoids related to a specific topic, the user selects screening attributes. Only factoids with those attributes will be returned by the search algorithm. Any number of options may be selected from one or more of the attribute categories. If more than one option is selected within a category, the program applies either/or logic. If multiple categories are selected, the user may choose single-criterion (either/or) or multiple-criteria (and) logic between categories. The selected factoids, along with bibliographic information for the source references, can be reviewed on the screen or written to a file for printing.

The database presently contains approximately 200 factoids extracted from more than 40 reference publications. Most of the factoids represent riparian vegetation and hydrologic conditions in Arizona and the desert southwest, although some are more general or derived from studies in other areas.

An advantage of the database is that users may add information for topics of particular interest to them such as information for particular locations or biota types. The user may also add new attribute categories and options so that searches can be more specific in a particular area of interest (although only factoids entered after that point will potentially be labeled with the new attributes). Finally, the independent additions of numerous users can be periodically merged into a master database. Thus, all users can benefit from each other's additions.

USER INSTRUCTIONS

Installing FACTOID

For reasonable response time, the FACTOID program should be installed on an IBM 386 or faster computer with at least 4 megabytes (MB) of random access memory (RAM). The database and program files occupy approximately 4.2 MB of disk space.

To install FACTOID, insert the first diskette into the floppy disk drive (A: drive assumed here), attach to that drive by typing **A:**, and typing the following command to decompress the program and data files and copy them to the C: drive: **pkunzip -d factoid C:**. You will be prompted to insert the second diskette into the A: drive. This installation process will create a new directory called "FACTOID" and two subdirectories on the C: drive and will copy the files to those directories.

The program is started by attaching to the "FACTOID" directory and typing: **factoid.** The program runs under DOS and should be executed directly from the DOS prompt and not from the DOS port in Windows.

Program Structure

The FACTOID program is organized with branching, pull-down menus. When FACTOID is started, the main menu appears. When menu items are referred to in this section, they are listed in boldface type. The main menu has six items or "submenus" that are active when the program is initiated: **System, Edit, Database, Program, Output,** and **Help**. The **Record** menu is active only under the **Program** item (refer to Program menu). The mouse or "Tab" and arrow keys allow the user to move the cursor among menu options. If the cursor does not respond to arrow key strokes, press the "Alt" key to reactivate the menu. The "Esc" key can be used to move up one menu level with the main menu at the top level. Menu items at any level or other items are selected by using the "Enter" key or by pressing the key matching the yellow or white highlighted letter in the menu option.

The **System** menu is used to exit the program. The **Edit** menu is used to delete factoids. The **Database** menu is used to reindex the database. The **Program** menu is used to search, add, and edit factoids and references. The **Output** menu allows the user to print lists of references or factoids to the screen, a file, or to a printer. The **Help** menu provides a contact for help with the program. There are no online instructions included with the program.

The **Program** is the most frequently used menu and offers six action options. **Factoids** allows the user to list, add, or edit factoids and references, query the database to select factoids according to their attributes, and add or edit attribute categories and options. Each of these options brings up screens with data fields to fill in or modify. In all of these screens, the "Tab" and arrow keys can be used to move between fields, and the "Enter" key selects the highlighted field. The "Esc" key returns the user to the next higher menu level.

Listing, Adding, Editing, and Deleting References

Selecting **References** in the **Program** menu displays the references window. The reference publication from which a factoid was derived must be entered into the database before the factoid can be entered into the database. The data fields for references include author, date, and title/publication. Most of the reference publications are journal articles or technical reports. A menu of options at the bottom of the screen allows the existing references to be listed or edited and new references to be added. Selecting the **List** option displays a list that can be searched by using the "Ctrl" key and pressing Ctrl-F and entering a search string. To delete a reference, select it from the list, type **Alt-R** to bring up the **Record** menu, and select **Delete**.

Listing, Adding, Editing, and Deleting Factoids

Selecting **Factoid** in the **Program** menu displays the factoid window. The data fields for factoids include the reference publication, the page number where the factoid was found, the factoid itself, and attributes assigned to the factoid. The factoids are one or more sentences or transcribed tables of information on a single topic extracted from the reference publication. In most cases, several factoids are drawn from each reference. A menu of options at the bottom of the screen allows the existing factoids to be listed or edited and new references to be added. To peruse the factoids (in the sequence in which they were added to the database) select **Next** (press **N**) from the bottom menu. Only the first four lines of each factoid are displayed in the **Factoid** field. To read an entire factoid, select **Edit** from the bottom menu, tab to the **Factoid** field, and use the down arrow to advance the text. The list of factoids can also be viewed and selected using the **List** option, which displays basic information for each factoid, one per line. The list can be searched by pressing Ctrl-F and entering a search string.

In most cases, the factoids are summaries of factual information developed directly by the authors of the reference publication. Authors' opinions or conclusions are less frequently included. If an author cites specific factual information from a prior publication, that information and reference are entered as separate factoids. These secondary references can be identified by the absence of a page number in the factoid data.

When adding or editing a factoid, it must be saved into the database using the **Save** option on the menu at the bottom of the screen. If the existing list of attributes or attribute categories is not adequate to describe a factoid, new attribute keywords and attribute categories can be added to the database using **Categories** or **Option Lists** under the **Program** menu.

To delete a factoid, the user should select a specific factoid by listing factoids, using the arrow keys to highlight the appropriate factoid, and pressing the "Enter" key. Once the factoid has been selected, press **Alt-R** to activate the **Record** menu at the top of the screen. Select **Delete** from the menu and press "Enter" to delete the factoid.

Querying the Database

The **Create Query Subset** option under the **Program** menu is used to design a search for factoids that meet user-defined criteria. The user specifies one or more attributes to search for by selecting first the attribute category then the desired keyword within that category. The program stores the search criteria from the previous search. To reuse or slightly modify these criteria, select the **Reload** option displayed in the dialogue box. Check marks indicate saved settings; asterisks indicate new settings. Use the **Clear** option to rebuild the search criteria from scratch.

To select or modify search criteria, tab to the appropriate attribute category field and press the "Enter" key. If multiple keyword options are selected from within a single category, the search algorithm applies either/or Boolean logic and selects factoids that have at least one of the selected options. If keyword options are selected from more than one category, the user may specify either/or (**Single criterion**) or "and" (**Multiple criterion**) logic between categories. In other words, if the user desires to retrieve all factoids that meet the keyword criteria selected for Location (e.g, desert southwest) and the keyword criteria selected for Biota (e.g., Cottonwoods, Willows, and Sycamores), the "multiple criterion" option should be selected in the **Create Query Subset** window. When the desired attributes have been selected, the search is initiated by using the "Tab" or arrow keys to highlight the **Select** item and pressing "Enter". A log screen appears that indicates the progress of the search, which generally lasts 10-20 seconds. The numbers in the search results area of the screen indicate the number of reference publications from which the selected factoids were derived and the number of matching attributes. The number of selected factoids is not displayed. The best method for viewing the search results is to exit the **Create Query Subset** and **Program** menus and go to the Output menu (see "Saving Search Results" below). That menu includes an option to output the selected factoids to the screen. The **View Query Subset** menu under the **Program** menu displays only the first 4 lines of each factoid and thus is of somewhat limited use.

Adding Attributes and Attribute Categories

The **Categories of Attributes** option in the **Program** menu allows the user to add new attribute categories. The current categories are Location, Biota Type, Life Stage, and Hydrologic Parameter. The Hydrologic Parameter category presently includes several attribute options that are not strictly hydrological in nature (such as Substrate and Channel Location) but that are useful variables for cataloging and retrieving factoids.

The **Options** selection on the **Program** menu allows the user to add new attribute keyword options under any attribute category. First, highlight and select a category using the arrow and "Enter" keys. For example, if the user would like to enter several factoids specifically pertaining to reptiles, "Reptile" could be added as a new option in the Biota Type category. If a new attribute option is added, however, the user may want to review existing factoids and add the new attribute to existing factoids using the **Factoids** option on the **Program** menu.

Saving Search Results

The **Output** submenu of the main menu allows the user to view the results of database searches on the screen, send them to the printer, or save them as a file. If the printing option does not function correctly because of hardware configurations, the results can be saved to a file and later printed using a word processing program. To minimize formatting problems when importing the

output file into a word processing program, the file should be saved from FACTOID with a **.prn** suffix and identified as a standard ASCII (DOS) text file when importing it into the word processor. If the file is printed using a word processing program, it may be necessary to decrease the marging widths or use an 8 point font (e.g., Times New Roman 8 pt) to avoid incorrect word wrapping and to position the preformatted page-breaks at the appropriate spots. Three types of reports can be created from the **Output** menu: **Reports, Lists**, and **System**. **Reports** is used to print the factoids selected by the most recent database search. **Lists** generates a complete list of all of the references. **System** creates a report containing system information such as error reports.

Interpreting and Presenting Results

The user may incorporate information contained in the factoids into reports, policy statements, and comment letters on proposed developments. Because of the great diversity of information in the factoids and variety of issues for which it might be relevant, it was not possible to create a standardized reporting format suitable for all occasions. Instead, the factoids provide credible, factual information from scientific literature that can be used to design management strategies or to develop positions on proposed development actions or local planning activities. The details of the biology and hydrology described in the factoids are also too complex and variable to develop simple graphs relating hydrological and biological variables. The information contained in each factoid must be evaluated by the user to determine its applicability to the case at hand.

Merging Copies of the Database

Two users who have independently added to their own copies of the database can have them merged into a single combined database. To merge two versions, the FoxPro programming software (not included with the end-user database copies) is used to open the data files from one copy and add the contents of the corresponding files from the other copy.

Chapter 6. Case Study of Proposed Verde Valley Ranch Development

The impact assessment tools developed for this project were applied to the proposed Verde Valley Ranch development near Tuzigoot National Monument. This chapter describes the application and results. Verde Valley Ranch is a proposed development for the area around Peck's Lake. Figure 6-1 shows the project boundaries. The development is primarily residential with some commercial land use and a large golf course.

The first step in assessing a project is to obtain the information required to run IMPACT.WK1. A site map and summary of the proposed project were obtained (Klimek pers. comm.). Approximately 925 residential units are planned to cover 460 acres of land. There will be 100 acres of open space and roughly 160 acres dedicated to the golf course. While this information did not identify the number of commercial water connections planned, it had sufficient information to complete the spreadsheet.

APPLYING THE IMPACT ANALYSIS SPREADSHEET

The water demand worksheet, while lacking information on commercial connections, was completed for residential and turf land uses. This worksheet suggests that turf irrigation would represent a large gross water demand (825 af/yr) and gross residential demand would be approximately 200 af/yr. Consumptive use is estimated to be 660 af/yr for turf irrigation and 50 af/yr for residences.

The groundwater worksheet provides information on impacts of groundwater pumping on aquifers. The proposed source of water for the project is a deep well, so Verde formation aquifer characteristics (i.e., transmissivity and storativity) were selected for this application. The well has an estimated yield of 176 gpm. Projected demand is estimated by the spreadsheet calculations to vary from 224 gpm in January to over 1,000 gpm in August. The well will not have to meet all of this demand because the project will use treated effluent for irrigating the golf course.

A constant pumping rate of 176 gpm was used in the worksheet to calculate short-term drawdown impacts. This pumping rate is equivalent to 0.4 cfs or, if continued for 1 year, 284 af/yr. The proposed water supply well is 400 feet from the Verde River; this distance was selected as the radius of interest for the drawdown calculations.

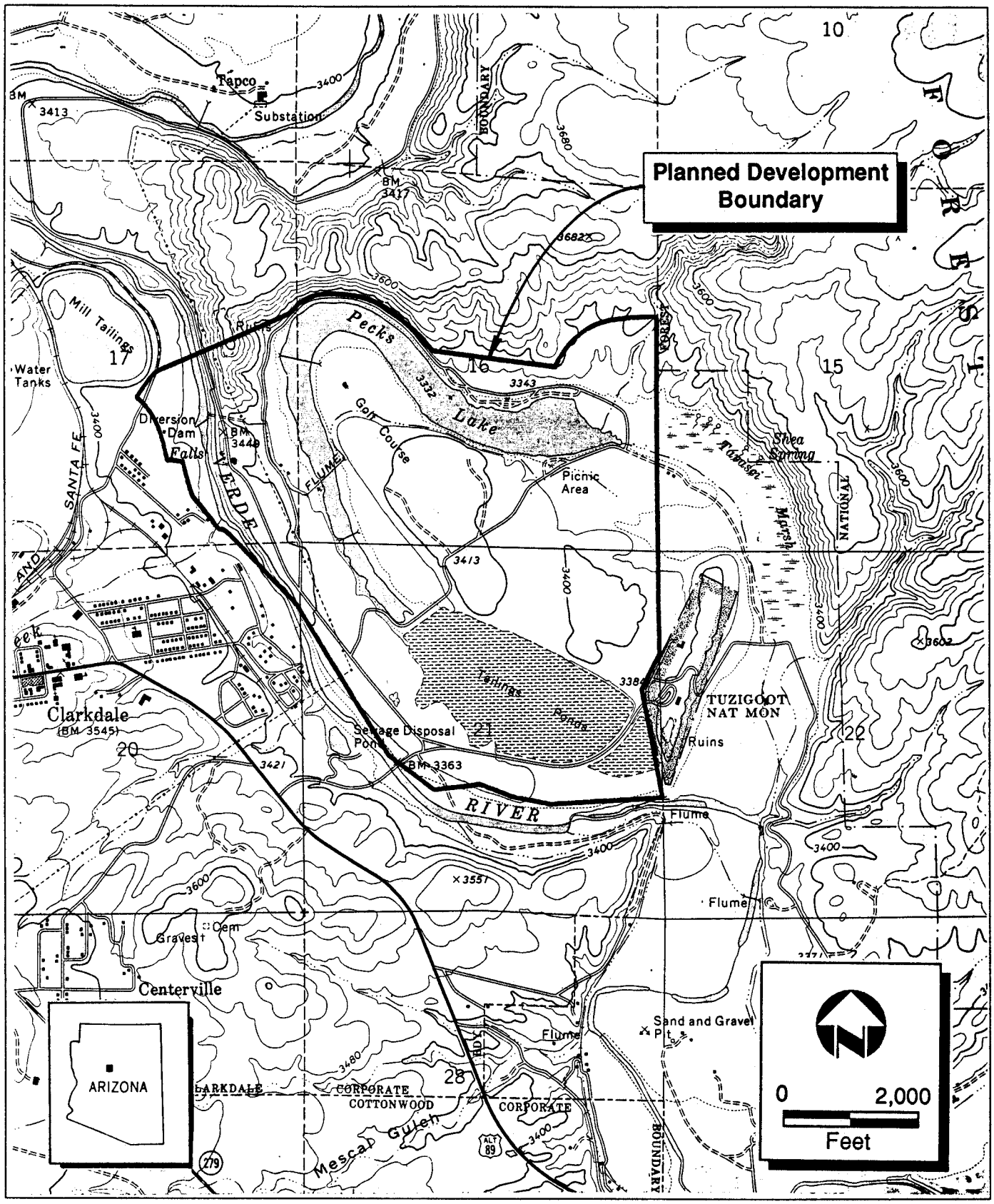
The short-term drawdown at a radius of 400 feet increased from 25 feet after 7 days to 45 feet after 1 year. When the pumping rate was assumed to equal the monthly varying gross water demand rate (31-143 af/month or 228-1,065 gpm), drawdown after 4 years ranged from 100 feet in winter to 380 feet in summer. When aquifer characteristics representative of the Coconino and Supai Formations were used instead of characteristics from the Verde Formation, short-term drawdown increased from 5 feet after 30 days to 8 feet after 365 days. After 4 years of a monthly varying pumping rate equal to the gross water demand, drawdown ranged from 18 feet in winter to 60 feet in summer. The smaller drawdowns in the latter set of calculations result from the higher transmissivity of the Coconino and Supai Formations.

The drawdown calculations indicate that the water table could decline by approximately 50 feet near the river if induced seepage does not turn out to be great enough to offset the decline. The resulting water table level would be substantially below the root zone of phreatophytic riparian vegetation.

The streamflow depletion worksheet gives an indication of whether the water table declines near the river would tend to be offset by increased seepage from the river. Assuming the water table is in hydraulic connection with the river, the maximum rate of induced seepage would be approximately 2.2 cfs (136 total acre-feet) in July. Induced seepage would be substantially offset by wastewater and irrigation return flows so that the largest net decrease in streamflow would be 1.1 cfs in June. The minimum recorded monthly flow in June is 59 cfs, so the net depletion would be, at most, 1.9% of the flow in the river. Because this is a small percentage of total flow, it is highly likely that the water demand for the project would be supplied by an equivalent amount of induced seepage from the river. The annual consumptive water demand for the project is 710 af/yr, which equals 1.9% of the average annual discharge of the Verde River at Clarkdale (36,800 af/yr).

Soils characteristics at the development site were not provided in the development description but can be obtained from U.S. Natural Resources Conservation Service (formerly Soil Conservation Service) soil surveys. Hydraulic conductivity (permeability) values of 0.1 to 0.5 inch per hour were assumed for this analysis. Two separate 6-hour rainfall events were included in the rainfall time series. The first event, from 0 to 5.5 hours, has a cumulative total rainfall representing a 2-year, 6-hour event for the Clarkdale area. The second event, from 6 to 12 hours, has a cumulative total representing a 50-year, 6-hour event.

Site topography indicates that under existing conditions, approximately half of the runoff from the project site flows toward Peck's Lake and half flows toward the Verde River. Runoff entering Peck's Lake gradually drains to the Verde River via the ditch along Tavasci Marsh. The effects of storage in Peck's Lake would attenuate the runoff peak before it reaches the marsh or the river. Under existing conditions, peak runoff to the lake during an average annual (2-year) event is approximately 70 cfs, and runoff volume is approximately 270 af. Because of attenuation, outflow through the ditch along Tavasci Marsh is less than 70 cfs and is probably contained in the ditch.



Base map: USGS Clarkdale, Arizona 7.5-minute quadrangle 1973.

Jones & Stokes Associates, Inc.

Figure 6-1
Verde Valley Ranch Development Area

The project description indicates that stormwater runoff from the entire site would be directed to Peck's Lake. Runoff would be detained long enough to pass through wetlands or sand filters to improve the quality of the discharged water. The stormwater worksheet does not reflect the effects of stormwater detention facilities, only the effects of increased impervious area. With the project, 1,620 af would flow toward the lake in a 2-year event, and peak runoff would be 408 cfs. Without detention, this volume and rate of inflow would greatly exceed the capacity of the outlet culverts under the road at the southeast end of Peck's lake. Water would flow over the road and through Tavasci Marsh. Overflow through the marsh already occurs in years with moderate to large flood events. The project would increase the frequency of overflow and the frequency and range of water level fluctuations in Peck's Lake would increase. These results indicate that detailed information regarding the capacity and operation of the proposed stormwater detention facilities is needed to adequately evaluate potential impacts.

There would be a corresponding change in peak flow in the Verde River. Direct runoff to the river in a 50-year flood would decrease by approximately 240 cfs (half of the 50-year peak runoff from the site under existing conditions). This might have no effect on the peak flow in the river if peak runoff from the site substantially precedes peak runoff from the Verde River watershed upstream of Clarkdale. The maximum change, assuming the peaks were coincident, would be a decrease in peak flow of approximately 0.5% in a 50-year event and less than 1% in more frequent event.

In summary, IMPACT.WK1 indicates a number of potential hydrologic impacts resulting from the proposed Verde Valley Ranch. These include lower groundwater elevations and modified peak flows (i.e., increased runoff volume but potentially reduced peak flow in the Verde River), increased water level fluctuations on Peck's Lake, and more frequent stormwater flushing of Tavasci Marsh. Net consumptive water use for the project would cause a small decrease in annual discharge in the Verde River. The development appears to be very close to the riparian corridor but it is uncertain whether vegetation will be removed or otherwise prevented from growing in the corridor. Additional information about the location of the development, including levees or other flood control structures, should be obtained to identify additional potential impacts to riparian species.

APPLYING THE HYDROLOGICAL/ BIOLOGICAL DATABASE (FACTOID)

The FACTOID database was used to identify biological impacts that could potentially result from the hydrologic impacts. The results of the IMPACT.WK1 calculations indicated that groundwater and stormwater are two potential areas of concern. The database was queried using a multiple criteria search in which desert southwest and Verde River basin were selected in the location category, and peak flow and groundwater were selected in the hydrologic parameter category. By default, all options in the biota type and life stage categories were included in the search. The search returned 42 factoids.

A review of the selected factoids revealed several potential biological impacts that could result from the changes in hydrology. One potentially large effect is decreased groundwater levels near the outer edge of the riparian corridor between the Verde River and the project water supply well. Induced seepage would tend to maintain shallow water levels close to the river channel, and lateral inflow from surrounding areas in the thin but relatively permeable alluvium would have a similar effect. Close to the well, however, the effects of drawdown would tend to dominate. The calculated amount of drawdown is large (tens to hundreds of feet), even for locations near the creek. These amounts of drawdown clearly are large enough to cause mortality of existing mature phreatophytic trees such as cottonwood, willow, and sycamore. Possible actions to avoid or minimize those impacts include screening the well only below the alluvium to spread the drawdown effects over a larger area, installing one or two shallow observation wells and testing the water supply well to measure actual drawdown, and distributing pumping among a larger number of supply wells to spread drawdown over a larger area. Drawdown is directly proportional to pumping rate, so any conservation measures that decrease gross or net water demand would also decrease drawdown-related impacts.

The increased frequency and range of water level fluctuations in Peck's Lake resulting from increased stormwater runoff peaks and volume could alter shoreline vegetation. More dynamic water levels could make the shoreline more suitable for establishment of early-succession riparian vegetation including willow and cottonwood. The width of the band of shoreline vegetation could increase slightly as upland vegetation retreats from the zone of water level fluctuation. There could also be minor changes in vegetation assemblage in Tavasci Marsh. The increased stormwater outflows from Peck's Lake would not have sufficient velocity to scour vegetation in the marsh, although there could be some uprooting and erosion along the outlet ditch from Peck's Lake. The greatest impact of increased stormwater flushing on the marsh could result from changes in water quality, especially that of increased loading of copper or other metals that can be toxic to some types of biota. To avoid these types of impacts, a hydrologic and hydraulic routing analysis should be done by the project applicant using measured water quality data and actual design and operation criteria for project stormwater detention facilities. An analysis method should be selected that would indicate changes in water level fluctuations in Peck's Lake, changes in frequency of stormwater flushing of Tavasci Marsh, and probable pollutant loading of the marsh.

This analysis of the proposed Verde Valley Ranch development illustrates how the impact analysis tools can be applied to identify and quantify potential hydrological and biological impacts associated with the development. The tools indicate where additional information is needed to determine whether certain potential impacts are large or small. They also focus further analysis and negotiations with the developer on issues of real concern instead of on a broad array of speculative concerns. Finally, the tools send a clear message to developers, local and state agencies, and the public that NPS has both the motivation and technical capability needed to actively defend and manage natural resources at the Monuments.

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